Innovation, Technology, and Knowledge Management

Tugrul U. Daim
Leong Chan
Judith Estep *Editors*

Infrastructure and Technology Management

Contributions from the Energy, Healthcare and Transportation Sectors

Springer

Innovation, Technology, and Knowledge Management

Series Editor

Elias G. Carayannis
George Washington University
Washington, DC, USA

More information about this series at http://www.springer.com/series/8124

Tugrul U. Daim • Leong Chan • Judith Estep
Editors

Infrastructure and Technology Management

Contributions from the Energy, Healthcare and Transportation Sectors

Springer

Editors
Tugrul U. Daim
Department of Engineering and Technology Management
Portland State University
Portland, OR, USA

Leong Chan
School of Business
Pacific Lutheran University
Tacoma, WA, USA

Judith Estep
Bonneville Power Administration
Portland, OR, USA

ISSN 2197-5698 ISSN 2197-5701 (electronic)
Innovation, Technology, and Knowledge Management
ISBN 978-3-319-68986-9 ISBN 978-3-319-68987-6 (eBook)
https://doi.org/10.1007/978-3-319-68987-6

Library of Congress Control Number: 2017959556

Printed on acid-free paper

This Springer imprint is published by Springer Nature
The registered company is Springer International Publishing AG
The registered company address is: Gewerbestrasse 11, 6330 Cham, Switzerland

Contents

Part I
Energy

Chapter 1
Landscape Analysis: Regulations, Policies, and Innovation in Photovoltaic Industry

Dmitriy Moskovkin, Anna Mary Mathew, Qin Guo, Roli Eyetsemitan, and Tugrul U. Daim

1.1 Introduction

Reflecting concerns over the environment, health, and security stemming from the consumption of conventional fossil fuel energy sources, such as gas, oil, and coal, has been raised in the world, which increases the expectation of replacing fossil fuels with renewable energy [1]. In addition to these concerns, rising prices of fossil fuels have forced many countries to support the development of renewable energy sources, such as, solar, wind, biomass, and geothermal [3]. Among these renewable energy sources, solar photovoltaics (PV), which is also known as solar electric system, has long been considered as a clean and sustainable energy that directly converts solar radiation into current electricity by using semiconducting materials [4]. A PV system comprises a PV module and other electrical components, such as charge controllers, inverters, and disconnects. The direct conversion of sunlight to electricity occurs without any moving parts or environmental emissions during operation, which significantly protects the environment. Meanwhile, it has been

D. Moskovkin (✉)
REFCCO Consulting Group, Portland, OR, USA
e-mail: dmoskovkin@yahoo.com

A.M. Mathew
Intel Corp, Portland, OR, USA
e-mail: anna.m.mathew@intel.com

Q. Guo • T.U. Daim
Portland State University, Portland, OR, USA
e-mail: guoqin@pdx.edu; tugrul.u.daim@pdx.edu

R. Eyetsemitan
Air Liquide Electronics, Portland, OR, USA
e-mail: eyetsem@pdx.edu

T.U. Daim et al. (eds.), *Infrastructure and Technology Management*,
Innovation, Technology, and Knowledge Management,
https://doi.org/10.1007/978-3-319-68987-6_1

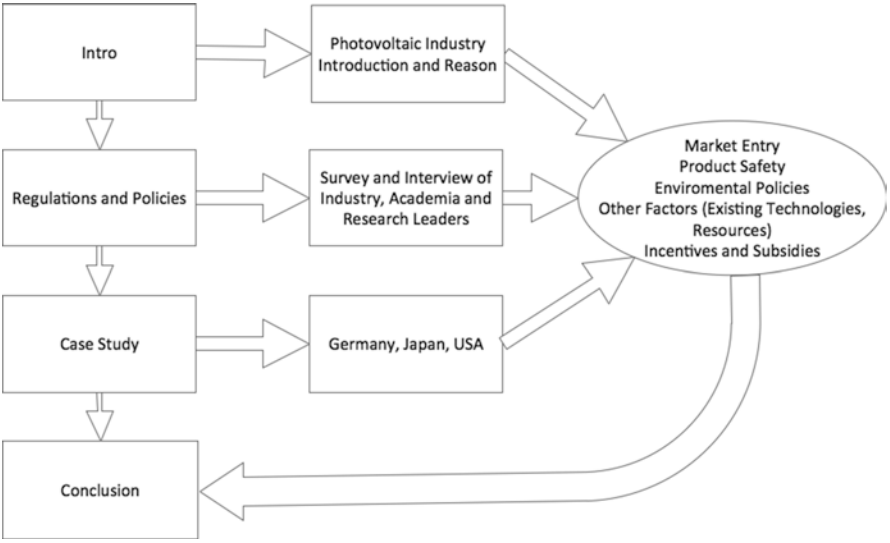


Fig. 1.1 The flow chart of the research

well proved that PV installations can operate for no less than 100 years with little maintenance, thus extremely reducing the operating cost [4]. As Fig. 1.1 shows, this report begins with a detailed analysis of policies and regulations influencing the current innovation activities of solar PV. In particular, this study pays attention to the government policy supporting technological innovation and market creation. In addition, this report profited substantially from the knowledge of a few experts and research leaders in the industry and academic field who made themselves available for interviews and other queries. Then followed with several case studies on three countries – Germany, Japan, and the USA – some data were collected to analyze how market entry, product safety, environmental policies, and incentives influence the innovation of PV industry. Finally, we provide conclusions and policy implications on the development of the solar PV industry.

1.2 Market Survey on Regulations Affecting PV Industry

Experts were consulted to gauge their feedback and further discuss the factors that affect the growth of the PV industry. The experts that were contacted were from industry, academia, and government laboratories (Table 1.1). The list of the experts is given below.

Telephone conversations and email correspondence were completed over a period of 3–4 weeks to discuss and analyze the information provided by the experts. The decision-making on this sector was done by the team based on a survey result. The survey that was put together had two questions.

Table 1.1 Expert panel from academia, industry, and government laboratories

Industry	Academia	Government laboratories
– First Solar – Accelerate Solar – Midnite Solar Inc. – Advanced Energy – Solar World – Absolutely Solar Inc. – SEIA – Accord Power	– Oakridge National Laboratory – MIT MECHE – WESRF (Wallace Energy Systems and Renewables Facility) – Portland State University – Sustainability – Penn State – Institute of Energy and the Environment	– NREL(National Renewable Energy Laboratory) – Argonne National Laboratory – Brookhaven National Laboratory – Lawrence Berkeley National Laboratory – Sandia National Laboratory

1. Rank the factors affecting the sector on a scale from 1 to 5, with 1 being the highest rank and 5 being the least. The factors that were listed were:
   (a) Market regulations
   (b) Product safety regulations
   (c) Incentives and subsidies
   (d) Environmental regulations
2. Any other factors affecting this sector.

The results of the survey are as follows:

The main comments that were obtained from the survey with respect to each of the regulations are listed below. The majority of the comments was related to incentives and subsidy regulations and was in line with the survey results indicating that incentives were the factor which had the most impact on this sector.

Comments Related to Market Regulations

"This can be a major problem when talking about grid tie equipment in Hawaii. The utilities throw up road blocks that make it hard for manufacturers to meet their requirements. The features that the utilities demand are in addition to UL and NEC standards. The utility companies are not solar friendly. What they say is not what they do. On the mainland there are utility companies that make it hard to have battery backup grid tie. They think people are going to sell their stored battery power to the grid. This doesn't make sense as it wears out the batteries. Batteries cost more than the utility power."

Anonymous Comments from the Survey Related to Market Regulation:

- Rate mechanisms (different than financial incentives) 4-grid integration technology.
- Permitting fees.
- Access to transmission lines is a barrier. I'm not sure where this fits into your classifications.
- Regulation of electric utilities.
- One of the largest challenges is the inconsistency of local jurisdiction on code requirements.

Comments Related to Product Safety Regulations
"This is a huge cost issue. The NRTL's go overboard on things that don't matter, but they have little choice. The people that make these standards set the rules. There are factors at work that sometimes have little to do with safety although it is rare. We have seen this happening first hand though on emerging standards. We spend a great amount of time and money on agency approvals. We have to do things that are not required in other countries. You have to wonder why? It affects cost of every installation, but we have no choice but to follow the rules. Standards are subject to interpretation and this also costs money needlessly. Standards change and that forces us to spend even more time and money to upgrade our products. That is senseless and wasteful" (Robin Gudgel, Midnite Solar).

Comments Related to Incentives and Subsidies
"These things help the solar and wind industry. There wouldn't be much of a solar industry without them. Conservative politicians do not see the benefit of solar so they continue to attempt to kill subsidies. They do not realize how much the oil industry is subsidized. The subsidies are not as visible. I would be all for no subsidies to any industry, but politics will never allow this. Big oil money talks big money. Solar cannot compete in the political arena. My company is heavily involved in the off-grid market where subsidies are not important. If you really need a solar system to light your house, you will get it with or without subsidies. I personally think that every house in America should have a battery based grid tie system installed. People would have more control of their power usage and would be more mindful of waste" (Robin Gudgel, Midnite Solar).

Survey Results of Panel Experts Related to This Regulation:

- Commitment to research funding.
- Support both basic and applied research at universities.
- Investment in research and development.
- Uncertainty affects growth because it potentially changes the rules. Implementing large incentive programs that flood the market with renewable energy credits waters down the price of credits for those who invested before the "free money" and is lingering disincentive after the "free money" is used up.
- Availability of low-cost solar financing.
- Research funding.
- Standards, regulations.
- Renewable portfolio standard (RPS), interconnection standards, solar access laws, training and support, building codes, solar community organizations, utility rate structures, emission requirements, R&D investments, import vs local (e.g., China vs USA).

1.3 Regulations Affecting the PV Industry

Based on the survey conducted of topic experts, the original theory of specific policies and regulations affecting growth and innovation in photovoltaic energy was confirmed. As some policies have direct impact due to involvement of governments by providing subsidies, incentives, and research funding, others may provide an indirect impact by regulating other traditional sources of energy (such environmental regulations), therefore making photovoltaic sources more cost competitive. Other regulations, which may act as financial burden for new companies entering the market, were also looked at: such as barriers for market entry and product safety requirements. Lastly consideration was also given to countries' available natural resources from existing competition as well as available solar insolation perspectives, infrastructure, and public perception to have a complete picture on a country's competitive position in regard to photovoltaic energy. The data was gathered, and comparative research was performed for Germany, Japan, and the USA. Regulations and policies in the following areas were considered: market entry, product safety, environment, other factors (existing competition, resources, and infrastructure), incentives, and subsidies.

1.3.1 Market Regulations

The product market regulations were categorized using the index developed at the OECD (Organization of Economic Cooperation and Development) on a scale from 0 to 6, with higher numbers being associated with policies that are more restrictive and stringent [5]. For each sector, the index combines information on state control (such as price control and ownership) (Fig. 1.1), barriers to entrepreneurship and administrative regulations (such as licenses and permits, administrative burdens, and legal barriers) (Fig. 1.2), and barriers to trade and foreign direct investment (such as tariffs and ownership barriers). It is evident from literature [5] that all three countries under evaluation have a total index scale below 1.3 with the USA being the least restrictive at 0.8 [5].

1.3.2 Product Safety Regulations

Product safety requirements in regard to hazards of electric shock, fire, electromagnetic capability, and hazardous substances exist in each country under evaluation. A manufacturer's Declaration of Conformity (CE marked) to applicable directives and national standards with countries' deviations is a minimum requirement for all products in the European Union and Japan. Furthermore, in Germany and Japan more stringent compliance standards (tested by accredited third-party agency such as TUV, VDE, and SEMKO) may be required by the distributors, which are particularly true for photovoltaic products including modules, inverters, and other energy interconnecting equipment. In the USA, similar requirements are governed by the National Electric Code, and authorities have jurisdiction for all electrical permanently installed products. The code requires that such products (modules, inverters, switchboard panels, charge controllers) to be listed by NRTL (National Recognized Testing Agency: UL, ETL, CSA).

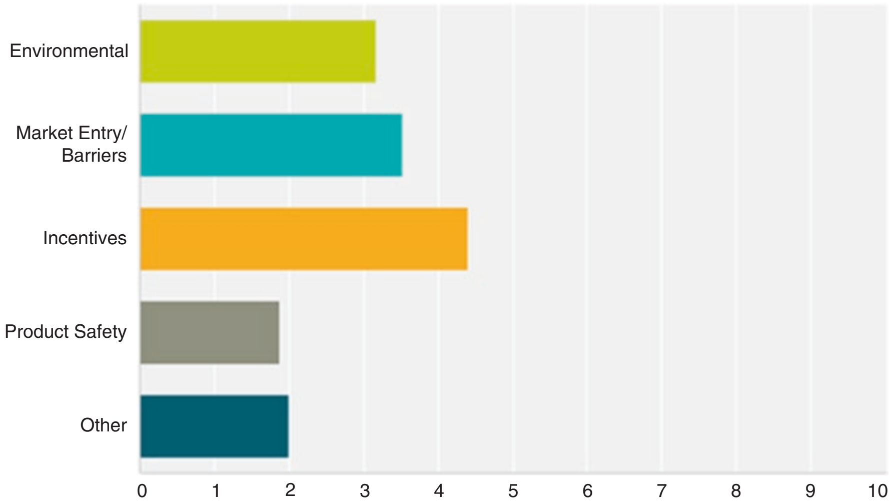


Fig. 1.2 Market survey results

1.3.3 Environmental Regulations

Environmental regulations provide an indirect positive contribution to the photovoltaic industry by setting standards and regulating those sources of energy that produce carbon emissions as their byproduct. According to OECD Environmental Directorate, a broader use of environmental taxation or an emission trading system would be one of the most efficient and effective ways of promoting green growth [6]. Taxes on pollution provide clear incentives to polluters to reduce emissions and seek out cleaner alternatives [7]. Germany (out of three countries under evaluation) is most regulated in regard to environmental regulations, it's important to note that this graph is based on revenues from taxes; therefore, countries' energy usage from all sectors needs to be taken in consideration. The next section discusses other factors related to existing competition, available resources, and infrastructure.

1.3.4 Existing Competition and Available Resources

Energy available resources, public perception, and energy cost play a significant role in government direction as well as public interests. Table 1.2 shows each country's energy consumption by source, while Table 1.3 shows the net export of fossil fuel energy sources. It's worthwhile to note that although the USA's net export for petroleum and natural gas is negative, it is the largest producer of petroleum and natural gas in the world (12,343 Thousand Barrels per Day for Petroleum and 29,542 Billion

Table 1.2 Breakdown of compliance requirements by country

Countries	Requirement	Standards
USA	OSHA accredited NRTL: UL, ETL, CSA.	UL 1703, UL 1741, UL 6142, IEEE 1547.
Germany	Self-declaration CE mark: Low voltage, EMC, and machinery. RoHS. Volunteered accredited by GS: TUV, VDE, SEMKO	IEC 60904, IEC 62109, IEC 61400, IEC 61727, IEC 62116, IEC 60364-7-712 With applicable Germany deviations.
Japan	PSE: Safety + EMC	IEC 60904, IEC 62109, IEC 61400, IEC 61727, IEC 62116, IEC 60364-7-712 With applicable Japan deviations.

Table 1.3 Energy consumption per source in 2013 [8]

Energy source	USA, %	Germany, %	Japan %
Coal	39	43	21
Natural gas	27	9.6	17
Petroleum	1	0.6	46
Nuclear electric power	19	15.9	11
Hydroelectric power	7	3.4	3
Geothermal	<1	4.3	<1
Solar/PV	<1	5.8	<1
Wind	4.13	8.6	<1
Biomass	1.48	7.0	<1

Cubic Feet of Natural Gas) [8]. Specific to natural resources, the tables below show it is evident that the USA has an overall energy independence compared to Germany and Japan, suggesting these two countries should be more aggressive when searching for alternative energy resources. Also, negative public perception for nuclear power (which is relatively a large source in Germany and Japan) adds to the trend of renewable energy, making PV a more attractive source in Germany and in Japan.

1.3.5 Incentives

Incentives are direct policy aimed to stimulate the competitiveness and growth of renewable energy technologies. Most recently, policy makers have looked to the fast-increasing demand for goods and services associated with renewable energy as an engine of economic growth. To help boost the rate of development of renewable energy in general, or photovoltaic in particular, all three countries under evaluation use market-based instruments that favor electricity generated from renewable energy [9]. Table 1.4 shows applicable methods of incentives by country with an explanation. In addition to direct subsidies for installation and growth, governments

Table 1.4 Energy net exports per source in 2013 [8]

Energy source	USA	Germany	Japan
Petroleum net exports (thousand barrels per day)	−5137.350	−2224.62	−4559.24
Coal (million short tons)	+919	−56.068	−192.852
Natural gas (billion cubic feet)	−1311	−2400.25	−4294.69

Table 1.5 Available incentives per country

Countries	Feed-in tariff	Feed-in premiums	Quota obligation	Tradable green certificates	Tax incentives	Net metering
Germany	Yes	No	No	No	No	Yes
Japan	Yes	Yes	Yes	Yes	No	Yes
USA	No	No	Yes	Yes	Yes	Yes

of countries under evaluation have other forms of incentives. These include funding research and development in an effort to raise the efficiency of renewable energy, improve its reliability, and reduce its costs. This type of incentive is further developed in the case study (Table 1.5).

Feed-In Tariffs (FIT) Renewable energy power investors are compensated for the power they provide to the grid and receive a long-term contract with a rate higher than the rate for traditional sources of energy [10].

Feed-In Premiums Payment level is based on a premium offered above the market price for electricity enabling developers to enjoy high returns when market prices increase, but also run a risk of losses when they decrease [10].

Renewable Portfolio Standards/Quota Obligation It is a regulation set by government where utility companies are obligated to generate a certain percentage of their power from renewable sources [11].

Tradable Green Certificates These are tradable certificates awarded for the generation of a given amount of power from solar sources [12].

Tax Incentives These are federal tax credits for development and deploying of renewable energy technologies.

Net Metering It is a billing mechanism where electricity generated by consumers and fed in to the grid is used to offset electricity consumed by the consumer [13].

1.4 Case Study: Photovoltaic Sector in Germany, the USA, and Japan (1990–2015)

The overall ranking of the countries based on solar energy generation by MW and other factors such as solar intensity, GDP, and population is considered. Patent activities in the green patent family which include the EPO (European Patent Office), PCT (Patent Cooperation Treaty), and USPTO (US Patent and Trademark Office) were considered. The country that emerged as the leader in the solar photovoltaic energy generation was Germany by producing nearly 27% of the total power generated using this technology. The two other countries that were studied were the USA as the country leads in patent activity in this domain and also contributes to 11% of the total solar power generated globally and Japan which falls close behind the USA with a contribution of 10% of the total solar power generated from photovoltaic.

1.4.1 Case Study 1: Japan

The Japanese photovoltaic (PV) market is expanding rapidly. By 2013, the installation of PV was over twice the amount in 2011, which places Japan among the world's largest PV markets, along with Germany, China, and the USA [2]. The national and local governments have implemented a variety of policy measures to support the innovation and diffusion of solar PV technologies in Japan (major policies are summarized in Table 1.6). These policies can be divided into two sections: demand side and supply side.

Demand-side policies could be used to "create a new market and develop demand for a new technology," including subsidies for purchase of "a particular product, tax breaks, and renewable portfolio standards." [1] For example, in July 2012, Japan introduced the FIT, which requires utilities to pay renewable energy producers a fixed price per kWh of production over a period of 10–25 years. Purchasing tariffs are reduced on annual basis but may be adjusted if deemed necessary. The government guarantees a purchasing rate of 37 yen (FY 2014) per each kilowatt-hour (kWh) for a time period of 10 years for systems smaller than 10 kW while larger get 32 yen (FY 2014) per kWh (excluding taxes) for a contracting period of 20 years granted for the total electricity production. The Japanese FIT will remain in place until 2021 with a revision of the scheme conducted every 3 years [3].

Supply-side policies are used to encourage firms to directly conduct innovation activities, including subsidies for R&D, illustration, and sometimes in early phases of commercialization [2]. For example, In the 1970s, the scarce local fossil fuel reserves and multiple issues associated with acquiring oil from foreign countries motivated the Japanese government to pursue the development of solar PV technologies. In 1974, the government launched the Sunshine Project, focusing on the development of solar cells and modules, which opened up an opportunity for most of the Japanese solar manufacturers, such as Hitachi, Toshiba, and NEC Corporation, to be involved in solar PV research and development (R&D). From 1993 to 2000, an additional R&D program, called the New Sunshine Project, was launched to develop the balance of system (BOS) technologies with the funding from the Japanese government (including inverters, mounting equipment, monitoring systems, and site assessment). The solar cell production had increased significantly since 1974. These national research and funding programs contribute to both the technological development and the growth of solar PV market in Japan (Table 1.7).

Table 1.6 Summary of major policies related to solar PV technology (demand side)

Demand-side policies		
Year	Policy	Notes
1974–2006	National residential subsidy	First phase: 1994–1996 Second phase: 1997–2001 Third phase: 2002–2006 (March)
1997	Act on special measures for the promotion of new energy use	Financial support for the business operators who use the new energy including solar energy
2003	Renewable portfolio standard	Requiring electricity retailers to supply a certain amount of renewable electricity to grid consumers
2009	National residential subsidy resumed	National residential subsidy will end in 2014
2012	Feed-in tariff	Electricity utility companies are obligated to purchase excess electricity generated through PV facilities

Table 1.7 Summary of major policies related to solar PV technology (supply side)

Supply-side policies		
Year	Policy	Notes
1974	Sunshine Project	A national R&D project for "new energy" including solar energy
1980	Establishment of the New Energy and Industrial Technology Development (NEDO)	Act on the promotion of development and introduction of alternative energy
1993–2000	New Sunshine Project	The successor of the Sunshine Project
2001–2005	NEDO 5-year plan	Development of technology to achieve 482,000 kW of installation of PV by 2010
2004	NEDO Roadmap 2030	Direction of photovoltaic technology development toward 2030
2009	NEDO Roadmap 2030+	Update of the Roadmap 2030

Japan's PNV industry witnessed remarkable growth in 2013 after the establishment of the feed-in tariff program in 2012. The feed-in tariff has been known to result in rapid growth in the renewable energy market in areas where it has been implemented. The Japanese government had one of the most generous feed-in tariff rates in the world, and they did not anticipate the growth that resulted from the program. The infrastructure to handle the amount of solar power produced was not in place, and as a result the utility companies were overwhelmed and started blocking access to the grid for new power solar generation. The country has since reviewed the programs and reduced the support [22].

1.4.2 Case Study 2: Germany

Solar power in Germany consists mostly of photovoltaic (PV) and accounted for an estimated 6.2–6.9% of the country's net-electricity generation in 2014 [14].

Germany is the world's top PV installer with an overall installed capacity of 38,359 megawatts (MW). The renewable energy sector contributes nearly 31% of the total electricity produced in the country. The German government long-term minimum targets of renewables' contribution to the country's overall electricity consumption are 35% by 2020, 50% by 2030, and 80% by 2050.

Factors Affecting Growth in Solar Sector

Boom period in Germany was during 2010–2012. More than 7 GW of PV capacity had been installed annually during this period. Due to the large amount of electricity produced, the country is currently facing grid capacity and stability issues. The country is increasingly producing more electricity than it requires, driving down prices and exporting its surplus to other countries (record exported surplus of 32 TWh in 2013 and 34 TWh in 2014) [15]. New installations of PV systems have declined steadily since 2011 and continued to do so throughout 2014. As of 2012, the FIT costs about €14 billion (US$18 billion) per year for wind and solar installations. The cost is divided across all ratepayers in a surcharge of 3.6 €ct (4.6 ¢) per kWh (approximately 15% of the total domestic cost of electricity).

The legislative reforms stipulate a 40–45% share from renewable energy sources by 2025 and a 55–60% share by 2035 [14].

1.4.3 Case Study 3: The USA

US Solar Innovation Timeline

Innovation in solar technologies began as far back as the seventh century and has continued to this day. Just like with the PC industry, there has been development and milestones achieved that have opened the way for new opportunities and growth in the industry. The USA has recorded tremendous progress in research and development in the PV sector; also noteworthy is the increased number of solar technology-related patents. The activities in the sector have been stimulated by the government's dedication to supporting research and development activities which would drive low cost and improve efficiency of solar PV systems. A timeline of US Solar Innovation is shown below [20]:

- 1955 Researchers at Bells lab overcome difficulty to create 6% efficiency PV.
- 1959 Manufacturers hit 10% efficiency.
- 1970 Western electric patents coating for solar cells.
- 1972 Institute of energy conversion formed.
- 1977 Department of Energy formed.
- 1978 California passes solar right act.
- 1980 Manufacturers break 1 MW barrier PV module in 1 year and IEC exceeds 10% efficiency.

- 1985 Stanford produces 25% efficiency cell.
- 1986 First commercial thin film solar module produced.
- 1993 Utility company installs first PV distributed system.
- 1994 NREL develops 30% efficient cell.
- 1996 National Center for PV created.
- 1998 Million Solar Roof initiative.
- 2000 First Solar builds world's largest PV manufacturing plant.
- 2011 SunShot Initiative announced.

PV Growth in the USA

There has been tremendous growth in the US PV industry in the last 4 years especially in utility and residential PV installation. 2014 witnessed a growth that was about three times what it was in 2011 and seven times what it was in 2010. In the first half of 2014, over half a million home owners and businesses had installed solar PV, and solar represented 36% of new energy that came online in 2014 [16].

Solar energy accounts for 0.3% of the total energy consumed in the USA. The capacity of utility scale solar has increased from 334.2 megawatts in 1997 to 6220.3 megawatts in 2013 [21].

One reason for the tremendous growth in the US PV sector in the last few years is the presence of low-cost PV modules from Japan in the US market. Although this increased the installation of solar systems, US manufacturers have been impacted and the US government imposed tariffs on PV systems from China, leading Chinese manufactures to outsource PV manufacture to Taiwan. US manufacturers have petitioned the government to impose tariffs on Chinese PV systems from Taiwan, a PV manufacturer in Hillsboro, Oregon. Solar World is in the forefront of this struggle.

Another reason for the growth in the sector is government incentives. Most governments at the state and federal level offer incentives to spur investment in the renewable energy sector. These incentives make investment in the renewable energy sector more appealing for public and private entities. Incentives are mostly financial and are in the form of loans, grants, tax deductions, or exemption [17].

US Federal Incentives

Incentives offered by the federal government to encourage growth in the PV sector include

Grants

- Tribal Energy Grant program provides funding for tribes to develop community and commercial scale renewable energy projects.
- USDA (Rural Energy for America Program (REAP) and Energy Audit and Renewable Energy Development Assistance (EA/REDA)) assists agricultural and small rural businesses with the development and setup of energy efficiency and renewable energy systems.

Loan Programs

- US Department of Energy (loan guarantee program) provides loan for new or improved technologies that reduce air pollution.
- FDA PowerSaver loan program is granted by the Federal Housing Authority to provide assistance to homeowners for energy efficiency and renewable energy upgrades.

- Qualified Energy Conservation Bands and Clean Renewable Energy Bonds – These bonds are used to finance renewable energy projects [18].

Tax Incentives

- Corporate tax credit
- Business energy investment tax
- Renewable electricity production tax credit
- Corporate tax exemption
- Personal tax credit
- Residential renewable energy tax credit
- Personal tax exemption
- Residential energy conservation subsidy exclusion

State Incentives

The USA is an amalgamation of 50 states with individual political processes, electricity prices, and unique sets of incentives and regulations to stimulate growth. PV sector state incentives include:

- FIT – This incentive has been proven to stimulate explosive growth in the renewable sector in areas where it is implemented, so much growth that the regulation has to be constantly reviewed. The feed-in tariff or some variation of it existed in California, Hawaii, Maine, Oregon, Rhodes Island, Vermont, and Washington in 2013 [19].
- Rebate for purchasing renewable generation equipment.
- Renewable portfolio standards to ensure that utility companies generate a percentage of power from renewable sources.
- Net metering – Power produced by consumers and supplied to the grid is used to offset the power he consumes.
- Tax incentives.

Another important factor promoting the growth in the US PV market is Research and Development.

Research and Development

The US government has not been as aggressive as Germany and Japan in their use of subsidies as incentives. Although the feed-in tariff has been adopted in some states, it has never been a federal initiative in the USA. The USA chose a slightly different approach to pursue growth in the PV industry. Given the fact that the cost of solar power is very high, even in Germany and Japan where it has been widely adopted, the USA is actively and aggressively involved in research and development in solar technologies to drive down costs and increase efficiency of solar systems. A number of programs have been established to help with this.

SunShot Initiative

The SunShot Initiative was established by the Obama administration in 2011, and it involves a 10-year plan by the Department of Energy aimed at making competitive solar power a reality. The plan is to reduce the cost of solar power and bring it to par with other traditional sources of power by 2020.

The goal is to drive this through innovation in manufacturing, installation, and market solutions. Less than halfway through the project lifetime, over a half of the goals have been accomplished, and solar power has been reduced to 11cents/kwh [5]. However, the goal of 6cents/kWh by 2020 seems rather ambitious considering the fact that China currently has the lowest cost in the world and their low cost is driven by government subsidy rather than innovation. The solar industry in China is heavily subsidized by the government; this is a strategy by the government to make China the world leader in the PV industry. If the USA is able to drive low cost by innovation, this would cause explosive growth in the US PV market.

1.5 Conclusion

In addition to differences in overall technological levels and life standards, reviewed regulations and policies although important do not completely explain cross-country differences in innovation.

The research showed that incentives and subsidies play a major role in emerging technologies during the initial process of "jump starting" the industry; however, transformation from directly subsidizing a somewhat mature industry to investments in Research and Development (Academia and Industry) and Public Education (Environmental Policies) is a critical step in innovation. As it appeared in case with Germany, simply increasing PV installation capacity and other renewable energy sources didn't translate into patent growth or reduction in cost, but rather had an opposite effect (refer to summary table below), due to excessive feed-in tariffs and grid management problems. Additionally, Germany's carbon output and global warming impact is actually increased despite increased in PV energy capacity, due to utilities being forced to use of dirty coal power because it's only a nonsubsidized power source.

Country	Solar energy capacity in GW in 2011	Solar energy patents global % in 2011	$/kWh in Cents in 2011	2009–2014 CO_2 emissions %
Germany	35.5	6.1	35	+1.2
Japan	13.6	34.1	26	+1.3
USA	12	14.1	12	−3.4

The combination of policies, market, and product safety deregulation is a very effective method of inducing innovation in emerging technology such as PV energy; however, the extent and aggressiveness of these policies should depend on a country's resources, infrastructure, and existing competition. Additionally, product safety regulations may set higher standards in efficiency, safety, and reliability, positively effecting innovation.

References

1. Takeda, C. "Government policy and innovation activity: a patent study of solar photovoltaic balance of system in Japan," *PhD diss*, 2014.
2. Friedman, B., Margolis, R., & Seel, J. "Comparing Photovoltaic (PV) costs and deployment drivers in the Japanese and U.S. Residential and commercial markets," *National Renewable Energy Laboratory (NREL)*, 2014.
3. Kimura, O., & Suzuki, T. "30 years of solar energy development in Japan: co-evolution process of technology, policies, and the market," *Berlin Conference on the Human Dimensions of Global Environmental Change: "Resource Policies: Effectiveness, Efficiency, and Equity,"* Nov, 2006.
4. Wikipedia. (2015, Mar). Photovoltaics. [Online].
5. Wolfl, A., Wanner, I., Kozluk, T., & Nicoletti, G. *The years of product market reform in OECD countries – insights from a revised PMR Indicator* 24-Apr-2009. Available: www.oecd.org/eco/working-papers. Accessed 14 Mar 2015.
6. OECD, Environmental Directorate. Environmental policy tools and evaluation. Available: http://www.oecd.org/env/tools-evaluation/environmentaltaxation.htm. Accessed 14 Mar 2015.
7. Braathen, N. A., & Greene, J. OECD, Environmental Directorate. Centre for Tax Policy and Administration. Available: www.oecd.org/env/taxes/innovation. Accessed 14 Mar 2015.
8. U. S. Energy Information Administration. Available: www.eia.gov. Accessed 14 Mar 2015.
9. Domestic incentive measures for renewable energy with possible trade implications. OECD Trade and Environment Paper No. 2013/01. Available: www.oecd.org/trade/envtrade. Accessed 14 Mar 2015.
10. Wikipedia. Available: http://en.wikipedia.org/wiki/Feed-in_tariff. Accessed 14 Mar 2015.
11. Wikipedia. Available: http://en.wikipedia.org/wiki/Renewable_portfolio_standard. Accessed 14 Mar 2015.
12. Wikipedia. Available: http://en.wikipedia.org/wiki/Renewable_Energy_Certificate_%28United_States%29. Accessed 14 Mar 2015.
13. Wikipedia. Available: http://en.wikipedia.org/wiki/Net_metering. Accessed 14 Mar 2015.
14. Wikipedia. Available: http://en.wikipedia.org/wiki/Solar_power_in_Germany. Accessed 10 Mar 2015.
15. http://www.germanenergyblog.de/?page_id=283. Accessed 15 Mar 2015.
16. http://www.renewableenergyworld.com/rea/blog/post/2014/09/u-s-solar-industry-continues-rapid-growth. Accessed 12 Mar 2015.
17. http://aceee.org/topics/financial-incentives-energy-efficiency. Accessed 11 Mar 2015.
18. http://programs.dsireusa.org/system/program?state=TER. Accessed 2 Mar 2015.
19. http://www.eia.gov/todayinenergy/detail.cfm?id=11471. Accessed 5 Mar 2015.
20. http://energy.gov/eere/sunshot/solar-innovation-timeline. Accessed 13 Mar 2015.
21. http://instituteforenergyresearch.org/topics/encyclopedia/solar/. Accessed 9 Mar 2015.
22. http://www.japantoday.com/category/opinions/view/japans-feed-in-tariff-program-becomes-a-solar-shambles

Chapter 2
Landscape Analysis: Fracking Technology

Rafaa Khalifa, Chih-Jen Yu, Joao Ricardo Lavoie, Momtaj Khanam, and Tugrul U. Daim

2.1 Introduction

Hydraulic fracturing of oil- and gas-bearing rocks, also known as fracking, is an established technology. Hydraulic fracturing was first started experimentally in 1947 in the Hugoton oil field in Kansas [1]. Fracking is an old technique that is used to increase the production of oil from the worked-out oil wells. However, it is considered as a new tool for producing natural gas. Fracking has been developed gradually by some international companies and organizations with no government support until the success has been proven.

Lately, in 2011, the shale gas boom has started to introduce the fracking technology with more power in the oil and gas industry. In the USA, researchers showed their interest to investigate the role of federal agencies in supporting gas industry experimentation by using shale fracking technique. The Department of Energy played a significant role in improving this technology. Also, the National Laboratories made a big contribution in developing the hydraulic fracking process.

Indeed, the fracking technology is considered in the oil and gas industry as a newly developed drilling technique because it is depending on a complicated process such as a high pressure, specific chemical solutions, and a huge amount of water mixing with the sand. These components are used to free oil and natural gas from the shale rocks under the earth's surface. This technology has made a lot of profit for oil and gas companies. However, fracking has some challenges, such as people from different societies arguing that fracking creates a negative impact on human and environmental health. On the other hand, others are saying that this

R. Khalifa (✉) • C.-J. Yu • J.R. Lavoie • M. Khanam • T.U. Daim
Portland State University, Portland, OR, USA
e-mail: rkhalifa@pdx.edu; yuchihjen@gmail.com; jlavoie@pdx.edu; momtaj@pdx.edu; tugrul.u.daim@pdx.edu

T.U. Daim et al. (eds.), *Infrastructure and Technology Management*,
Innovation, Technology, and Knowledge Management,
https://doi.org/10.1007/978-3-319-68987-6_2

technology helps to meet the current and future energy needs. Also, it could save the countries' economies from collapsing.

Therefore, most of oil and gas companies work hard to make sure that the fracking is a sustainable development process for money-making opportunities. Most of these companies often give large sums of money to societies by running some social investment programs or sustainable development projects. These initiatives aim to develop the people and their facilities around areas of fracking operations.

2.1.1 Fracking Process

The Environmental Protection Agency (EPA) described the hydraulic fracking as a high technology process which is drilled vertically or at a measured angle. This process is starting from the well surface to a depth of 1–2 miles (approximately 1.6–3.2 km, some times more). During the drilling, the vertical well is coated by steel or usually by the specific material of cement to ensure the well doesn't run the risk of leaking [2].

Once the vertical well reaches the layer of rock that includes the natural gas or oil, the drilling converts horizontally along that rock layer. Then, the horizontal drilling curves about 90°, and the drilling can extend more than a mile (1.6 km) after the end point of the vertical drilling process.

After the fracking well is fully drilled and protected (shielded) by adding a coating of steel or specific cement around the well formation, fracking fluid is pumped down into the well at extremely high pressure.

The high pressure that is created by high power machines is powerful enough to fracture the surrounding rocks. The high pressure is used to create cracks through the rocks that help the oil and gas flow to the surface.

The slick water is the fluid that is pumped into the well which contributes to fracture the deep rocks. The fluid is mixed sand, salts, and chemical components. The rate of the chemical solution that is added to the fluid is usually about 0.5–2%, while the remaining percentage consists of plain water. Sands and clay particles are also added to the fluid. Both of these elements are pumped into the fracking well to open the fractures through the rocks. The fluid is formed under high pressure to ensure that gas and oil can continue to flow out from the fractured rocks. The chemical solution helps the fluid to keep liquefied and direct the oil and gas to the surface even after the pumping pressure is released.

The injecting of fluid by high-pressure pumps is the most critical process in the hydraulic fracking operation. This fluid requires millions of gallons of freshwater and high-pressure pumps that are able to trap and extract the natural gas and oil to inject them back to the surface [2].

2.1.2 Research Objectives

This research aims at general Assessment of Fracking Technology in Energy Industry without being constrained to any specific issue. Thus, it had three distinct objectives which are designed as questions:

Q1. Why is the energy industry jumping into fracking?
Q2. What are the economical, environmental, social, political, and technical effects/impacts of adopting fracking technology?
Q3. Is fracking a suitable technology for future energy?

2.1.3 The Big Energy Source and Its Future Challenge

The future of energy has changed especially in the oil and gas industry. In the past, the growth in production was measured based on the western market demand. Natural gas has a significant role in the future energy. New technologies are being developed to explore and extract the conventional and unconventional gas with many ways to get a maximum benefit from its abundance. Increase in the natural gas production has improved producer countries' GDP growth [1]. During the past decade, oil and gas prices have moved to a permanently high level. Power companies have been working hard to produce more efficient power plants and transportation facilities and supply alternative fuels to reduce the future impact of the full dependency and the huge demand of the oil and gas in some industries. On the other hand, always there are new innovative technologies and techniques which have been introduced by some international companies and manufacturers to improve the production process and to reduce the production cost and uncertainty of producing unconventional oil and gas in this world. So, there is a question of why natural gas is the most inspiring product in the future? To answer this question, we should discover the oil challenges in the energy market in two scenarios (low and high price):

2.1.3.1 Low Oil Price Scenario

The Organization of Petroleum Exporting Countries (OPEC) is the organization that manages the oil and gas production market shares among its members. Although the significant efforts of OPEC are continued to control the oil and gas production, in the low oil price scenario, the results are still less successful in restricting production. As a result of OPEC effort in this scenario, its share of total world liquid production is expected to increase reaching 49% by 2040. On the other hand, in spite of the lower price of oil and gas in the world market, the non-OPEC producers are expected to maintain their production at roughly 54 million barrels per day, through 2030. Moreover, due to high cost, they decline to use the enhanced oil recovery (EOR) technologies to develop the existing worn-out fields. In the case of the low oil and gas price, the average costs for resource development are considered high. For this reason, the non-OPEC countries are not able to develop their worn-out fields. As the non-OPEC production rises slightly in the projection through 2030, the expectation indicates to return their crude oil production to roughly 51 million barrels per day in 2040. In 2015, the crude oil price had fallen below $80 per barrel and then to $70 after a few months. In 2016, the price fell below $50 and is expected to follow by a slow increase to average $75 per barrel in 2040. Due to lower economic growth especially in non-OECD (Organization for Economic Cooperation and Development) countries, the oil price impacted negatively the world [2].

2.1.3.2 High Oil Price Scenario

In this scenario, the GDP growth in non-OECD indicates that its rapid growth is more than the projected in the reference case. The liquid fuel consumption per unit of GDP is declining than projected in the reference case. Due to the continuing restrictions on oil production, OPEC maintains its market share of total liquid fuel production. OPEC produces about a million barrels per day which about 37–40% of the world market share. This value is lower than the value in the reference case. The limited access to the existing resources and lower discovery rates lead to consider the increase in the oil prices in non-OPEC petroleum production expanding approximately as the rate in the reference case. Other liquids rise to eight million barrels per day and are considered as strong in response to the higher prices in 2040. In the high oil price case, the oil increases from $155 per barrel to $237 in 2020 to 2040, respectively. Based on the increase in the robust price, the total world demand maintains within the range of expected production capabilities [2].

2.2 The STEEPLE Method (History and Rationalization)

The PEST (political, economic, sociocultural, technological) analysis technique was innovated by professor Francis Aguilar at Harvard. In the early 1970s, Arnold Brown came up with the acronym "STEPE" when he added a second "E" for Ecological issues in addition to Aguilar's Social, Technical, Economic, and Political Perspectives [3]. The technique went through a sequence of changes. Various acronyms used by practitioners are as follows: PEST (political, economic, sociocultural, technological), PESTEL (political, economic, sociocultural, technological, environmental (or ecological), legal), PESTLIED (political, economic, sociocultural, technological, legal, international, environmental (or ecological), demographic), and STEEPLE (sociocultural, technological, environmental (or ecological), economic, political, legal, ethical) [4]. STEEPLE analysis identifies the changes in the macro environment external to the organization in order to respond to the changing environment in a timely and appropriate manner [3]. In the energy sector, STEEPLE analysis helps

Table 2.1 Importance of STEEPLE for energy technologies [6–9]

Issues	Description
Social	It is important to clarify social acceptance at the initial stage of energy technology development. Conflict may cause a blockade of the technology. It is important to understand the intensity of rejection of the technology to manage or take a decision at the early stage of development
Technological	Energy technology systems need to be clarified objectively. Rather than relying on developers or practitioners, technology needs to be critically analyzed by experts to identify and recognize all consequences and issues
Economical	Initial investment and leveled cost of the technology needs to be assessed in order to rationalize its adoption
Environmental	Energy technologies should reduce emissions. A full assessment is needed to reveal consequences that may affect the plant, animal, and human species
Political	Political interference can significantly affect energy technology adoption. Political pressure can make the government facilitating the development or arranging subsidy programs or other incentives contribute in increasing the number of beneficiaries. On the contrary, politicians may exacerbate the adoption by propaganda
Legal	Legal or policy instruments enhance the adoption and commercialization of energy technologies. The government is the key player in formulating policies that pervade all other criteria. Social, technological, economical, and environmental consequences can promote adoption or rejection of a certain energy technology. However, these consequences are mediated by government policies
Ethical	Any technology that harms the environment and puts human life in jeopardy is ethically unjust. In spite of its huge potential, the development of energy technologies gets hindered if it cannot live up to ethical codes

to analyze technology from a different perspective. It facilitates the development and diffusion of energy technologies [5]. Table 2.1 describes the importance of different perspectives for energy technologies.

2.2.1 Description of the Model

The STEEPLE model in Fig. 2.1 describes the different issues that are considered in assessing the fracking technology.

2.3 Fracking Technology Assessment

2.3.1 Social Perspective

Social perspective identifies aspects that affect society positively or negatively [10]. Four important aspects in social perspective are public perception, employment, health and safety, and Local Infrastructure Development.

Fig. 2.1 STEEPLE for fracking technology assessment

2.3.1.1 Public Perception

Views that are shared by population, social norm, and media coverage shape the perception of the mass. Public perception is reflected in aesthetics, lifestyle, social benefits, and social acceptance. National polling data published in the year 2014 found American population to be mostly ignorant or ambivalent toward fracking. A small minority who knows about fracking are equally divided into a pro-fracking and antifracking stance. Those who are in opposition to fracking are found to be mostly women, open minded, and knowledgeable about fracking issues as these women possess a habit of reading the newspaper more than once a week and talks about the impact of fracking on the environment. People in favor of fracking are mostly older; minimum educational qualification is bachelor's degree, conservative political views, watch TV, and appreciative about the economic and energy supply effect due to fracking. The accepted perception that better education creates negative impression toward fracking is proved wrong through the survey [11].

2.3.1.2 Employment

Employment is pertaining to job. It clarifies job creation, availability of workers, and poverty alleviation. The creation of job opportunities by fracking is an issue of controversy. Different groups have conflicting claims. Pro-fracking groups claimed the creation of 48,000 jobs from the end of 2009 to early 2011. However, antifracking parties denied this claim in the plea that these were new hires and the actual number was proven to be 5700 during the same period. Bureau of Labor Statistics revealed that the employment created by oil and gas operations (onshore and offshore) is less than 1/20th of 1% of the overall US labor market since 2003–2011. Moreover, employment of less educated workforce and high wage lead to increased number of dropouts of college students in these counties and cripple the ability for future development [12]. Migration of more people in the fracking areas burdens existing services, traffic, and accommodations, and there is a struggle for limited resources that sometimes leads to animosity among people from different cultures and places.

2.3.1.3 Health and Safety

Health and safety are concerned with safety, health, and welfare of people, society, and workplace. Technology should not affect public safety and work safety and should not cause long-term health issues. People and workers are vulnerable in areas of fracking to different contaminants emitting out of fracking operation. This causes many forms of respiratory diseases. Occupational health hazard of workers in the fracking industry is an issue of concern. Workers may get affected by chemicals and also machineries used in fracking sites. Workers are exposed to dust, crystalline silica, and fracking fluids that cause fatal health hazards. Also, workers may get hit by moving equipment and high-pressure lines, be entrapped in between two moving parts of a machine, or suddenly be exposed to high-pressure release. Due to flammable gas and materials in fracking sites, there is a high probability of fire explosion. Worker sometimes needs to work in a confined space under high power lighting. All these events may lead to fatal injury, disability, or sometimes death [13]. The nonoccupational health hazard is caused by polluting gases and harmful chemicals and silica that are used in the fracking process and contaminate groundwater or atmosphere. Sudden economic expansion or recession which is known as "Boom and Bust" sometimes causes mental stress to people in the community. Fracking causes a sudden increase in economic activity. This increase in local economic activity is often followed by a rapid decrease upon depletion of the resources. Living cost soars as oil and gas industry can pay more. This creates hardship for the community.

Local Infrastructure Development Infrastructure development is supposed to improve transportation, help to develop related industry, and better productivity and quality of life.

Due to the construction of well pads, waste pits, access roads, pipelines, compressor stations, and other infrastructure, pristine landscapes are ravaged by industrial zones. Spoiled infrastructure and economic, environmental, and social degradation are the aftermaths of a sudden halt of fracking. The cost of destruction is shared by taxpayers. Human habitats are replaced, lands are divided, open spaces are sacrificed, and sometimes tourist attractions are crushed to make way for fracking [12].

Many probable actions have been proposed by government, practitioners, and researchers to minimize or eliminate the negative impacts of fracking. Occupational Health and Safety Administration (OSHA) and National Institute of Occupational Health and Safety (NIOSH) developed a detailed guideline for protecting workers of fracking industries. Protective equipment, planned work process, engineering control, worker training, and mostly minimizing exposure of workers to harmful chemicals are some of the suggestions made by the organizations [14]. In many states, the probable impact of fracking is assessed for a certain locality and ranked based on their severity. Depending on the intensity of impact, preventive measures and action plans are prepared ahead of time to reduce the negative effect of fracking on human health [15]. Several states as well in many countries, for example, in South Africa near diamond production zones, industries are compelled to pay an impact fee, and it is saved as fund during the boom period. This fund is utilized when fracking process discontinues or the bust period starts, to compensate the people impacted, restore the landscape, or drive the economic activity. Rural, forests, farmlands, and locations of tourist attractions are impacted with fracking constructions. This can be reversed by implementing zonal restrictions by the government and protecting places and landscapes of public importance [16].

2.3.2 Technical Perspective

The oil and gas industry has a positive impact on the economy by introducing the new fracking technology to extract hydrocarbons from areas and distances that previously thought unreachable. The new technology improves the horizontal drilling in addition to the enhanced oil recovery (EOR) [17, 18]. The fracking new technology could extract oil or gas double recoveries of that amount in the conventional drilling [19]. Recently, light and medium oil and gas production have started to get more attention by smaller players in oil and gas business. They are focusing on the more profitable light-to-medium oil production. Also, as a result of increasing market demand regarding the natural gas, international oil and gas companies develop sour gas plants to increase the natural gas liquid productivity [20].

2.3.2.1 Diesel Fumes

The hydraulic fracking uses the diesel fuel as the main source to power the drilling machines in the drilling and production process. However, the diesel-powered equipment can be a high potential risk or annoying source of harmful pollutants. Also, it can be a source of the carbon emissions that might affect the environment and cause global warming. Recently some international companies announced that the natural gas would be the primary source of fracking power machines. The natural gas will reduce the carbon emission and the fuel cost that is used during the fracking operation by about 40%. Solar panels are another energy source which has been adapted by Halliburton oil and gas service company in the fracking process. The company innovated the sand castle vertical storage silo technique to use entirely with the solar panel. Moreover, Halliburton was successful in reducing the consumption of power on site by 70%. They developed the powered pump trucks to be working at the location of the natural gas [21]. The diesel fuel contains BTEX compounds (benzene, toluene, ethylbenzene, and xylene). These compounds are considered as risk that might impact the human health through its potential leaks to the drinking groundwater [22]. Now companies are working hard to sophisticate engines and turbines that use natural gas as a fuel [23–25].

2.3.2.2 Fracturing Period

There are differences between the typical use of hydraulic fracturing between the US states. The fracking process may take weeks to get access to the oil or gas sources through the reservoir rocks. Horizontal drilling is a complicated process which requires lengthy fracturing periods. Also, the horizontally drilled production wells need about four to eight millions of gallons of water. This amount of water is injected under the surface with constant pressure which might need extended period of time to complete its process. However, the fracking in California has sophisticated by using innovative technology to reduce the fracturing time. They use less fluid to fracture within a narrow vertical band along a well; then they change the direction of drilling horizontally only a few hundreds of feet from the last point of vertical drilling [26]. To integrate a steam fracking process, the use of low-gravity hydrocarbons as a diluent for the targeted heavy oil can decrease the fracturing periods [25, 27].

2.3.2.3 Safety: Blowout Prevention

According to statistics of energy wire organization, the federal labor section, the oil and gas industry workplace fatalities result in about 10% of deaths caused by fires and explosions during the past 5 years. Safety has become increasingly important in the oil and gas industry. Due to fracking boom which pushes into closely populated areas, oil and gas companies are required to perform the safety process before, during, and after the drilling and production operations. Also, the workforce and people inside and around the operation areas should have enough knowledge of safety procedures.

Recently, the Wall Street Journal reported that “At least 15.3 million Americans lived within a mile of a well that had been drilled since 2000, that is more people than live in Michigan or New York City” [28]. Also, a research paper from the Public Health School at the University of Colorado noticed that “Accidents at well sites don’t simply threaten workers but can also expose those who live nearby to fires, explosions and hazardous chemicals” [28].

Fracking companies are required to comply with all safety procedures and processes that are recommended by the American Petroleum Institute (API). They should carry out all blowout prevention equipments of inspection process during the drilling and production. Companies are required to register and record all inspection and closure test as scheduled by the safety department. In case blowout prevention equipment is not functioning well, the operation should hold the blowout prevention equipment until it is fixed and retested [29].

2.3.3 Economic Perspective

2.3.3.1 Abundance of Shale Gas Reserve/Supply

The US Energy Information Administration (EIA) assessed 48 shale gas basins in 32 countries, with a result of 6622 Tcf (trillion cubic feet) shale gas and 6609 Tcf conventional gas worldwide. This means that the shale gas reserve contains a similar amount of conventional natural gas [30]. Later, EIA report indicated that 2013 estimation for the total world would be increased to 7299 Tcf, considering 41 countries, 95 basins, and 137 formations, as shown in Table 2.2 [31]. It appears that the global estimation of shale gas reserve has been promising over the recent years.

In the USA, the Marcellus Shale is reported to contain large amount of shale gas across western New York, Pennsylvania, and Ohio states. The reserve has been estimated to be sufficient for 45 years of the consumption [30]. By looking at the estimation reports over the past few years, the reserve of the shale gas seems to be increasing, due to more basins and formations being discovered and incorporated.

Table 2.2 Reports of shale gas reserve from EIA 2011 and 2013 [31]

ARI report coverage	2011 Report	2013 Report
Number of countries	32	41
Number of basins	48	95
Number of formations	69	137
Technically recoverable resources, including the USA		
Shale gas (trillion cubic feet)	6622	7299
Shale/tight oil (billion barrels)	32	345

2.3.3.2 The Increase of Natural Gas Production

As a result of the sufficient reserve fund, the gas production has been stimulated and growing. For instance, the natural gas production in the USA has been increased over a decade. The shale gas is considered as the largest contributor to this growth from 2012 to 2040 [32]. EIA (2015) reported that the total natural gas had been produced 35% more during the period 2005–2013, which is mostly attributed to developing shale gas in 48 states. In addition, for the year 2040, the shale gas production is estimated to be increased by 73% and reach to 19.6 Tcf under reference case [33]. These figures and numbers reflect the significant increase in natural gas production in the USA over the past 10 years and the tendency of the continuous growth for the next 25 years.

2.3.3.3 Lower Natural Gas Price

Shale gas has depressed natural gas prices in the USA significantly, compared to the major markets. The natural gas price is estimated to be 2.5 times higher by 2050 if shale gas has not been developed. This may facilitate global competition and geopolitical shifts that break long-standing monopolies. For example, this could lessen European dependence on Russian gas, reducing Russia's ability to leverage higher prices [30].

2.3.3.4 Increased Global Investment in Fracking Wells

It has been reported that International Energy Agency (IEA) predicted global investment of $6.9 trillion in the shale gas development including lots of expected new wells during the period 2012–2035. This causes the rise of unconventional oil and gas and a fast shift from traditional producers to plentiful domestic resources. It has been estimated that 80% of natural gas well drilled in the next decade is expected to employ hydraulic fracturing [30, 34]. With more fracking well established, the production of shale gas will continue to grow accordingly.

2.3.3.5 Economic Development Growth

Some evidence has been reported about the economic development as a result of the increase in shale gas production. For example, in Pennsylvania, the active wells grew from 350,000 to 650,000 and generated 29,000 new jobs in 2008. For the Marcellus Shale across West Virginia and Pennsylvania, it was reported to bring $4.8 billion in gross regional product, caused 57, 000 new jobs, and generated $1.7 billion in tax collections. For Texas at the Barnett Shale, $11.1 billion annual output

Table 2.3 Direct and indirect economic benefits from shale gas production in the USA

Shale play	Estimated impact	In the year	To the economy of
Marcellus	$4.2B in output 48,000 jobs	2009	Pennsylvania
Marcellus	$8.04B in revenues 88,588 jobs	2010	Pennsylvania
Barnett	$11B in revenues 111,131 jobs	2008	Dallas/Ft. worth area
Haynesville	$2.4B in revenues 32,742 jobs	2008	Louisiana
Fayetteville	$2.6B in revenues 9533 jobs	2007	Arkansas
Marcellus	$760M in revenues 810 jobs	2000 wells over a 10-year period	Broome county, NY
Marcellus	$2.06B in revenues 2200 jobs	Gas production per year	Broome county, NY

Adapted from Kinnaman (2011) [35]

and 100, 000 jobs have been reported [30]. These direct and indirect economic benefits from shale gas production are shown in Table 2.3:

It also has been observed that fracking has transformed the USA into an energy super power. In 2013, the USA has become the world's largest producer of oil and natural gas. The personal income is projected to be increased to $3500 more per home in 2025. Fourty percent more oil and natural gas jobs has been estimated during 2007–2012. Government revenue is estimated to be $1.6 trillion increase to federal, state, and local government from 2012 to 2015. $180 billion trade deficit is estimated to be reduced by 2022. $1.14 trillion is predicted to be spent on infrastructure between 2014 and 2025. $533 billion increase in US GDP in 2025 is forecasted [36].

2.3.3.6 The Effect of Trade Shock

One of the potential effects induced by fracking is to impose trade shock on the exporters and importers of oil and gas. There is an estimation of economic effects of a 50% reduction in the volume of US gas and oil imports over the period 2007–2012. As a result, some countries may encounter some negative effects. For example, Canada appears to experience a reduction of 0.5% of GDP. Other countries such as Yemen, Egypt, Qatar, Equatorial Guinea, Nigeria, Algeria, and Peru have also been estimated to experience a decline in GDP of up to 0.5% [37]. This indicates that fracking can provide major benefits to some countries like the USA, but also may create significant negative economic impacts on some countries relying on exporting oil and gas.

2.3.3.7 The Profitability of Drilling Shale Oil

Since fracking involves more sophisticated drilling and extraction process, it is considered costlier to operate. In views of the declining oil price, oil companies are forced to consider the cost of expensive compared to less expensive fracking extraction methods. A report from *The Wall Street Journal* revealed that at $90 a barrel and below, many hydraulic-fracturing projects start to become uneconomic and the break-even point may lie around $80 to $85 [38]. Another article shows that fracking may still survive below $60 per barrel. However, new exploration and production may decrease, and some wells with higher cost have been shut down [39]. This information did indicate that further oil price declining risk is very likely to make expensive shale drilling unprofitable. Therefore, for a drilling company, more investigation and analysis on profitability challenge are deemed necessary, in light of the higher cost of fracking and the declining price of oil.

2.3.4 Environmental Perspective

Fracking requires an enormous amount of water as much as four to eight million gallons per well. The Environmental Protection Agency (EPA) in America indicated that about 35 thousand of fracking wells during drilling annually required a huge amount of water (equivalent to five million usages) [40]. Also, the big issue that the water sources are used for fracking operations varies and is not well documented or monitored. Some studies referred to the danger of the chemical solutions that are used in the fracking process; about 25% of fracking chemicals could cause cancer or other diseases.

Also, fracking can be one of the reasons of climate change because it produces methane which harms the environment. Methane is often released from the fracking wells during the drilling and production process. Some studies have shown that if the percentage of leakage is more than 3%, the burning of natural gas can be worse for the climate [41].

Fracking operation can also cause earthquake even though it is sometimes considered as small or under low-risk category. Many reasons can cause earthquake; in fracking, earthquake can be caused by drilling vibration or injecting water under a high pressure. Researchers referred to some actual cases that exposed to significant earthquakes because of the abuse of using underground injection during fracking. Those cases were registered in Oklahoma and Prague; many local homes were impacted and thousands of dollars worth of damage [41].

Wildlife also has been affected by fracking which comes with strong and fast industrial development, including the massive truck traffic. Fracking requires multiple routes for trucks to transport millions of freshwater from its sources to the operation areas. Animals are poisoned by chemicals added to water, and they are pushed to leave the wild areas to survive [41].

Human, animals, earth, water, and weather have been affected by the oil and gas industry operations [42]. Its processes have significant impacts on the environment because of the lack of control and complying with the environmental policy and regulations [43]. Due to the fast growth of the fracking operations in North America, people and some health and environment organizations continue protesting and asking to band the fracking activities [44, 45]. Recently, Alberta Energy Regulator (AER) issued a restrictive policy regarding the fracking operations including a list of requirements. Fracking companies are required to provide all information relating to the fracking operation such as the amount of waters used during the process and its sources and also the type of chemicals and solutions added into the water and used in each single operation.

Richards [43] pointed to the debate and the miscommunication between the environmental organizations and the producer companies regarding the propaganda and fact. The industry is always fighting back to prove that all information and data provided against the fracking are classified under the misrepresentation, misinformation, or misunderstanding category [46].

2.3.4.1 Water Use

Fracturing technology and its risk to water resources gained much attention from both environmental organizations and the media. They argue against the chemicals used in mixing with the fracking operation fluid and its risk for groundwater contamination. Water management is required to reduce the environmental and the media debate surrounding the fracking operation areas. Despite the continued development of fracking technology, using and reusing the vast quantities of produced water during the fracking process is one of the key issues that need to find alternative management strategies for managing this issue [47]. Drought contingency plans are started to be legally required by water companies for assessing the potential risk of using water resources before approving its use for fracking. Moreover, minimizing water consumption and reusing of fracturing fluid are challenges that need comprehensive management and disposal of wastewater plans [41, 47].

2.3.4.2 Methane Emissions

Methane is a type of gas that is usually located under the Earth's surface. Due to the fracking process, methane released from the land to the air creates poisoning emissions. Recently, some governments and environmental organizations have taken some steps to control the gas emissions produced by conventional and unconventional gas industry. Releases of methane have long been noticed and recorded in several parts of the world. After completing the fluid injection process, the fluid returns to the surface combined with significant quantities of methane gas [48].

Nowadays, there is an innovative technology that helps reduce the methane gas emissions by up to 90%. This technology is called the reduced emission completion (REC), and it is used during the flow-back period. However, this technology requires a proper implementation process such as installing special pipelines to the well in preparation for the fracturing completion [48]. Fracking companies have shown high interest in making more business than investments to reduce methane gas emissions. In this case policies and regulations are needed to push these companies for complying the reducing of methane emission rules [49].

In America, the federal oil and gas leases pointed to the study that proved the difference of methane emission rate among regions. The Utah state has strict regulations regarding reducing the methane emissions compared with the state of Colorado [50]. On the other hand, the study mentioned that in some areas with no fracking activity, a methane emission increase was recorded; the origin of the trends in the data is far from clear. So additional measurements and research are required by the US Energy Information Administration (EIA) [51].

2.3.4.3 Seismicity

The hydraulic fracking induced seismicity during or after the fracking operation. It typically forms an elongated cloud of event locations [52]. Recently, several innovative technologies were implemented to control seismicity occurrence and mitigate the seismic hazard. Increasing number of sensible earthquakes would be a sign of real seismicity that might increase the rate of damages and fatalities. Fracking is a complicated process, and the injecting of fluid under high pressure is considered the most difficult stage that may cause seismicity. The shear slip may occur during the fracking process due to high pressure that might lead to creating shear stresses. This explanation is still under studies, and some researchers argue in the way of creating the seismicity during the fracture operation [54]. However, some of them pointed to the induced shear slip might lead to the diversity of fracture surfaces and create new layers formation [55]. EIA experts illustrated in their report that in over 35,000 hydraulically fractured wells, only four wells had noticeable earthquakes in the USA [56]. To avoid this issue, fluid injections should be short-lived and injected at lower pressures [53].

2.3.4.4 Land/Surface Use

Usually, in the conventional oil and gas industry, the operations need a huge land area, but in the unconventional, operations by fracking technology require less land use. However, in both types, the surface that uses resources is still the main issue in some cases. Environmental and safety organizations continue complaining against the fracking operations in regard to negative environmental impacts. Some cases that had harmed the land or surface during the oil and gas operation were recorded by the industry or environmental and safety organizations. In Louisiana (2009), some animals were poisoned by chemicals and founded near a drilling area. In Pennsylvania (2008), the Monongahela River was contaminated by chemicals and a high level of salt content found in the river. In the same state (2009), a spill of fracking fluid into a surface and the depth water results to death of organisms that live in the river [57]. So, the impacts of surface disturbance can extend over large areas and both plant and animal species. Continuous improvement of best practices is required by industry organizations [58].

2.3.4.5 Groundwater Contamination

The fluid that is injected into the oil or gas reservoir contains from more than 750 distinct chemicals. Fracking uses high-pressure pumpers to pump fluid through the drilling well to the host rocks [59]. The chemical represents about 2% from the total fracturing fluid volume. Large quantities of wastewater are generated during the fracking process and represent about 98 percent of the volume. The Environmental Protection Agency in America has started since 2010 to identify the potential risk of hydraulic fracturing on drinking water [60]. The fracking companies are getting benefits from exemption under the regulation of Safe Drinking Water (SDW) that was issued by the Energy Policy Act (EPA) in 2005. However, the environmental agencies are still working to identify contamination from shale gas exploration. Scientists explained the reason of limited identification of the groundwater contamination from shale gas operation. They emphasized that the large-scale exploration of shale gas has begun recently compared to groundwater flow rates. So, the much longer time frame is needed to identify and evaluate possible groundwater contamination.

> *The fraction of drinking water wells that had chloride concentrations >250 mg/L (EPA threshold for drinking water) in groundwater from Garfield County doubled between 2002 (4%) and 2005 (8%), with chloride up to 3000 mg/L in drinking water wells.*

Overall, there might be real cases that exposed chemicals affected the groundwater in some areas, but many researchers and environmental agencies believe that conventional and unconventional oil and gas exploration has an impact on the environment and health [61–64]. For eliminating the impact of this issue, more studies are undertaken by EPA including a review of the literature, analysis of existing data, laboratory studies, and real case studies [59].

2.3.5 Political Perspective

The political perspective deals with players and factors that can potentially influence the creation and/or modification of policies and also with players and factors that can influence and modify the perception and attitude of those whom policies are made for. Although usually overlooked, this perspective can be very important and change the competitive scenario in many cases.

Regarding the case of fracking technology, the most important factors and players identified are as follows:

The Environmental Protection Agency (EPA) The agency's mission is to protect human health and the environment [65]. After 1997, EPA was mandated (by law) to regulate fracking fluids, as they caused many health and environmental concerns. Since then, it has started to conduct several studies about fracking fluids and also to regulate its usage (what would be the allowed and not allowed substances and chemicals) [66]. EPA, with their studies and regulations, might have the ability to hinder shale gas extraction and put more pressure on the oil industry through public opinion. On the other hand, EPA representatives have already stated that fracking can be done without harming the environment [67].

Policy-Makers and Legislators Either on the State or Federal level, there are clearly two distinct movements, a pro-fracking and an antifracking. Both have power depending on the state/region. Pro-fracking movements highlight and trust the economical and strategic benefits America would get from exploring more natural gas reservoirs, and they open an opportunity to the industry when they are open to discuss how to use fracking techniques while decreasing environmental impact (e.g., Colorado and Texas) [67]. Antifracking movements highlight the environmental and social hazards that may surge from fracking and state that potential economical benefits are not worthy of the risk. They pose a threat as they do not want to take chances and are leaning toward banning the technique (e.g., NY and Vermont) [66].

Nongovernmental Organizations (NGO's) Nongovernmental organizations play a major role in today's policy-making [73], and their importance is growing in every sector. For fracking technology, the ones that are most relevant are environmental organizations and activist groups. These organizations can be very powerful in influencing the public opinion, by organizing constant protests, manifestations, and making studies showing the potential hazards of fracking.

Public Opinion The public opinion is the perception of public over any given issue/subject. The public in general can exercise strong influence over policy-makers and legislators [74]. Public opinion against fracking can make it very difficult for activities to continue, once policy-makers would then be leaning toward more restrictive policies and regulations.

Federal Agencies Strong agencies include Department of Energy (DoE), Department of Defense (DoD), and Department of Homeland Security (DHS). Such powerful institutions could, once they decide to support any given initiative/movement, influence policy-makers (not through political lobby but through the experience and expertise of its employees and leaders) [75]. These agencies might easily realize the benefits of the expansion of fracking and future American independence from foreign fossil fuels. In that case, the fracking industry might gain powerful allies.

2.3.6 Legal Perspective

The legal perspective deals with factors that reflect the legality or illegality of the technology, namely, laws, standards, codes, and regulations. The importance of these factors is obvious, given the fact that once a technology (or anything related to it) is set outside the limits of any legal instrument, it automatically becomes not suitable. Regarding the fracking technology, these are the legal factors that should be considered:

The Fracturing Responsibility and Awareness of Chemicals Act (FRACT Act) In 2009, twin laws were passed in the House of Representatives and in the Senate [68, 69], giving EPA authority to regulate fracking and mandating fracking companies to disclose the chemicals used in the fracking fluids. The law was seen as a threat since the industry would have to deal with more regulations. Also, it would have to disclose some of their trade secrets, the fracking productivity highly depends on how the cracks in the shale rocks are kept open, and these cracks are "produced" and sustained by the chemicals and other substances used in the fracking fluid. Therefore, no company wants to publicize the composition of its fluids.

Federal Laws As of now, eight different federal laws apply to fracking (same as to conventional drilling) [72]. The discussion evolves around the question of whether or not new laws and regulations would be needed. It presents an opportunity for companies to argue that no extra or specific laws and regulations are needed. Nonetheless, antifracking movements argue that none of these existing laws properly deal with fracking, because fracking involves different techniques and therefore different hazards when compared to conventional drilling and oil/gas extraction.

The "Halliburton Loophole" The Halliburton Corporation is one of the biggest companies in the oil sector, providing services of several natures to the oil companies [76]. In 2005, a provision in an energy bill exempted fracking from the Safe Drinking Water Act, removing any authority of EPA over fracking activities [69, 70]. Although it helped the industry in the short term, it was terrible for the image of fracking and oil companies in general (especially because the then vice-president, Dick Cheney, was a former Halliburton CEO, which has risen numerous suspicions).

The Ban on Fracking In December 2014, New York joined Vermont by banning fracking activities in the State [71]. Those laws pose a serious threat to fracking. If public opinion supports it, several other states might join the ban.

Prospective Laws Potential laws that might be enacted could present either opportunities or pose threats, depending on the content. As an action plan, the industry should pay close attention to all political factors and players, as these can be a motivation for new laws.

2.3.7 Ethical Perspective

Technological innovations have changed our lives in an unprecedented way. However, new technological innovations are never without dispute as there are many shades of gray underlying its application. The same technology can shape our future on the one hand when used to make this world more humane, while on the other hand, it can make us disconnected or extinct as a human race due to dishonest demagoguery [78]. Fracking technology is no exception to this controversy and has sparked dichotomy between its benefits and potential drawbacks. The key stakeholders in this issue are industry, government, pro-fracking and antifracking advocacy groups, landowners, and community or neighbors.

Ethics is a standard that guides human behavior in different context. Many times, innovators are ignorant or possess a telepathy mindset about the impact of technology [77]. Some of the issues that cause conflict among social norms, moral values, and technological innovation are information use; human interaction, reproduction, privacy, values, and discrimination; sustainability; power disparity; and international relations. Ethical perspective is intended to anticipate diabolic consequences of technology and address ethical issues not only during technology development but also during the whole life cycle of the technology and prevent probable backlash [78].

In an attempt to analyze the ethical perspective of fracking, a model known as "CAT scan" is used. The tool was first proposed by Goodpaster, a former professor at Harvard Business School, in his book *Conscience and Corporate Culture* in the year 2006 [77]. The CAT scan is a matrix that combines five steps of case analysis and discussion with four ways of ethical analysis.

Describe There could be several interest groups or people. It is important to identify the people whose actions prompt ethical questions. Clarifying relevant facts and information helps to find out ethical implications.

Discern There could be several ethical issues. But it is imperative to find out the most important ethical issue(s) and trace the connection or impact to other issues.

Display Understanding the players and the ethical issues facilitates to list out probable actions by the actors. However, the actions need to be specific, brief, and doable.

Decide At this stage, the players must choose optimal solution considering the environment. It should be the best ethical response in the prevailing contexts.

Defend Finally, the decision should be backed up by moral principles [77].

The four major means of ethical analysis are interest based, duty based, right based, and virtue based.

2.3.7.1 Interest-Based Thinking

In this view, ethics is related to actions that impact a human being. Hence, a certain action or policy is only ethically acceptable if the outcome positively serves the interest of the human society or reduces the cost of achieving benefit.

2.3.7.2 Right-Based Thinking

An action is morally agreeable if it ensures social justice or "fairness." Everyone should get an equal share of opportunity, wealth, liberty, or freedom.

2.3.7.3 Duty-Based Thinking

The motto of this philosophy is whether an individual is contributing their share as part of the whole community. Hence, ethical behavior is playing one's part according to social and legal norms.

2.3.7.4 Virtue-Based Thinking

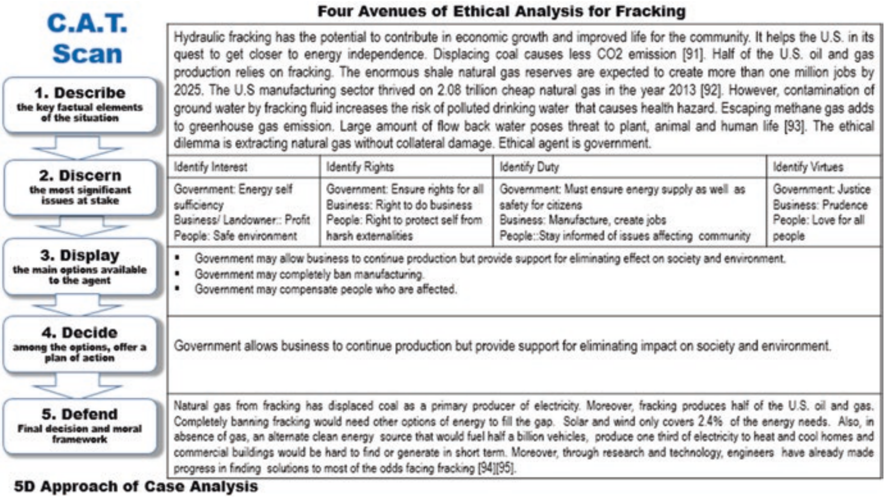
Ethical actions are measured against prudence, temperance, courage, justice, faith, and love. Deviation from these virtues is considered as unethical action or behavior [77].

The ethical analysis using CAT scan model is shown in Table 2.4.

Half of US oil and gas is now being produced by fracking [79]. Marcellus Shale formation is assumed to contain 489 trillion cubic feet of natural gas. At the present rate of consumption of natural gas in the New York State, the reserve is calculated to last for 400 years. However, some of the potential impacts of fracking are contamination of groundwater, tributary, and the difficulty of disposing a large amount of flow-back water. The gas employees and shareholders of the gas companies are benefitted economically. Landowners also gain from leasing. However, the landowners are at risk in case the surface water gets contaminated as it would reduce the property value [80].

A number of cities, states, and countries have banned fracking. Two California counties (Boulder County, Colorado) – New York and even in Texas where the technique was developed – have banned fracking. Also, there are other states who joined in this group such as Pittsburgh, Pennsylvania (2010); Philadelphia, Pennsylvania (2012); Broadview Heights, Mansfield, Oberlin, and Yellow Springs, Ohio, (2012); Hawaii County (2013); Mora County, New Mexico (2014); and Beverly Hills, California (2014). Internationally, fracking is prohibited in some European countries such as Germany, France, Scotland, Northern Ireland, and Bulgaria [81].

Table 2.4 Ethical analysis of fracking technology by CAT scan model [77–80]



C.A.T. Scan — **Four Avenues of Ethical Analysis for Fracking**

5D Approach of Case Analysis				
1. Describe the key factual elements of the situation	Hydraulic fracking has the potential to contribute in economic growth and improved life for the community. It helps the U.S. in its quest to get closer to energy independence. Displacing coal causes less CO2 emission [91]. Half of the U.S. oil and gas production relies on fracking. The enormous shale natural gas reserves are expected to create more than one million jobs by 2025. The U.S manufacturing sector thrived on 2.08 trillion cheap natural gas in the year 2013 [92]. However, contamination of ground water by fracking fluid increases the risk of polluted drinking water that causes health hazard. Escaping methane gas adds to greenhouse gas emission. Large amount of flow back water poses threat to plant, animal and human life [93]. The ethical dilemma is extracting natural gas without collateral damage. Ethical agent is government.			
2. Discern the most significant issues at stake	Identify Interest	Identify Rights	Identify Duty	Identify Virtues
	Government: Energy self sufficiency Business/ Landowner:: Profit People: Safe environment	Government: Ensure rights for all Business: Right to do business People: Right to protect self from harsh externalities	Government: Must ensure energy supply as well as safety for citizens Business: Manufacture, create jobs People::Stay informed of issues affecting community	Government: Justice Business: Prudence People: Love for all people
3. Display the main options available to the agent	• Government may allow business to continue production but provide support for eliminating effect on society and environment. • Government may completely ban manufacturing. • Government may compensate people who are affected.			
4. Decide among the options, offer a plan of action	Government allows business to continue production but provide support for eliminating impact on society and environment.			
5. Defend Final decision and moral framework	Natural gas from fracking has displaced coal as a primary producer of electricity. Moreover, fracking produces half of the U.S. oil and gas. Completely banning fracking would need other options of energy to fill the gap. Solar and wind only covers 2.4% of the energy needs. Also, in absence of gas, an alternate clean energy source that would fuel half a billion vehicles, produce one third of electricity to heat and cool homes and commercial buildings would be hard to find or generate in short term. Moreover, through research and technology, engineers have already made progress in finding solutions to most of the odds facing fracking [94][95].			

2.4 Conclusion

The aim of this chapter is to analyze the hydraulic fracturing (fracking) technology through the STEEPLE methodology. STEEPLE assesses a technology from different perspectives, namely, social, technical, economical, environmental, political, legal, and ethical. The model concludes if fracking technology would be an oprion for addressing energy challenges by the USA in the near future.

Specifically, the three research questions posed are why is the energy industry jumping into fracking? What are the STEEPLE factors that come into play when adopting fracking? Is fracking a suitable technology for the future? The first question is addressed in the introduction part where the present industry situation is discussed, and the reasons why the key players are interested in fracking are identified. The second question is addressed in the assessment section where each perspective of the methodology is analyzed, and main factors and players are identified, explained, and discussed. The third question is addressed in this section.

A summary of the technology assessment with pertinent benefits and/or challenges for each perspective is captured in Table 2.5.

As discussed earlier, there is an ethical dilemma involved in choosing whether to use fracking or not. Also, the political and legal perspectives may offer benefits and/or challenges depending on how the many players behave. On the technical side, there are minor benefits and challenges (The technology is not new, and it is evolving. It is perfectly feasible from a technical standpoint). The economical perspective is, by far, the most positive. It presents several advantages that could be beneficial for the USA. However, both social and environmental factors are unfavorable and offer serious challenges for the technology to be fully deployed.

Table 2.5 Analysis summary table

Perspective	Benefit	Challenge
Social	NO	YES
Technical	YES	YES
Economical	YES	YES
Environmental	NO	YES
Political	NO YES	NO YES
Legal	NO YES	NO YES
Ethical	YES	YES

Taking the perspectives altogether, one can say that fracking is a very promising technology, but it has extremely serious adversities associated with it. It is clearly feasible from the technical perspective, and it has great economical potential. Ethically, it has been proved to be acceptable. Nevertheless, the social and environmental issues make it unsuitable as an energy option. The key point is, if negative impacts are taken care of – al least mitigated – fracking can become a suitable energy technology for the near future of the USA. In order for that to happen, the technology needs to evolve to deal with those issues, and at the same time, all the political players involved need to be willing to talk and negotiate.

2.5 Recommendations

As some major environmental drawbacks associated with fracking technology have been identified, other alternatives such as renewable energy sources as well as exploring safer means of extracting natural gas may need to be taken into account for meeting sustainable energy expectations. Besides, in order to enhance the commitment of environmental protection and social welfare, the laws and regulation pertaining to fracking technology need to be reviewed and improved by involving all stakeholders and considering all relevant perspectives and impacts.

In view of the diverse arguments of fracking technology, both research works and monitoring of fracking activities are deemed essential and required to be reinforced by the US Energy Information Administration (EIA) and Environmental Protection Agency (EPA). These efforts are expected to clarify the relevant benefits and challenges, reduce the negative impacts, and validate the suitability of being a future sustainable energy technology. In addition, all environmental groups and O&G companies should support and encourage the Center for Sustainable Shale Development (CCSD) to continue the implementation of improvement and innovative practices for fracking technology development, because the sustainability consideration cannot be thoroughly enhanced without close collaboration among all stakeholders.

References

1. Mitchell, J. What next for the oil and gas industry? The Royal Institute of International Affairs, October 2012.
2. Energy Information Administration. (2013). *Annual energy outlook 2013 with projections to 2040*. Washington, DC: US Department of Energy.
3. DCOSTA (Amanda), '*PESTLE analysis history and application*', in Bright Hub Project Management, May 2011, Accessed 11th May 2015. http://www.brighthubpm.com/project-planning/100279-pestle-analysis-history-and-application/
4. Cadle, J., Paul, D., & Turner, P. (2010). *Business analysis techniques: 72 essential tools for success* (p. 260). British Comp Society Series (BCS), The Chartered Institute, 2010 – Business analysts.
5. Zalengera, C., Blanchard, R. E., Eames, P. C., Juma, A. M., Chitawo, M. L., & Gondwe, K. T. (2014). Overview of the Malawi energy situation and A PESTLE analysis for sustainable development of renewable energy. *Renewable & Sustainable Energy Reviews, 38*, 335–347.
6. Daim, T. et al. (2011). "*Technology Assessment: Forecasting the Future Adoption of Emerging Technologies", Operation and Technology Management* (pp. 1–5), Erich Schmidt Verlag, Book.
7. Zalengera, C., Blanchard, R. E., Eames, P. C., Juma, A. M., & Chitawo, M. L. (2014). Sustainable development of renewable energy. *Renewable and Sustainable Energy Reviews, 38*, 335–347.
8. Daim, T., et al. (2015). Policies and programs for sustainable energy innovation: Renewable energy and energy efficiency. In *Business & Economics* (p. 454). Switzerland: Springer International Publishing.
9. Stephan, S., & Mader, K. (2013). *Bridges between science, society and policy: Technology assessment-methods and impacts* (Vol. 22). Springer Science & Business Media.
10. Sheikh, N. J. (2013). Assessment of solar photovoltaic technologies using multiple perspectives and hierarchical decision modeling (Ph.D. Dissertation), *ProQuest/UMI (UMI Number 3568075)*, pp. 1–238, 2013.
11. Boudet, H., Clarke, C., Bugden, D., Maibach, E., Roser-Renouf, C., & Leiserowitz, A. (2014). "Fracking" controversy and communication: Using national survey data to understand public perceptions of hydraulic fracturing. *Energy Policy, 65*, 57–67. http://doi.org/10.1016/j.enpol.2013.10.01.
12. ASBC (American Sustainable Business Council). (2014). The business case for rethinking fracking.
13. Asadourian, B. L. (2012). *Health effects that may result from fracking* (p. 1). 25: Lehigh Edu.

14. Musick, T.. (2014). "*Fracking and worker safety: U.S. oil boom is in full swing, as are questions about hazards*". Safety + Health: Official Magazine of NSC Congress and Expo. http://www.safetyandhealthmagazine.com/articles/11434-fracking-and-worker-safety
15. Boyle, M. D., Payne-Sturges, D. C., Sangaramoorthy, T., Wilson, S., Nachman, K. E., Babik, K., Jenkins, C. C., Trowell, J., Milton, D. K., & Sapkota, A. (2016). Hazard ranking methodology for assessing health impacts of unconventional natural gas development and production: The Maryland case study. *PLoS One, 11*(1), 1–15. https://doi.org/10.1371/journal.pone.0145368.
16. Pennsylvania, Guiding Southwestern, Through Shale, and G A S Development. (2014). "Getting the boom without the bust." *Center for Energy Policy and Management: Environmental Law Institute and Washington & Jefferson College*.
17. Cattaneo, C. (2011). New age for old oil. *Financial Post*. http://business.financialpost.com/2011/01/29/new-age-for-old-oil/
18. Tait, C., & Cryderman, K. Alberta's new boom from old oil, 2013 http://www.theglobeandmail.com/reporton-business/industry-news/energy-and-resources/albertas-new-boom-from-oldoil/article11790035/
19. Cattaneo, C. (2011). New Age for Old Oil. *Financial Post*, 2011. http://business.financialpost.com/2011/01/29/new-age-for-old-oil/
20. Government of Alberta. *Alberta Oil & Gas Industry, Quarterly Update, Fall 2013*. http://www.albertacanada.com/files/albertacanada/OilGas_QuarterlyUpdate_Fall2013.pdf
21. Kiger, P. J. Green fracking? 5 technologies for cleaner shale energy, National Geographic, March 2014.
22. Smith, M. U.S EPA supports natural gas extraction/fracking, March 2013. http://benitolink.com/us-epa-supports-natural-gas-extractionfracking
23. Golden, J. M., & Wiseman, H. J. (2014). The fracking revolution: Shale gas as a case study in innovation policy. *Emory LJ, 64*, 955.
24. The Nat Geo website, http://news.nationalgeographic.com/news/energy/2014/03/140319-5-technologies-for-greener-fracking/. Accessed on 31 May 2016.
25. The Breaking energy website, http://breakingenergy.com/2013/05/23/cabot-using-natural-gas-instead-of-diesel-to-power-fracking-equipment/. Accessed on 31 May 2016.
26. The Conservation website, http://www.conservation.ca.gov/dog/general_information/Pages/HydraulicFracturing. Accessed on 31 May 2016.
27. The Slo County Water website, http://www.slocountywater.org/site/Water%20Resources/Advisory%20Committee/pdf/HF%20Technical%20Resources.pdf. Accessed on 31 May 2016.
28. The EE News website, http://www.eenews.net/stories/1060007532. Accessed on 31 May 2016.
29. The Pacode website, http://www.pacode.com/secure/data/025/chapter78/s78.72.html. Accessed on 31 May 2016.
30. Sovacool, B. K. (2014). Cornucopia or curse? Reviewing the costs and benefits of shale gas hydraulic fracturing (fracking). *Renewable and Sustainable Energy Reviews, 37*, 252–254.
31. US EIA, Technically recoverable shale oil and shale gas resources: An assessment of 137 shale formations in 41 countries outside the United States, p.2, June 2013.
32. US Energy Information Administration, Annual Energy Outlook 2015 with projections to 2040, pp. MT 23, April 2014.
33. US Energy Information Administration, Annual Energy Outlook 2015 with projections to 2040, pp. 20–21, April 2015.
34. Sovacool, B. K. (2014). Cornucopia or curse? Reviewing the costs and benefits of shale gas hydraulic fracturing (fracking). *Renewable and Sustainable Energy Reviews, 37*, 252.
35. Kinnaman Thomas, C. (2011). The economic impact of shale gas extraction: A review of existing studies. *Ecological Economics, 70*, 1243–1249.
36. American Petroleum Institute, Hydraulic Fracturing: Unlocking America's Natural Gas Resources, July p. 4, 2014.

37. ODI, The development implications of the fracking revolution, pp. 14–15, April 2014.
38. Gold, R., & Ailworth, E. Fracking firms get tested by oil's price drop, Oct. 9, 2014. http://www.wsj.com/articles/fracking-firms-get-tested-by-oils-price-drop-1412899027 Retrieval date: 26 May 2016.
39. Rosenberg, E. Can fracking survive at $60 a barrel? INVESTOPEDIA, http://www.investopedia.com/articles/investing/072215/can-fracking-survive-60-barrel.asp Retrieval date: 26 May 2016.
40. Beckwith, R. (2010). Hydraulic fracturing: The fuss, the facts, the future. *Journal of Petroleum Technology, 62*(12), 34–41.
41. Environmental Protection Agency (EPA), www.epa.gov. Accessed on 31 May 2016.
42. Alberta Energy, Oil Frequently Asked Questions: Does crude oil production have environmental consequences? 2013. http://www.energy.alberta.ca/Oil/764.asp
43. Richards, T., Spills and Leaks. Alberta Views. (2013). https://albertaviews.ab.ca/2013/10/02/spills-and-leaks/
44. Alberta Energy Regulator. (2014). What is Hydraulic Fracturing? http://www.aer.ca/about-aer/spotlight-on/unconventional-regulatoryframework/what-is-hydraulic-fracturing.
45. Foster, J. (2013). The fossil fuels war. *Monthly Review, 65*(4), 29.
46. Grant, P. (2013). The facts of fracking: The drilling industry gets proactive. *Business in Calgary, 23*(9), 87–93.
47. Vidic, R. D., Brantley, S. L., Vandenbossche, J. M., Yoxtheimer, D., & Abad, J. D. (2013). Impact of shale gas development on regional water quality, science.sciencemag.org.
48. Greenhouse gas emissions reporting from the petroleum and natural gas industry. Background Technical Support Document. http://www.epa.gov/climatechange/emissions/ downloads10/Subpart-W_TSD.pdf. Accessed 3 Jan 2011.
49. Harris, D. A. (2010). *Determining lost and unaccounted for gas loss* (pp. 1–7). Houston: Tech. Rep.
50. Federal oil and gas leases: Opportunities exist to capture vented and flared natural gas, which would increase royalty payments and reduce greenhouse gases. GAO-11–34 U.S. General Accountability Office Washington DC, 2010. http://www.gao.gov/new.items/d1134.pdf
51. Howarth, R. W., Santoro, R. & Ingraffea, A. (2011) Climatic change 106: 679. https://doi.org/10.1007/s10584-011-0061-5
52. Phillips, W. S., Fairbanks, T. D., Rutledge, J. T., & Anderson, D. W. (1998). Induced microearthquake patterns and oil-producing fracture systems in the Austin chalk. *Tectonophysics, 289*(1), 153–169.
53. Pearson, C. (1981). The relationship between microseismicity and high pore pressures during hydraulic stimulation experiments in low permeability granitic rocks. *Journal of Geophysical Research, 86*, 7855–7864.
54. Moriya, H., Nakazato, K., Niitsuma, H., & Baria, R. (2002). Detailed fracture system of the Soultz-sous-Forets HDR field evaluated using microseismic multiplet analysis. *Pure Applied, 159*(1–3), 517–541.
55. Brown, S. R., & Bruhn, R. L. (1998). Fluid permeability of deformable fracture networks. *Journal of Geophysical Research*, *103*, 2489–2500.
56. U.S Energy Information Administration (EIA). https://www.eia.gov/
57. Vaughan and Pursell, A.D. Vaughan, D. Pursell. (2010). *Fracking attack: Risks, hype, and financial reality of hydraulic fracturing in the shale plays*. Reservoir Research Partners and Tudor Pickering Holt and Co, Houston.
58. U.S. House Committee on Energy and Commerce. Chemicals used in hydraulic fracturing: Minority Staff, April 2011.
59. U.S. House Committee on Energy and Commerce. Chemicals used in hydraulic fracturing: *Minority Staff*, April 2011. http://democrats.energycommerce.house.gov/sites/default/files/documents/Hydraulic%20Fracturing%20Report%204.18.11.pdf
60. EPA. Draft Hydraulic Fracturing Study Plan. (2010). http://water.epa.gov/type/groundwater/uic/class2/hydraulicfracturing/index.cfm

61. Osborn, S. G., Vengosh, A., Warner, N. R., & Jackson, R. B. (2011). Methane contamination of drinking water accompanying gas-well drilling and hydraulic fracturing. *Proceedings of the National Academy of Sciences of the United States of America.*
62. Jackson, R. B., Vengosh, A., Darrah, T. H., Warner, N. R., Down, A., Poreda, R. J., Osborn, S. G., Zhao,K., & Karr, J. D. (2013). Increased stray gas abundance in a subset of drinking water wells near Marcellus shale gas extraction. *Proceedings of the National Academy of Sciences of the United States of America.*
63. Warner, N. R., Jackson, R. B., Darrah, T. H., Osborn, S. G., Down, A., Zhao, K., White, A., & Vengosh, A. (2012). Geochemical evidence for possible natural migration of Marcellus Formation brine to shallow aquifers in Pennsylvania. *Proceedings of the National Academy of Sciences of the United States of America.*
64. Thyne, T. (2008). Review of phase II hydrogeologic study (Prepared for Garfield County).
65. The Environmental Protection Agency website, https://www.epa.gov/aboutepa. Accessed on 30 April 2016.
66. Rahm, D. (2011). Regulating hydraulic fracturing in shale gas plays: The case of Texas. *Energy Policy, 39*(5), 2974–2981.
67. The What is fracking website, http://www.what-is-fracking.com/epa-cut-pollution-fracking/. Accessed in 30 April 2016.
68. The Government Track website, https://www.govtrack.us/congress/bills/112/s587/text. Accessed on 1 May 2016.
69. The NY Times website, http://www.nytimes.com/2009/11/03/opinion/03tue3.html?_r=0. Accessed on 1 May 2016.
70. The Gasland The Movie website, http://www.gaslandthemovie.com/whats-fracking/faq/what-is-the-halliburton-loophole. Accessed on 1 May 2016.
71. The Forbes website, http://www.forbes.com/sites/judeclemente/2015/06/07/why-new-yorks-fracking-ban-for-natural-gas-is-unsustainable/#7dc77dae27b0. Accessed on 1 May 2016.
72. The What is Fracking website, http://www.what-is-fracking.com/which-federal-laws-apply-to-shale-development/. Accessed on 1 May 2016.
73. The National Academy press website, http://www.nap.edu/read/10240/chapter/20. Accessed on 1 May 2016.
74. The Guardian website, http://www.theguardian.com/public-leaders-network/2012/sep/03/public-opinion-influence-policy. Accessed on 1 May 2016.
75. The DoD website, http://www.defense.gov/About-DoD. Accessed on 1 May 2016.
76. The Halliburton Corporation website, http://www.halliburton.com/en-US/about-us/corporate-profile/default.page?node-id=hgeyxt5p. Accessed on 16 May 2016.
77. Goodpaster, K. E. (2007). *Conscience and corporate culture. Book, philpapers.org*. Wiley-Blackwell.
78. Palm, E., & Hansson, S. O. (2006). The case for ethical technology assessment (eTA). *Technological Forecasting and Social Change*, *73*(5), 543–558.
79. USA Today Editorial Board. (2016, April 21). "*Objections to fracking are weak*" http://www.newsleader.com/story/opinion/editorials/2016/04/21/objections-fracking-weak/83363870/
80. Potter, A., & Rashid, M. H. (2013). "An ethical approach to hydraulic fracturing," *2013 ASEE Southeast Sect. Conf.*, pp. 1–7.
81. Baddour, D. (2015, February 2). *List of places than ban fracking keeps growing*, http://www.chron.com/business/article/List-of-places-thanban-fracking-keeps-growing-6057266.php

Chapter 3
Landscape Analysis: Connected Lighting System

Nina Chaichi and Tugrul U. Daim

3.1 Introduction

The lighting industry has gone under major transformations in recent decades. These changes are both at components/luminaires and system level. In 1999, Haitz stated that lumen per package will increase by a factor of 30 and the cost per lumen will decrease by factor of 10 [1]. This is also known as Haitz's law [2]. In 2011, Haitz's law is revisited; though the cost per lumen decremental rate remained the same, lumen per package incremental rate dropped to 20 [3]. According to revised Haitz's law, LED has entered to era that can overcome its adoption barrier—high lamp price and low light output per emitter [2, 4]—in general lighting section. Next Generation Lighting Industry Alliance (NGLIA)'s presentation to the Department of Energy (DOE) shows that LED would disrupt the traditional lighting resource and dominate the lighting market by 2020 [5].

The benefits of LED at luminaires level include high-energy efficiency, long lifetime, design flexibility, directional light, robustness, dimming capability without color shift, absence of regulated toxic substances (e.g., mercury), absence of heat or UV in light beam, and low-voltage DC operation [2] among others. However, the digital nature of LED offers new opportunities at a system level to change the symbolic meaning of lights as well as the industry landscape and improve the value of lighting. For instance, LED enables the visible light communication which has values such as high-rate data communication and indoor positioning [6, 7]. All of this new lighting functionality, coupled with new wireless communications protocols, the ubiquity of smartphones, the emergence of home automation, the Internet of Things (IoT), and the large-scale data collection and analytics, will enable a vast

N. Chaichi • T.U. Daim (✉)
Department of Engineering & Technology Management,
Portland State University, Portland, OR, USA
e-mail: nchaichi@pdx.edu; tugrul.u.daim@pdx.edu

T.U. Daim et al. (eds.), *Infrastructure and Technology Management*,
Innovation, Technology, and Knowledge Management,
https://doi.org/10.1007/978-3-319-68987-6_3

new range of features that can be embedded into solid-state lighting (SSL) products and expand the range of lighting applications [8].

The purpose of this paper is to focus on technology and practices beyond efficiency of energy and maintenance that would be enabled by utilizing LEDs. In order to tie benefits with the connected lighting features, we have developed convergence framework discussed in Sect. 3.2. Besides, we identified two big trends for benefits beyond energy efficiency——human centric lighting and indoor positioning——elaborated in Sect. 3.3. In Sect. 3.4, we discussed the technological landscape in office, retail, and healthcare section. Conclusions are provided in Sect. 3.5.

3.2 Convergence Framework

Intelligent connected lighting design characteristics and functionality directly depend on the objective of the system; therefore, based on the objective of the system, specific hardware and software would converge together to serve the purpose of the system. For instance, Acuity Brands have tiered solutions where tier one is composed of luminaires and its controller and tier two sensors, such as occupancy, are added to the system to gain a little bit more energy efficiency. Tier three is a complete solution that provides benefits like taking advantage of daylight harvesting and building automation [9]. In this paper, we tried to build a simple yet comprehensive framework which can be used as a reference to help understand various systems, compare the solution with each other, and evaluate their added value. Following the framework is the result of studying existing products, white papers, interviews, and other resources.

Connected lighting system can be broken into four sections——connection, integration, interface, and function. The first three sections are related to the hardware part of the system, and function section is the functionality of the system based on integrated hardware, most of the time in conjunction with the related software. The system functionality would really determine the added value of the system. Figure 3.1 shows the convergence framework and three solutions. Each solution——based on how it converged——would yield different values. For instance, solution 1 illustrates high functionality and low usability; on the contrary, solution 3 shows high usability and low functionality. Solution 2 is a more balanced case according to functionality and usability. The following further describes each section:

(a) *Connection*: includes wired or wireless communication interfaces. The wireless interfaces considered for system are WiFi, LP WiFi, Bluetooth, BLTE, 3G/4G/LTE (GPRS), Zigbee, Zwave, 6LoWPAN, WiHART, RFID, VLC, and LiFi. The main wired interfaces include power-line communication (PLC), Ethernet, Power over Ethernet (PoE), digital addressable lighting interface (DALI), digital multiplex (DMX512), and KNX. These interfaces have been utilized to communicate within the system and with external systems, external systems such as building management system (BMS); personal smart devices; smart objects, e.g., blinds and thermostats; and so forth [10–13].

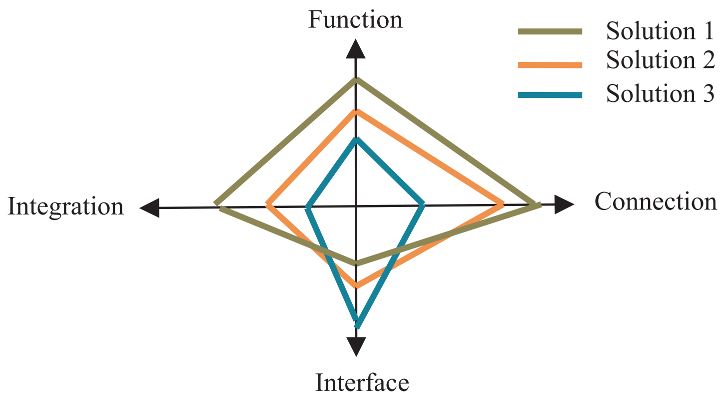


Fig. 3.1 Connected lighting convergence framework

(b) *Integration*: lights are an ubiquitous source of power. Because of these characteristics, they are an ideal host for various sensors and devices. Sensors are utilized to gather extensive data for various purposes from environment. These purposes can be classified into several categories——presence detection, failure detection, room condition, air quality, etc. Devices like controllers, cameras, speakers, recorders, and others can be integrated into light fixture as well.

(c) *User interface*: users can interact with connected lighting systems through interfaces. These interfaces can be push-button panels, smartphones, tablets, PC, etc.

(d) *Function*: the connected lighting system which consists of connection, integration, and user interface part can enable vast range of functions. Sometimes, this hardware needs to be combined with an appropriate set of software to enable specific functions. These functions can be categorized as monitoring, reporting, scheduling, controlling, and business applications. It can monitor energy consumption, failure, air quality, occupancy, foot traffic, light characteristics, and so forth. Also, streamed data can be analyzed and visualized and published as a report. Besides, relevant data can help to set different schedules for lighting, temperature, and maintenance. Gathered data can help in the optimal control of multiple systems like lighting, heating, and cooling. In addition, there are business applications like payment on a personal device and dynamic and personalized marketing using indoor positioning.

Cisco has taken this convergence one step further and introduced a digital ceiling. The purpose of their approach is to not only increase smartness but also connectivity. Their approach is to put disparate networks including lighting, HVAC, and security on a unified IP system. This unified IP system consists of Cisco Catalyst switches, PoE, universal PoE, and Constrained Application Protocol (CoAP). Connected lighting is the basis for the digital ceiling. IP system for lighting is the backbone of digital ceiling's IP system; as well, the lights are the intelligent gathering agents for the system [14, 15].

3.3 New Trends

There are some developments in design concepts and new technologies and programs that would possibly shape the future objective of lighting systems. Human centric lighting and indoor positioning are, respectively, new design criteria and technologies that would influence the future of lighting. In this section these two trends are briefly discussed.

A. Human Centric Lighting

Peter Boyce defines human centric lighting (HCL) as a "light devoted to enhance human performance, comfort, health, and well-being individually or in some combination" [16]. Any of HCL's elements can be affected by light through visual and nonvisual systems. The following questions need to be answered to thoroughly analyze the light effects on HCL's elements.

The first related questions are how visual and nonvisual systems are working and how are they influenced by light?

Retina contains five photoceptor types which provide inputs to visual and nonvisual systems. Visual system receives its input from three types of cones and rods. These photoceptors have their own specific visible light spectral sensitivity from 400 to 700 nm——see reference [17] for each types of spectral sensitivity. Photoceptors absorb light and excite retinal ganglion cells (RGC). RGC sends signal via POT to LGN/IGN and then virtual cortex for processing the image [16].

On the other hand, the fifth photoceptor is the main input provider for nonvisual system. A few RGC (1–5%, depending on the species and method of estimation) are called intrinsically photosensitive RGC or ipRGC and can act as independent photoceptors through expression of melanopsin [17]. These photoceptors are sensitive to short wavelengths of the visible light spectrum with the highest sensitivity at approximately 480 nm [17, 18]. IpRGCs send signal directly and indirectly to the nonimage-forming part of the brain including suprachiasmatic nuclei (SCN), pineal gland, etc. [19]. Unlike the visual path, the nonvisual path is not well known. It is shown that light influences the secretion of melatonin through influencing pineal gland indirectly via SCN and PVN [16]; however, it is also argued that pineal gland is directly affected by light [20].

Furthermore, ipRGCs can be stimulated through connected rods and cones, so they can be influenced by other spectral range as well, though this intraretinal connection is not fully understood yet [17, 21]. For this reason and others such as pupillary light reflex (PLR) fully outlined in [17], it is impossible to expect predetermined nonvisual effects based on intensity and spectral composition of the light. Yet, there is general guidance in order to minimize and promote ipRGC output. Lower light intensity which is biased toward longer visible wavelengths minimizes the activation of ipRGC outputs, while higher light intensity which is biased toward the blue/green region of the visible light promotes ipRGC photoceptors [17].

Also, visual and nonvisual response depends on other photic factors rather than intensity and spectral composition of light. Light direction is considered as a factor

Table 3.1 Light effect on human being [18, 24]

Visual		Nonvisual		
Visual performance	Subjective well-being	Psychological health	Physiological health	Performance
• Object recognition • Contrast perception/ visual comfort	• Emotion • Satisfaction • Aesthetic appreciation	• Depression • Stress • Anxiety/ agitation	• Cardiovascular disease • Diabetes • Sleep disorders • Gastrointestinal disorders • Cancer • Easing pain • Decreasing recovery time	• Alertness • Adapting to night shift • Jet lag
Improves mostly with higher level of intensity and some cases with direction of light		Improves with changing light characteristics (color, intensity, temperature) over time to keep circadian rhythm in sync		

playing a role in visual response [22]. On the other hand, factors playing a role in nonvisual response are timing and duration of light exposure and retinal irradiance [16, 23].

The second set of related questions are as follows: how are HCL's elements affected by visual or nonvisual systems and are these influences direct or indirect?

Lots of studies have been done to understand the effect of visual and nonvisual systems on visual performance, visual comfort, well-being, psychological and physiological health, and human performance in general. Table 3.1 illustrates these effects and their connection with each system. Visual performance and comfort as well as subjective well-being are related to visual systems [18]. These factors are tied to quality of light which directly relates to adequacy of light intensity, brightness, aesthetic, and also reduction of glare and flicker [16, 18].

On the other hand, non-visible effects are associated with circadian, neuroendocrine, and neurobehavioral system [17, 25]. Neurobehavioral system explains the action between nervous system and behavior including depression, anxiety, stress, alertness, memory, attention, and concentration [26, 27]. The neuroendocrine system has evolved to effectively integrate neural and hormonal information and accordingly take physiological actions [28]. Circadian system is in charge of keeping body's internal 24 h clock in sync in order to let biological events repeat themselves in regular intervals. There are three factors that affect circadian rhythm——internal clock, external stimuli including light, and hormones [29].

These three systems interact with each other. The nonvisual photoceptor sends signal to suprachiasmatic nuclei (SCN) and indirectly controls the release of hormones including melatonin and cortisol. These activate relevant parts of the brain effecting alertness. Stimulating the receptors suppresses melatonin production and leads to an alertness increase. Changes in the level of alertness during the day regulate internal clock and circadian rhythm. However, exposure to light from late evening to early morning can reset the internal clock forward or backward [18, 29].

In Table 3.1 the effect of light on these three systems is categorized as psychological and physiological health and performance. Table 3.1 organized the most simple and direct relation. It only considered the relation which can be distinguishable between visual and nonvisual systems. For example, mood hasn't been included in the table since some considered it as visual effect [16, 18], while other research suggests that it is effected by nonvisual system directly and indirectly [30]. Though this is a good approach to determine influential factors for each system, it is not necessarily enough to design light for a given outcome. For instance, as it is illustrated in [16], human performance can be effected by almost all the categories mentioned in Table 3.1 directly and indirectly. It can be influenced by alertness, sleep-wake rhythm, visual performance, and even factors such as personality and personal management skill which are not under influence of light [16].

Another question is as follows: are light spectral and intensity composition and timing and duration of light exposure only influenced by a given element?

As briefly mentioned above, in most cases, light is not the only influencer. There are some factors such as age, health, and circadian robustness (clock genes) that can influence light effects on HCL's elements [16, 20, 23], while external stimuli such as food and exercise can independently have an effect on circadian system and influence outcomes [20]. Moreover, factors such as personality, beliefs, culture, etc. can have effects on a person's response to the light [31]. Overall, the effect of light on human performance, comfort, well-being, and health is very context dependent.

Finally we consider how artificial light design can influence the effect outcome.

Two types of light sources have been considered to study the effect of light on human——natural light and artificial light [18]. Human centric lighting can be achieved in three ways. The first is increasing the daylight availability in an indoor area by improving the form of building such as adding window and skylight [31]. The second is by improving artificial light via enhancing their flexibility and quality [16]. The third approach is a hybrid approach that improves daylight and artificial light simultaneously [32]. Here, we will talk about efforts which have been made to make artificial light more flexible.

In traditional lighting design, the design factors include aesthetic, visual performance, and comfort [17]. In human centric lighting design, additional factors required to take into consideration include dynamic light spectrum, dynamic color temperature, dynamic light intensity, and flexible light direction. Dynamic light control systems enable light characteristics to change over time directly and indirectly.

(a) Direct dynamic lighting control system: this can also be considered as a personalized light control system in which light characteristics and direction can be changed based on user's preference. The system consists of connection, integration of controller, and user interface. The system is capable of allowing some or all of the light characteristics to be set through the user interface. This system can be set based on the preference, aesthetic, task, etc. The system can provide both preset light scenarios and fully personalized light setting.

(b) Indirect dynamic lighting control system: in this system light characteristics and direction have been controlled to achieve a desirable light output. The objective in indirect dynamic control system is mostly either mimicking daylight or responding to daylight. The difference between these two systems is the way they are programmed to provide HCL. The former system is more focused on enhancing flexibility of artificial light system as primary light source for HCL, while the latter system is more focused on adapting artificial light to varying needs based on daylight availability where natural light is primary the light source for HCL. Natural light differs based on the architecture, windows, blinds, weather, etc., and increasing natural light might reduce comfort by increasing temperature or glare. In these cases, there is a need to control natural light through other controlling systems such as manual or automatic blinds. This system consists of connection, integration of controller and light sensor, and added software or algorithms to provide expected function. This system can have a user interface though the purpose is for either overriding current control or providing non-light-related inputs to the system.

Personalizing lighting can enhance visual performance and well-being which indirectly helps with enhancing task performance [33]. One problem associated with the personalized control system is that this system would be changed based on individual's preference mostly for improving visual performance and comfort which might not support nonvisual effects of light. Though direct dynamic lighting control system implementation is fairly easy, on the contrary, indirect dynamic lighting control system can get very complicated for several reasons. First, it might require interaction with other controlling systems such as a blind control system to control the amount of natural light that the room receives [31]. Second, it may also be required to keep balance between light parameters to support more than one characteristic of HCL, e.g., performance and health [17]. Third, in some spaces, light needs to support more than one application concurrently, as an example in a healthcare facility. Fourth, right lighting characteristics are very context dependent [17], e.g., light characteristics required for a given application might be different for different age groups [34].

Furthermore, nonimage-forming effect of light is a new and immature field of research which makes it difficult to expect certain result based on light characteristics [17]. Also, there are not widely accepted metrics to take into account all of light effects especially nonvisual effects [17], despite efforts [35–37]. These problems, as well as the implementation problem mentioned above, might slow down the adoption of indirect dynamic control system in comparison with direct dynamic control system.

B. Indoor Positioning

Indoor positioning is a system to locate people or objects in an indoor environment to provide location-based services. IPS principles consist of anchor or reference points and solutions to determine the position of the mobile nodes with respect to those reference points [38]. Though IPS has the same main principle as GPS, it

Table 3.2 IPS technologies and solutions

Technology (location transmitter)	Solutions (positioning algorithm)
- WiFi - Bluetooth Low Energy (BLE) - Ultra-wide band (UWB) - Radio-frequency identification (RFID) - Zigbee - Visible light communication (VLC) - LiFi	- Proximity/identity - Triangulation/geometry/range - Scene analysis/fingerprint - Image transformation

differs from GPS in respect to the technologies utilized as anchor nodes. Table 3.2 summarizes some of the technologies and solutions which have been implemented in IPS so far.

VLC and LiFi are very similar such that in many cases, they could be replaced for the other technologies. However, both technologies use LED to transmit data wirelessly; VLC has been conceived as a point-to-point communication technique; on the other hand, LiFi is a bidirectional multiuser communication system. LiFi can communicate from point to multipoint and vice versa which makes it a complete wireless networking system [39].

IPS solutions or positioning algorithms are classified into four categories; however, different terminologies are used to address them in literature——Table 3.2 includes the alternative terminologies. Also, multiple techniques have been used to implement each positioning algorithm:

(a) Proximity: this technique uses a grid of fixed location transmitters to locate the mobile node based on the anchor node that serves the user. If more than one node is picked by the user, then strongest signal received——RSS methods——will determine the location of the user. This solution provides IPS with low cost and low accuracy [40–42].
(b) Triangulation: this solution is also called geometry and range which measures the geometric relation between the mobile node and location transmitter [38, 42]. This solution can be implemented by two techniques——lateration and angulation techniques. The former technique includes received signal strength (RSS), time of use (ToU), time difference of arrival (TDoA), and roundtrip time of flight (RTOF) methods. Angulation technique includes arrival of angle (AoA) method which is also called direction of arrival (DoA). For more detailed discussion, refer to [40, 41, 43].
(c) Image transformation: in this technique, mobile nodes equipped with a camera——image sensor——take pictures of local environment or location transmitter. Mobile node position is determined in a camera coordination system based on the taken image or series of them. Image transformation technique helps to find the location of the camera in world coordinate system and position the mobile node [43].
(d) Scene analysis: this consists of two steps——an offline and online step. In the offline step, a site survey is performed to build a priori location fingerprint database of the environment using triangulation methods such as RSS, ToU, TDoA,

AoA, or image transformation techniques. In the online step, the mobile node is positioned with respect to fingerprint database using methods including k-nearest neighbor (KNN), neural networks, support vector machine (SVM), smallest M-vertex polygon (SMP), and so forth. For more detailed discussion, refer to [40, 41].

IPS performances are dependent on both the technology and positioning solutions. Most frequent performance metrics to compare various IPS options include accuracy, precision, scalability, latency, complexity, robustness, cost, security, and privacy [38, 40–46]:

(a) Accuracy and precision: accuracy is the mean distance error between an estimated location and the actual location, while precision measures the robustness and consistent accuracy of the measurement. Cumulative distribution function (CDF) has been used to convey the performance of IPS considering both accuracy and precision.
(b) Scalability: this characteristic depends on three parameters——geographic, density, and space dimensions. Geographic illustrates the area or space covered by IPS, and density represents the number of mobile points present in the unit space per time period. Large or crowded covered areas could congest IPS and affect its normal operation. Another parameter to consider is the space dimension of the system. Some IPS can locate mobile nodes in 2D and 3D space or both.
(c) Latency: measures how fast IPS can locate a moving object. The measurement depends on the inherent delay associated with each technology, computational process time of algorithms, and available hardware for computation. For example, lower latency is expected for IPS using scene analysis solution if the computational process is using a centralized server side—higher processing power and enough power supply—rather than on mobile node platform or client side.
(d) Robustness: shows how IPS can keep functioning normally under partial failure and incomplete information. Examples include signal obstruction, environment changes, introduction of new component, and so on.
(e) Security and privacy: security ensures the system resilience against external threats, while privacy ensures confidentiality of client data to determine the location. IPS architecture and operational factors would affect the security and privacy level of the system. For example, running positioning algorithm on client device ensures more privacy than utilizing a centralized server to run the computation.
(f) Cost and complexity: cost and complexity of IPSs are directly tied to the decision made about operational metrics including accuracy, scalability, robustness, security, and privacy of the system. Another contributing factor in system cost is the reusability of any existing infrastructure to implement the IPS. Complexity is a combination of hardware and software complexity. Tables 3.3 and 3.4 illustrate the complexity of both components individually. However, software and hardware can positively and negatively affect each other's complexity [41, 43]. For instance, VLC with an image transformation solution has less complexity

Table 3.3 IPS technologies complexity [43]

Low complexity	Medium complexity
Zigbee, VLC	WiFi, BLE, UWB, RFID

Table 3.4 IPS solution complexity [43]

Low complexity	Medium complexity	High complexity
Proximity	Triangulation	Scene analysis Image transformation

than VLC. With the triangulation solution, however, image transformation is a complex process which can be reduced by using auxiliary equipment which results in more hardware complexity [43]. As a result, the information in Tables 3.3 and 3.4 needs to be adjusted with respect to IPS package.

VLC-based IPS manufacturers believe that VLC is the winner among the indoor positioning technologies. This belief is mostly because of the better accuracy and precision [47]——0.01–0.35 cm excluding VLC with proximity solution——and lower complexity and cost due to existing infrastructure [43]. Though VLC has the highest accuracy among indoor positioning technology, it is not a decisive winner when it comes to complexity and cost. Reference [41] illustrates how considering VLC along with different solutions will change the complexity level from low to high; however, it is not only considered photodiode-based VLC architecture.

VLC IPS architecture can be classified into two categories——photodiode-based design and camera-based design. Photodiode-based designs utilize proximity, triangulation, and scene analysis with triangulation-based reference database, while camera-based designs use image transformation and scene analysis with image transformation-based reference database. Photodiode-based design is a more accurate system in comparison with camera-based design. However, the latter has less hardware complexity. On the other hand, image transformation techniques are fairly complex and can negatively affect the response time. The complexity of image transformation can be reduced at the cost of increasing hardware complexity and cost [43].

Qualcomm's Lumicast technology is a VLC IPS. Lumicast uses a camera——image sensor——to determine the location and orientation of mobile objects in three dimensions. System accuracy is 10 cm and the response time is a tenth of second. In addition to high accuracy and low latency, Lumicast——in general VLC IPS—— is scalable and robust. The other factors that are needed to take into consideration are energy efficiency of system and its impact on smartphone's battery life in which Lumicast is doing good as well [47].

Besides, the cost of VLC system is low, since it can reuse infrastructure if LEDs are already installed. For example, Lumicast requires a firmware and mobile software in addition to LED network to position the objects. Firmware can be run on microcontrollers present in LED fixture drivers, and mobile software is needed to be installed on mobile devices [47].

However, VLC services are limited to where and when light is available. To overcome this restriction, some solution utilize other technologies, e.g., Bluetooth Low Energy (BLE) along with VLC to increase the robustness of system [47, 48].

3.4 Landscape Analysis in Different Sectors

Connected lighting benefits would differ from one sector to another. For instance, the main purpose of human centric lighting would be increasing productivity in one sector and improving health condition in another one. Also, indoor positioning technology enables various location-based services in different sectors. A landscape analysis is conducted in three sectors——office, retail, and health care——to study the trends, benefits, and barriers of connected lighting in each sector. Conducted landscape analysis is broken down into four steps. In the first step, we gathered case studies, white papers, manufacturer's reports, market research, and any resource which will provide an insight into technological trends. In the second step, we analyzed the content of materials gathered in the first step to identify the stakeholders, benefit for each of the stakeholder, stakeholder expectations, and so forth. In third step, we tried to relate each benefit with technological feature. And in the last step, we tried to cross-check the opportunities and identify the barriers with analyzing literature and market research.

A. *Office*

A smart connected office is a growing market so as connected office lighting as part of it. There are numerous case studies that have been published by lighting manufacturing on implemented smart connected office lighting as well as expected benefit from it. We studied about 40 case studies from major players in this field including Philips, Cisco, Lutron, Acuity Brands, Osram, Cree, GE, and Daintree (to obtain cases, refer to [49–56]).

There are three primary stakeholders——employee, employer, and the building owner——that can benefit from connected lighting. The benefits of smart connected lighting can be listed into three groups based on associated stakeholder. The mentioned benefits for employee are as follows——visual comfort, reducing eye strain and fatigue, improving concentration, task tuning, maximum comfort by personalizing the light, happiness and satisfaction, improving psychological status, and improving immune system. These benefits can be categorized as (i) visual benefit, (ii) subjective well-being, and (iii) health.

Extracted benefits from case studies for employer can be summarized as improving employee's effectiveness, performance, and occupational safety and health, managing office resource, and adapting light to business need, for instance, by shifting the attention to specific space. Connected lighting gathers data which helps employer to create optimal workspace by providing insight into employee preferences. Also, it helps with optimizing office space utilization.

Connected lighting benefits for building owner come down to building performance and operation. Analytics and data on building operation assist building owner in measuring and verifying energy efficiency for various certifications. Besides, it ensures sustainable practices by benchmarking facilities against each other and centrally manages geographically distributed facilities. Connected lighting is a flexible system which easily adapts to changes to accommodate tenants with different needs, provides limitless options, and is future proof.

Benefits have been linked to various technologies. For instance, some of the benefits for employees are linked solely to LED, since it provides glare-free and high-quality light. However, most of the benefits are linked to various features of connected lighting including personal control (lighting and environment), dynamic lighting, flexible lighting, connectivity with BMS, integrated building system, and its intelligence (sensors).

It is estimated that salaries and benefits of employee are about 85.5% of office operation cost [57]. So, employers would benefit a lot from lighting system which improves employee's productivity, absenteeism, or staff retention [57, 58]. There is an effort to quantify the benefits for employer; in their case study, the benefit of improved productivity is significantly higher than improved absenteeism and staff retention though considered improvement for all was equal and trivial [59]. Potential productivity gain could lower the total cost of ownership (TCO) of connected lighting and increase its adoption. Though the relation between the connected lighting features and the benefit including improvement in building performance and operation, business, and utilizing office resources is apparent, it is not the case for benefits related to employees.

Researchers do not have consensus on both potential benefit of human centric lighting for office worker and the path that connected lighting would yield these benefits. It is argued that light can affect employee's health, well-being, and alertness [58]; however, the first year of longitudinal study shows significant relation between dynamic lighting with only increasing employee's satisfaction and not with recovery, vitality, alertness, headache and eyestrain, mental health, sleep quality, or subjective performance [60]. Also, in an effort to establish influence path [33], linked mechanism map is proposed based on other research results. The purpose of this mechanism is to understand the effect of personal controller and illuminous condition on task performance, well-being, and health through influencing visual performance, comfort, appraisal, and so forth. However, the final map does not match the proposed map. Furthermore, there are other light or non-light-related variables [16, 61] which contribute in task performance and overall human performance and need to be considered when analyzing light effects.

As stated, it is challenging to prove the benefit of human centric lighting for office space, to link the benefit with specific technology, and to recommend lighting design that ensures alleged benefits. Though this could be a barrier for connected lighting adoption in office section, connected lighting itself can be a test-bed to overcome these barriers.

B. *Retail*

It is believed that retailers could increase the size of basket, sales, and profits via enhancing customer experience and improving operational efficiency. This is tightly tied to the retailer's strategy and adapting capability to changing environment. Retail sectors are witnessing the changes in shopper behaviors. The mentioned drivers for such changes are millennials'—digital——generation [62], technology [63, 64], and economy, regulation, globalization, and interaction between these environmental factors [64]. For instance, researches showed that mobile devices are shaping the shopping behavior and changing the expectation of the customers [65, 66]. More shoppers use mobile when shopping in store, online, or on the go. Among these shoppers, millennials are more likely than baby boomers to use and express concern about mobile channel [65], though it does not negatively affect their in-store shopping frequencies, as research showed they are more likely than baby boomers to shop in-store [65]. Since shoppers also expect to use mobile to find product information, compare prices and products, use shopping list, locate and navigate to in-store item, order out of stock items, get real-time promotions, use discounts and coupon automatically, etc., these activities are not specific to one category, and it is fairly widespread among all categories such as grocery, appliances, apparel, health and beauty products, etc. [66].

These behavioral and expectation changes underline the importance of shopper marketing practices over traditional marketing. Definitions provided for shopper marketing emphasize on marketing activities that influence not only shoppers' entire path to purchase but also shoppers' path beyond purchase from retention to recommendation [67] by focusing on shoppers' needs through deep insight into their behavior, engaging and creating unique experience for them, building brand equity, and so forth [68], though this fairly young area of marketing requires new innovations to reach to its full potential, innovations such as digital activities, multichannel marketing, store atmospheric and design, new efficient and targeted promotion and pricing, etc. [64, 69].

Overall, shopper marketing would reach to its full potential when it provides seamless shopping experience to customers. Location-based services are one of the most important contributors to shopper marketing. Location-based services require indoor positioning technology to locate mobile objects, mobile device as a platform to deliver services, digital indoor map to enable navigation, and loyalty app to implement the services.

Retailer uses loyalty app to enhance customer experiences by providing efficient, convenient, omnichannel, and personalized shopping. Mentioned location-based services in [47, 48, 65, 70, 71] which are included in the loyalty app to drive customer engagement and loyalty can be categorized as:

- Navigation: store navigation for shopping list or finding fast checkout lane
- Information: product information, price comparison, product reviews, and suggestions
- Assistance: find store employee, order out of stock item from other channels, etc.
- Personalized and location-based promotions

Also, the customer experience can be enhanced while improving operational efficiency by effective staffing and merchandizing [71]. Effective merchandizing is possible through analyzing location-related data gathered via loyalty app or indoor positioning system. Data analytics can help to improve store layout, shelf, and display strategy [71].

Retailers do not meet customers' expectation of seamless in-store shopping experience [65]; besides, VLC IPS is accurate and low cost which provides great value proposition for retailers to implement location-based services. Though customers and technologies are ready for location-based services, there are some barriers on the retailers' side to adopt these services. Current research shows that retailers do not invest and believe in the benefit of location-based services; besides not all retailers have loyalty app [72]. Besides, the bigger barrier for adoption is ambiguity about location-based marketing. There are several pilot projects utilizing VLC IPS in retail section around the globe which help retailers to test their marketing strategy before vastly implementing the location-based services.

C. *Health* Care

The healthcare industry can be categorized as an outpatient and inpatient facility. The former includes medical offices and clinics, while the latter includes nursing home/assisted living and hospitals. In this section, we have done content analysis for 20 lighting case studies. These case studies are mostly on inpatient facilities and clinics which are implemented and conducted by Philips, Acuity Brands, Cree, and Sacramento Municipal Utility District (SMUD). (To obtain cases, refer to [23, 49, 51, 55].)

The beneficiary of lighting can be categorized as three stakeholders——patients and visitors, caregivers and staff, and healthcare administrators. Healthcare administration goals are improving operational efficiencies while providing the best care to the patients and visitors. Connected lighting system can contribute to achieve those goals by providing human centric lighting to visitors, patients, caregivers, and staff. Analyzed cases show that caregivers and staff can benefit from human centric lighting to improve their performance and well-being. There are numerous instances that connected lighting contributes in improving performance as follows:

- Visual comfort.
- Visual performance: LED provides high-quality and glare-free lighting which improves visibility and visual performance. However, personal light (task tuning light) as a feature of connected lighting also improves visual performance. For instance, it can provide various light scenarios by controlling color, intensity, and temperature of light which improves diagnosis. Besides, the ability of controlling the light intensity can improve visual performance for different activities, e.g., lowering the intensity of light to provide better visual performance for X-ray view.
- Communication with patient through light.
- Enable different types of therapies. For example, psychiatrists can tune the light according to their requirement and objective to assist with the therapy.

Patients in outpatient and inpatient facilities can benefit from modern lighting in different ways. For outpatient visitors, modern light is mostly used to improve subjective well-being via exciting positive emotion; improving mood, satisfaction, and aesthetic appreciation; and decreasing stress and anxiety. On the other hand, the benefit of light for patients in inpatient facility comes to not only improving subjective well-being but also health.

Dynamic light which mimics natural daylight has gained attention in improving psychological and physical health. Dynamic light can improve the quality of life for patients in assisting living centers and decrease recovery time for patients in hospitals. The mostly reported nonvisual effect in inpatient facilities is improving the sleep-wake rhythm which is a well-known problem for patients in hospital and care facilities. It is also mentioned that it can improve patients' behavior in care facilities. Besides, there is visual effect of light that can affect health. It is reported that improving visibility can reduce falling incidents in care facilities.

The benefits mentioned in literature including "enabling performance of visual tasks, controlling the body's circadian system, affecting mood and perception, facilitating direct absorption for critical chemical reactions within the body" [29] almost match with the benefit extracted from case study. However, the sources of light mentioned to achieve the benefits are quite different. Increasing kight intensity can improve visual performance and well being as a result [22]. Direction of the light is important for the elderly [22]. On the other hand, important light factors that affect nonvisual response are (i) spectral content of the light source, (ii) intensity level of the light source, (iii) duration of exposure, (iv) timing of the exposure, and (v) age/health of individuals [17, 21, 23]. With considering electric source as light concentrated in limited areas of spectrum and not varying over time, the only source which can help with improving health is natural light. However, tunable LED with right controlling system would be able to mimic daylight pattern and provide similar benefits.

Healthcare facilities especially inpatient facilities are complex and dynamic with various light requirements for multiple activities and humans in their environment [73]. Doctors, nurses, administrative staff, and support staff need different light characteristics due to their type of work, the shift of their work, and their age. Besides, it might be a conflict for appropriate light characteristic, e.g., nurses require high intensity light for good visibility to provide better care, though exposing patients to high-intensity light at night can cause sleeping disorder. As conducted survey result [34] shows, controlling light is an important aspect for nurses, and they believe light for night navigation requires the most improvement.

Connected lighting provides healthcare facilities' flexibility to accommodate various and sometimes contradictory requirements and easily adapt to any changes. However, the difficult parts are as follows: to find light source which provides spectral range close to daylight and decent color rendering and, also, to set up multiple lighting scenarios considering all the stakeholders' benefits.

Though there is no case found that used LED (VLC) as indoor positioning technology for location-based services in healthcare system, here, we briefly discuss the location-based services available in healthcare field enabled by other technologies rather than VLC. For instance, location-based services provided by Navizon are listed as services to enhance patient experience and improve operation, safety, and asset management. Mentioned services for each category are as follows [74]:

(a) *Patient experience*:

- Wayfinding
- People-finding services

(b) *Operation*:

- Staff finding and tracking
- Patient flow
- Business intelligence
- Process automation
- Location aware messaging and alerting

(c) *Safety*:

- Patient safety: tracks wanderers, prevents elopement, prevents infant abduction, and reduces risk of injury or death
- Emergency response: summons help implementing wireless nurse call
- Infection control: enables identification of staff, patients, and equipment coming in contact with infection sources, reduces impact of hospital-acquired infections (HAIs), and provides documentation for regulatory reporting
- Staff duress/panic: panic button that enables security alerts
- Positive patient ID

(d) *Asset management*:

- Asset tracking: tracks equipment location and status, prevents theft and loss, facilitates patient flow for better care, improves handling recalls, eliminates over-purchasing and unnecessary rentals, facilitates timely preventive maintenance for improved regulatory compliance, enables automated inventory management, enables automated work orders, and helps eliminate operational bottlenecks

The accuracy required for the system can be different based on the location-based service [73]. For instance, services like wayfinding require higher accuracy rather than emergency response. Though VLC may lose its accuracy advantage based on implemented services, it still keeps its advantage when it comes to cost.

3.5 Conclusion

In this study, we established convergence framework based on four aspects——connection technology, user interface, integrated sensors, and the functionality of system as well as program and software required to enable them. Then we elaborated on human centric lighting and discussed how visual and nonvisual system works and how they are affected by light, whether light is influenced directly or indirectly and whether light is the only influencer, and the role of artificial lighting design. For other big trends——indoor positioning system—we discussed and explained underlying factors for IPS location transmitter technologies and positioning algorithm. Then, we discussed the criteria to evaluate the effectiveness and goodness of IPS. At the end we discussed VLC-based indoor positioning advantages and why it is considered the winner among all. In the last section, we talked about the benefit of human centric lighting and indoor positioning among others in office, retail, and healthcare system. We captured lighting manufacturing perspective and matched it with academia's perspective to identify the opportunities and barriers for connected lighting system. This paper tried to put the connected lighting system into consideration from different perspectives to help decision makers in various positions. Our analysis highlighted that there are uncertainties in the case of the benefit of human centric lighting. The uncertainties are related to the immaturity of neuroscience field associated with the nonvisual effects of light as well as lack of comprehensive system which links different features of connected lighting system to the human centric benefits in each sectors. In the indoor positioning case, the uncertainty in location-based services is less than human centric lighting. The uncertainty is mostly in retail sector where implementing successful business model relies on location-based services. With regard to proposed convergence framework, these uncertainties are mostly associated with functionality of the system where required changes can be applied through software changes. Only concerns to hardware system are the LEDs' light quality and its capability to provide needed spectrum in case of human centric lighting. So we hope the framework as well as other discussion help decision makers to implement the connected lighting system to be future proof based on their needs and also use it as test-bed to harness promising benefits.

Acknowledgment This study is made possible by a grant provided by Energy Trust of Oregon. We would like to thank Fred Gordon and Mike Bailey from ETO for initiating, guiding, and supporting this project all way along. And also, we would like to thank Debbie Driscoll, Mark Rehley, and Chris Wolgamott for their valuable feedback and guidance throughout the project.

References

1. Haitz, R., Kish, F., Tsao, J., & Nelson, J. (1999). The case for a national research program on semiconductor lighting. *Optoelectronics Industry Development Association*. pp 1–24, available at http://www.sandia.gov/~jytsao/hpsnl_sand_report_2000.pdf

2. Steele, R. V. (2007). The story of a new light source. *Nature Photonics, 1*(1), 25–26.
3. Haitz, R., & Tsao, J. Y. (2011). Solid-state lighting: 'The case' 10 years after and future prospects. *Physica Status Solidi A: Applications and Materials Science, 208*(1), 17–29.
4. Schubert, E. F., & Kim, J. K. (2005). Solid-state light sources getting smart. *Science, 308*(5726), 1274–1278.
5. Cook, K. *Next generation lighting industry alliance presentation for DOE*. [Online]. Available: http://www.nglia.org/pdfs/Keith-Cook-Presentation-DOE-092110.pdf. Accessed: 28 Jun 2016.
6. Bhalerao, M. V., & Sonavane, S. S. (2014). "Visible light communication: A smart way towards wireless communication," (ICACCI, 2014 International Conference on Advances in Computing, Communications and Informatics), pp. 1370–1375.
7. Jovicic, A., Li, J., & Richardson, T. (2013). Visible light communication: opportunities, challenges and the path to market. *IEEE Communications Magazine, 51*(12), 26–32.
8. Top Sector HTSM, *Lighting Roadmaps 2015 – Holland High Tech*. [Online]. Available: http://www.hollandhightech.nl/nationaal/innovatie/roadmaps/lighting. Accessed: 28 Jun 2016.
9. Nagel, V., Lydecker, S., & Mcllwraith, G. *Lux interviews: Acuity Brands' management team*. [Online]. Available: https://www.youtube.com/watch?v=timZ0oDVSHU
10. Higuera, J., Hertog, W., Perálvarez, M., Polo, J., & Carreras, J. (2015). Smart lighting system ISO/IEC/IEEE 21451 compatible. *IEEE Sensors Journal, 15*(5), 2595–2602.
11. Orion Energy System Inc. (2016). *Cisco digital ceiling* (*White Paper*). [Online]. Available: http://pages.orionlighting.com/rs/648-ATG-478/images/white-paper-c11-736542.pdf
12. McCall, D. *Intel's open interconnect consortium introduction* (*2015 DOE connected lighting systems presentations*). [Online]. Available: http://energy.gov/sites/prod/files/2015/11/f27/mccall_interoperability_portland2015.pdf
13. U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy. *Solid-state lighting R&D plan*, Jun-2016. [Online]. Available: http://energy.gov/sites/prod/files/2016/06/f32/ssl_rd-plan_%20jun2016_0.pdf. Accessed: 23 Nov 2016.
14. Cisco. (2016). *Cisco digital ceiling* (*Whitepaper*). [Online]. Available: http://pages.orionlighting.com/rs/648-ATG-478/images/white-paper-c11-736542.pdf
15. Kerravala, Z. *A digital ceiling is now a BUSINESS IMPERATIVE (whitepaper)*, Aug-2016. [Online]. Available: https://www.cisco.com/c/dam/en/us/solutions/collateral/industry-solutions/cisco-digital-ceiling.pdf
16. Boyce, P. R. (2014). *Human factors in lighting*. Crc Press. Baco Raton, FL.
17. Lucas, R. J., et al. (2014). Measuring and using light in the melanopsin age. *Trends in Neurosciences, 37*(1), 1–9.
18. De Kort, Y. (2014). Light and quality of life, in Encyclopedia of quality of life and well-being research. By Michalos A, In. Springer. New York NY.
19. Chellappa, S. L., Steiner, R., Blattner, P., Oelhafen, P., Götz, T., & Cajochen, C. (2011). Non-visual effects of light on melatonin, alertness and cognitive performance: Can blue-enriched light keep us alert? *PLoS One, 6*(1), e16429.
20. Albrecht, U. (2012). Timing to perfection: The biology of central and peripheral circadian clocks. *Neuron, 74*(2), 246–260.
21. Gooley, J. J., Rajaratnam, S. M., Brainard, G. C., Kronauer, R. E., Czeisler, C. A., & Lockley, S. W. (2010). Spectral responses of the human circadian system depend on the irradiance and duration of exposure to light. *Science Translational Medicine, 2*(31), 31ra33–31ra33.
22. Figueiro, M. G., Gras, L. Z., Rea, M. S., Plitnick, B., & Rea, M. S. (2012). Lighting for improving balance in older adults with and without risk for falls. *Age and Ageing, 41*(3), 392–395.
23. Pacific Northwest National Laboratory. (2016). *Tuning the light in senior care.* U.S. Department of Energy, Sacramento Municipal Utility District, and ACC Care Center. 1–37, available at https://energy.gov/sites/prod/files/2016/09/f33/2016_gateway-acc.pdf
24. Rajaratnam, S. M., & Arendt, J. (2001). Health in a 24-h society. *The Lancet, 358*(9286), 999–1005.

25. Bellia, L., Bisegna, F., & Spada, G. (2011). Lighting in indoor environments: Visual and non-visual effects of light sources with different spectral power distributions. *Building and Environment, 46*(10), 1984–1992.
26. Sandberg, M. A. (2011). Neurobehavioral functioning inventory. *Encyclopedia of Clinical Neuropsychology*, 1739–1740.
27. Hanifin, J. P., & Brainard, G. C. (2007). Photoreception for circadian, neuroendocrine, and neurobehavioral regulation. *Journal of Physiological Anthropology, 26*(2), 87–94.
28. Levine, J. E. (1997). New concepts of the neuroendocrine regulation of gonadotropin surges in rats. *Biology of Reproduction, 56*(2), 293–302.
29. Joseph, A. (2006). *The impact of light on outcomes in healthcare settings*. Center for Health Design. 1–14, available at https://www.healthdesign.org/sites/default/files/CHD_Issue_Paper2.pdf
30. LeGates, T. A., Fernandez, D. C., & Hattar, S. (2014). Light as a central modulator of circadian rhythms, sleep and affect. *Nature Reviews. Neuroscience, 15*(7), 443–454.
31. Tregenza, P., & Wilson, M. (2013). *Daylighting: Architecture and lighting design*. Routledge. New York, NY.
32. Mayhoub, M. S., & Carter, D. J. (2010). Towards hybrid lighting systems: A review. *Lighting Research and Technology, 42*(1), 51–71.
33. Veitch, J. A., Newsham, G. R., Boyce, P. R., & Jones, C. C. (2008). Lighting appraisal, well-being and performance in open-plan offices: A linked mechanisms approach. *Lighting Research and Technology, 40*(2), 133–151.
34. Lydon, P., Davis, R., & Wilkerson, A. *The nurses' perspective on hospital patient room lighting*. Department of Energy's webinar, 13-Sep-2016. [Online]. Available: https://energy.gov/sites/prod/files/2016/09/f33/Nurses-Study-Webinar_09-13-16.pdf. Accessed: 03 Jan 2017.
35. Rea, M. S. (2015). The lumen seen in a new light: Making distinctions between light, lighting and neuroscience. *Lighting Research and Technology, 47*(3), 259–280.
36. Rea, M. S., Figueiro, M. G., Bullough, J. D., & Bierman, A. (2005). A model of phototransduction by the human circadian system. *Brain Research Reviews, 50*(2), 213–228.
37. Andersen, M., Mardaljevic, J., & Lockley, S. W. (2012). A framework for predicting the non-visual effects of daylight–Part I: Photobiology-based model. *Lighting Research and Technology, 44*(1), 37–53.
38. Haute, T., et al. (2016). Performance analysis of multiple Indoor Positioning Systems in a healthcare environment. *International Journal of Health Geographics, 15*(1), 1.
39. Haas, H., Yin, L., Wang, Y., & Chen, C. (2016). What is LiFi? *Journal of Lightwave Technology, 34*(6), 1533–1544.
40. Liu, H., Darabi, H., Banerjee, P., & Liu, J. (2007). Survey of wireless indoor positioning techniques and systems. *IEEE Transactions on Systems, Man, and Cybernetics Part C: Applications and Reviews, 37*(6), 1067–1080.
41. Kavehrad, M., Chowdhury, M. I., & Zhou, Z. (2016). Indoor positioning methods using VLC LEDs. *Short-Range Optical Wireless: Theory and Applications*, 225–262.
42. Deng, Z., Yu, Y., Yuan, X., Wan, N., & Yang, L. (2013). Situation and development tendency of indoor positioning. *China Communications, 10*(3), 42–55.
43. Hassan, N. U., Naeem, A., Pasha, M. A., Jadoon, T., & Yuen, C. (2015). Indoor positioning using visible led lights: A survey. *ACM Computing Surveys, CSUR, 48*(2), 20.
44. Hossain, A. M., & Soh, W.-S. (2015). A survey of calibration-free indoor positioning systems. *Computer Communications, 66*, 1–13.
45. K. Al Nuaimi and H. Kamel, "A survey of indoor positioning systems and algorithms," in Innovations in information technology (IIT), 2011 international conference on, 2011, pp. 185–190.
46. Basiri, A., Peltola, P., e Silva, P. F., Lohan, E. S., Moore, T., & Hill, C. (2015). *Indoor positioning technology assessment using analytic hierarchy process for pedestrian navigation services*, in 2015 International Conference on Location and GNSS (ICL-GNSS), pp. 1–6.

47. Jovicic, A. *Qualcomm® LumicastTM: A high accuracy indoor positioning system based on visible light communication* (*whitepaper*), Apr-2016. [Online]. Available: https://www.qualcomm.com/media/documents/.../lumicast-whitepaper.pdf
48. Acuity Brands. *Illuminating the in-store experience* (*whitepaper*)." [Online]. Available: http://www.acuitybrands.com/solutions/services/indoor-positioning-white-papers
49. Acuity Brands. *Acuity brands case studies*. [Online]. Available: http://www.acuitybrands.com/solutions/inspire-me/case-studies#content-1
50. Cisco. *Cisco case studies*. [Online]. Available: http://www.cisco.com/c/en/us/solutions/cisco-on-cisco/it-success-stories.html
51. Cree. *Cree lighting case studies*. [Online]. Available: http://lighting.cree.com/applications
52. GE. *GE lighting case studies*. [Online]. Available: http://www.gelighting.com/LightingWeb/na/case-studies/
53. Lutron. *Lutron case studies*. [Online]. Available: http://www.lutron.com/en-US/Residential-Commercial-Solutions/Pages/SolApp/AllCaseStudies.aspx
54. Osram. *Osram case studies*. [Online]. Available: https://www.osram.com/osram_com/applications/case-studies/
55. Koninklijke Philips, N.V. Philips lighting case studies. [Online]. Available: http://www.lighting.philips.com/main/cases/cases.html
56. DaintreeNetworks. *DaintreeNetworks case studies*. [Online]. Available: http://www.daintree.net/resources/case-studies/
57. Energy Star. Energy star building upgrade manual chapter 6: Lighting. [Online]. Available: https://www.energystar.gov/sites/default/files/buildings/tools/EPA_BUM_CH6_Lighting.pdf. Accessed: 10 Jul 2016.
58. Van Bommel, W. J. (2006). Non-visual biological effect of lighting and the practical meaning for lighting for work. *Applied Ergonomics, 37*(4), 461–466.
59. ATKearney Consulting Company. *Quantified benefits of Human Centric Lighting*. [Online]. Available: http://www.lightingeurope.org/uploads/files/Quantified_Benefits_of_Human_Centric_Lighting_April_2015.pdf
60. De Kort, Y. A. W., & Smolders, K. (2010). Effects of dynamic lighting on office workers: First results of a field study with monthly alternating settings. *Lighting Research and Technology, 42*(3), 345–360.
61. Veitch, J. A., Stokkermans, M. G., & Newsham, G. R. (2013). Linking lighting appraisals to work behaviors. *Environment and Behavior, 45*(2), 198–214.
62. Donnelly, C., & Scaff, R. (2013). Who are the Millennial shoppers? And what do they really want? *Accent. Outlook, 2*, 1–7.
63. Frazer, M., & Stiehler, B. E. (2014). Omnichannel retailing: The merging of the online and off-line environment. *Global Conference on Business & Finance Proceedings, 9*, 655.
64. Shankar, V., Inman, J. J., Mantrala, M., Kelley, E., & Rizley, R. (2011). Innovations in shopper marketing: Current insights and future research issues. *Journal of Retailing, 87*, S29–S42.
65. Accenture Consulting. *Retail customers are shouting—are you adapting?* (2016). [Online]. Available: https://www.accenture.com/t20160728T162953__w__/us-en/_acnmedia/PDF-7/Accenture-Adaptive-Retail-Research-Executive-Summary-V2.pdf
66. Google Marketing Agency Council and M/A/R/C Research. *Mobile in-store research*. [Online]. Available: https://www.thinkwithgoogle.com/research-studies/mobile-in-store.html
67. Shankar, V. (2011). *Shopper marketing*. Cambridge, Massachusetts: Marketing Science Institute.
68. Deloitte Research. Shopper marketing: Capturing a shopper's mind, heart and wallet. (2007). [Online]. Available: https://www.gmaonline.org/downloads/research-and-reports/shoppermarketing.pdf
69. Grewal, D., Ailawadi, K. L., Gauri, D., Hall, K., Kopalle, P., & Robertson, J. R. (2011). Innovations in retail pricing and promotions. *Journal of Retailing, 87*, S43–S52.
70. Philips. *Unlocking the value of retail apps with lighting* (*whitepaper*). [Online]. Available: http://www.lighting.philips.com/main/education/white-papers.html

71. Opusresearch. *Retaining relevance in the omnichannel journey* (*whitepaper*).” [Online]. Available: http://www.acuitybrands.com/solutions/services/indoor-positioning-white-papers
72. WBR Digital & RetailMeNot inc. (2016). *Digital retail study 2016, evaluating the changing landscape of retail marketing*”. [Online]. Available: https://retailmenot.uberflip.com/i/642942-evaluating-the-changing-landscape-of-retail-marketing
73. Coyle, L., Neely, S., Nixon, P., & Quigley, A. (2006). “*Sensor aggregation and integration in healthcare location based services*,” in 2006 Pervasive Health Conference and Workshops, pp. 1–4.
74. Navizon. *Navizon applications in health care*. [Online]. Available: https://navizon.com/pdf/table_apps_healthcare.pdf

Chapter 4
Technology Assessment: Developing Geothermal Energy Resources for Supporting Electrical System in Oregon

Ahmed Shehab Alshareef, Tugrul U. Daim, and Ibrahim Iskin

4.1 Introduction

In the USA, the Department of Energy gives a lot of attention to the use of renewable energy and supports a diverse range of research that focuses on applying renewable energy in different areas, which reflects a broad energy market. The government participated in the development of renewable energy through minimizing the tax and loan and making that in their policy [1, 2]. In addition, they found that changing the work system (policy) will have a large effect on investment. The new policy work system supports renewable energy, which will lead to minimize the risk on financial premiums [3]. The US government has spent more than $1 billion between 1995 and 2000 to develop research in renewable energy, and the USA has more development and updates of the information than other countries [2].

Geothermal energy has significant impact as a source of electricity generation. There are more than 20 countries that benefit from geothermal plants, which generate more than 6000 megawatts. The geothermal plants are considered as environmentally benign in terms of emission abatement and water and land use as compared with other alternative sources of energy [4].

Geothermal energy is one of the most important renewable energies, and the potential to obtain energy from it is huge, so the Department of Energy pays a lot of attention to the development of the uses of this type of alternative energy to cover all applications in the USA such as electricity, heating and cooling for large building and homes, agriculture, and sterilization [5]. Consumers benefit from the heat of

A.S. Alshareef • T.U. Daim (✉)
Portland State University, Portland, OR, USA
e-mail: aalsha2@pdx.edu; tugrul.u.daim@pdx.edu

I. Iskin
Demandbase, Seattle, OR, USA

T.U. Daim et al. (eds.), *Infrastructure and Technology Management*,
Innovation, Technology, and Knowledge Management,
https://doi.org/10.1007/978-3-319-68987-6_4

geothermal energy that comes from extracting the Earth's surface, and this energy is clean. There is no emission of pollution from this type of renewable energy, so it will not affect greenhouse emissions [6, 7]. Most geothermal energy resources are available beneath the Earth's surface with different depths and forms such as volcanoes, hot springs, and geysers [8]. The energy from geothermal resources with a depth of 10,000 meters can reach to 50,000 times more than other natural resources like oil and natural gas. Also, it makes nearly 68 billion kilowatt-hours of electricity that cover six million typical US households [9]. Many countries in the world like the USA, Italy, France, and Iceland have begun to depend on geothermal power plants, but most of the activities of geothermal energy occur in Japan, the Philippines, the Aleutian Islands, North America, Central America, and South America as these countries are within the Ring of Fire [10–12]. Most resources of geothermal energy that can be found in the USA are in California, Nevada, Alaska, Hawaii, Idaho, Oregon, Utah, and Wyoming [13, 14].

Oregon is one of the eight states currently using geothermal energy and uses it in different applications such as generating industrial, agriculture, and commercial/residential electricity [15, 16]. So far the use of geothermal energy in Oregon is low, but the potential for success is very high when the opportunity is available to benefit from this type of renewable energy. This is why it's important to study the use of geothermal energy. Oregon has been ranked third in the potential use of geothermal energy after Nevada and California. Oregon depends on the Geo-Heat Center at the Oregon Institute of Technology to supply all technical information that helps to develop geothermal applications [8]. Because of the high temperature of geothermal areas, Oregon has the ability to produce 2200 megawatts of electricity. Since the 2009 installation of 0.3 megawatts of geothermal electrical plant in the Oregon Institute of Technology—Klamath Falls campus, many projects now are under construction in Oregon, and they are planning to reach the maximum use of geothermal energy. They work on the development of projects by increasing the production of electricity to reach 22 megawatts in Malheur County, 1.2 megawatts in the Oregon Institute location, and 3.1 megawatts in the progress of construction in Lake County. In addition, Oregon is close to having 2200 thermal wells and springs that can be used to provide direct heat to many facilities [17]. There are many investments in the field of geothermal energy, and the Office of Energy Efficiency and Renewable Energy (EERE) invested 21.4 million on the AltaRock enhanced geothermal system (EGS) at the Newberry Volcano close to Bend, Oregon. This project successfully reduced the cost for development of geothermal resources [18, 19]. The Oregon Department of Geology and Mineral Industries provided new maps that clarify all hot springs and volcanic vents and examine the performance of the wells and other resources of geothermal sources in the state [20].

One of the important aspects in geothermal energy projects is to look for economic analysis since it's preferred in literature. Multi-criteria decision-making (MCDM) will be used in this study. We will also use the analytical hierarchy process (AHP) since this process is complicated because it requires looking at the problem from different sectors, assessing the model, and, finally, reviewing the model to reach a final decision. MCDM techniques are successfully used in sustainable energy management. AHP is the more popular technique to use in different energy plan decision problems than PROMETHEE and ELECTRE [21]. MCDM is used to analyze and clarify the problem, by dividing the problem into multi-decision criteria. MCDM is required to develop renewable energy by showing the uncertainty within more complicated processes, which leads to finding a methodology that can handle different criteria and has the ability to simplify the problem and make it easy to solve [22–24].

4.1.1 Background of the Problem

In Oregon, there is also the problem of supplying energy to all consumers. Many factors are affected by this problem, which has led the Department of Energy in Oregon to search for a suitable solution as they see the following problems. The consumption of total energy reached 773 trillion British thermal units (Btus) in 2000, and this amount of consumption increased to 15% compared to consumption in 1990. Moreover, closely half of the energy consumed comes from petroleum products, and most of this is used for transportation. The price is always increasing in Oregon as Oregon imports 100% of natural gas and oil, which has an effect on the economy. In addition, the price of petroleum increased between 1999 and 2003 for residential heating oil, on-highway diesel, and regular gasoline to 39%, 25%, and 30%, and the residential consumers increased to 23%. The increase is higher for business customers. Also, between 1999 and 2004, the natural gas price increased by 168%. Due to the rise in energy cost and the effect on the industry, in 2000 there was a loss of more than 14,700 manufacturing jobs out of 208,700. Also, natural gas is considered a critical component in chemical manufacturing. This affected more than $519 million from the export from Oregon in 2005 and supported more than 3750 jobs [25]. The cost of electricity increased to 75%, and between 2000 and 2007, the price of natural gas and transportation fuels increased to 91% and 102%. In addition, climate change and peak oil are threatening the quality of life in Oregon. In addition to all of these problems that affect the potential to use the energy, buildings also had a large effect on energy consumption as they take more than half of the total used energy, which leads to an increase in the search to improve buildings' electrical usage and to increase the diversity of energy supply to these buildings [26]. All of these factors helped in the search to find other solutions that cover all these problems, and they found that the best thing to do is to use renewable energy. The world today tries to find the best way to benefit from natural resources such as water power, wind power, biomass, solar power, and geothermal energy that are sources of sustainable energy generation and to reduce the cost to make renewable energy suitable to all consumers. Due to its suitable environment and natural resources, Oregon has huge potential to use renewable energy alongside its electricity sector.

4.1.2 Problem Statement

Although the American Council for an Energy-Efficient Economy (ACEEE) considered Oregon as third in electrical efficiency, Oregonians consume annually approximately $15 billion on energy, and they still work to minimize the cost of energy to maintain both environmental and public health costs. In the legislature created for the Oregon Department of Energy in 1975, there is a requirement to review the continued growth for renewable energy forms to avoid problems that will occur in the future. Improvement for clean energy creates a positive impact on the environment, and Oregon has the opportunity to do that. So it's important to have remote renewable energy generation resources accessible to an area that has a heavy load of energy demand and to create greater resiliency to the Western electrical grid in the next 30 years [27]. Geothermal sources have the ability to deal with environmental and health costs because it's clean energy and it can generate clean energy. Also, it can be installed in different areas to serve different cities, and it can be modified to connect with the electrical grid.

In 2012, Oregon released a 10-year energy action plan because it's difficult to reach a 100% of new electrical growth without working with public buildings. The State Building Innovation Lab (SBIL) works to create deep energy savings into public buildings through working with lab pilot innovation in financing and program design. For creating benchmarks, it requires a data model and works to improve the model by coordinating with other entities and shaping data standardization. This process calculates cost efficiency for the next 10 years. There will be difficulties in clean energy infrastructure improvement unless finance and regulating barriers are removed [27]. From the literature review on geotechnical energy, research studies showed that geothermal sources are a requirement for future progress in reducing the energy load as public buildings consume a lot of energy, and that requires a recalculation of all processes of energy consumption and looking for best way of using energy. In the end, this will maintain the environment and reduce the financial cost.

On the part of consumption, although Oregon has a diversity of energy resources by depending on petroleum, natural gas, and renewable energy to cover all the consumption in the state, the main energy sources go to home heating. In 2012, electricity use for home heating was 50%, natural gas was 37.5%, and fuel oil was 2.5%. Most of energy consumption goes to transportation, which uses annually 63 million barrels of petroleum. According to the Energy Information Administration in 2012, Oregon consumption by end-use sector is 30.7%for transportation, 25.1% for residential, 25.0% for industrial, and 19.1% for commercial. It's necessary to find a solution to the pollution that comes from the transportation industry. Most people in Oregon use cars that depend on gasoline, and a few people use electric vehicles [27]. We can use renewable energy like geothermal energy for commercial, industrial, and residential use, thereby reducing the dependence on resources like petroleum and the effect of pollution on the environment.

Much of the electricity supplied to Oregon energy consumers comes from outside of the state. The nuclear power comes to Oregon via the Bonneville Power

Administration that depends on the Columbia Generating Station in Hanford, Washington. Coal covers 33% of the requirement for electricity, and the source comes from Portland General Electric (PGE) in Boardman, Oregon, as well as plants in Utah, Wyoming, and Montana. With the creation of new wind facilities in 2011, PGE revised and decided to terminate the use of the Boardman coal plant by December 2020 [27]. The use of wind and geothermal sources and other alternative energies will create more dependence on Oregon's own resources.

According to the Energy Information Administration (EIA), the price of natural gas fluctuates each year. The rate of electricity per sector also increases each year. Commercial rates increased to 8.68 cents/kwh in 2014 compared to 7.57 in 2010, and industrial rates increased to 6.29 cents/kwh in 2014 compared to 5.65 in 2010. The EIA shows the increase in the retail price of electricity in residential, commercial, industrial, and transportation sectors [27]. The use of geothermal sources will create a constant price rate if Oregon knows how to obtain the full advantage of this resource, and ultimately this will reduce the price of energy.

In terms of carbon emissions, Oregon is trying to find the best way to address climate change by making several changes by evaluating proposed carbon reduction plans. This process for developing the plan is complicated because it needs collaboration between the Oregon Department of Environment and other state agencies and requires many mechanisms to achieve the carbon reduction required by the plan. One proposed outcome is to reduce carbon emission by about 50%. The closure of the coal station at Boardman will support this outcome by 2020 [27]. Using geothermal sources will lead to the reduction of carbon emission since geothermal sources will have no effect on the environment.

Oregon consumes a lot of thermal energy, and 80% come from natural gas and electricity. Thermal energy is used in different applications like heating and cooling for our homes and buildings. By the end of 2009, Oregon use by sector showed 51% for industrial, 32% for resident, and 17% for commercial purposes [27]. Using geothermal sources will lead to a reduction in the load on the electrical system.

Nuclear energy is also a risk to people who live in Oregon, especially those people who live within the 50-mile nuclear emergency planning zone in Hanford and Columbia Generating Stations in Washington. Approximately 29,000 people live in the communities of Boardman, Irrigon, Hermiston, and Umatilla, Oregon. Any accident that leads to a fire or an explosion generates an airborne release of radioactive materials. The Oregon Department of Energy (ODOE) worked extensively with Morrow and Umatilla counties and other agencies through inspecting regularly their emergency preparedness programs. These counties stopped receiving funds supporting their emergency preparedness program in 2012, although they still participate in nuclear emergency planning [27]. Using geothermal sources will effectively reduce the risk that comes from nuclear energy, and it will be safer for people who live in this area.

There is good opportunity to invest in renewable energy because Oregon has made progress from ranking 35th in the country in 2010 to ranking 30th in 2012 by making 497 trillion Btu of renewable energy. Geothermal is a good investment for this progress of renewable energy production, as Oregon has the third ranking in the opportunity for having energy after Nevada and California [27].

4.1.3 Research Objective

The objective from the research study is to find the assessment model framework that can be used for supporting the electrical system in Oregon by the development of geothermal energy sources. The research study works through collaboration between utility objectives and goals for filling the gap that is available and works to have a solution by making a comprehensive decision-making process to evaluate the accurate outcome. Multi-criteria decision-making (MCDM) is a suitable tool to do the decision-making process. This approach will help to evaluate the diversity of users, which will reduce the uncertainty associated with this diversity [22–24]. Overall, the research model will increase the knowledge about how to develop geothermal energy sources for supporting the electrical system in Oregon and thus to minimize the uncertainties in decision-making, to create a better understanding of the potential applications in different areas inside of Oregon, and to find the optimum way to reach the goal of the best course of action.

The research development model for geothermal energy sources will try to find answers to the following research questions:

- What are the criteria for assessing the support of the electrical system from geothermal energy sources?
- Which geothermal energy resource alternative has the highest impact for developing the electrical system?
- How will changes in the energy resources affect the analysis for making decisions?
- What are the current technologies that are available that will allow for the more efficient extraction of geothermal resources and that will be more effective in the electrical system?

The research questions listed above try to support the achievement of the research objective in the following ways:

- To identify the main criteria that affect the enhancement of the electrical system by depending on geothermal energy resources
- To develop a multi-criteria model for enhancing geothermal energy resources that better reflects the electrical system by collecting information from different sectors, which will create better usage from the electrical system
- To identify and rank the main technologies that support the adoption of geothermal production in Oregon

4.2 Literature Review

4.2.1 Decision-Making in Energy Planning

In the 1970s, researchers focused their studies on creating a single outcome that was focused on the economics of renewable energy, which motivated them to create small model interactions with the energy economic sectors. The stated goals were to have a constant price and to establish the role of structured parameters. Through this structure, they were able to calculate the total expenses of the energy sectors and could understand the best way to keep energy economics cost-effective [28–30]. With continuous demand on energy, different issues began to show in terms of energy planning since one dimension, such as the economy, cannot solve the complicated process. Because of its popularity in solving complicated processes, MCDM began to be used in decision-making for sustainable energy. MCDM is successful in dealing with the multi-dimensions of sustainability goals and in the combination of socioeconomic and biophysical systems. MCDM differs from previous methods, which work with one dimension only, and it works with different criteria in the energy supply system from technical, economic, environmental, and social aspects. Different comprehensive MCDM methods are used for this purpose: analytical hierarchy process, TOPSIS, and ELECTRE. MCDM works with decision uncertainty and helps the decision-maker to choose the best acceptable innovation technology in the energy sector [22, 31–34].

After the exploration of oil and gas in the 1960s, many studies found that decision analysis (DA) was important in solving complicated problems, and that contributed to the use of DA in the application from industry to the public sector. DA can be used as strategic or policy decision-making for solving uncertainties and multiple conflicting criteria. Decision analysis methods can be divided into three groups, single-objective decision-making (SODM) method, decision support system (DSS), and MCDM method [35].

SODM: Works with a class of methods for reaching the available solution under a single-objective situation. SODM uses a decision tree (DT) and an influence diagram (ID) Both work to make SODM a simpler and more compact representation of decision problems.

MCDM: Gives the decision-maker the choice to prioritize alternatives by depending on several criteria. MCDM has mainly two branches: multiple-objective decision-making (MODM) and multi-attribute decision-making (MADM). The reason to choose MODM is to find the best among alternatives. MADM is the popular choice to use in energy planning.

DSS: Uses flexible and adaptable software systems that cover models, databases, and other decision-aiding tools.

Zhou et al. [35] reports that decision-making in energy planning can be used in different applications, and it can be narrowed down into two groups: strategy/policy(S/P) and operational/tactical (O/T) levels. The S/P level works with macro-issues like energy policy analysis, energy investment planning, and energy conservation strategies. The O/T level works with operational and short-term development like bidding, pricing, and technology choice. After that it has seven application areas: energy policy analysis, electrical power planning, technology choice and project appraisal, energy utility operations and management, energy-related environmental policy analysis, energy-related environmental control and management, and miscellaneous category [35].

The methods in decision analysis can be divided into the following aspects: economic analysis, decision analysis, and system analysis methods.

4.2.1.1 Economic Analysis Methods

Tools that can be used with economic analysis method are divided into:

Cost/benefit analysis
Cost-effectiveness analysis
Life cycle cost assessment
Payback period analysis
Real option analysis

4.2.1.1.1 Cost/Benefit Analysis

Cost/benefit analysis has two parts and it requires both sides to work. The first part of the cost/benefit analysis is the measuring of costs and benefits with the progress in time which is evaluated in terms of willingness to pay. For benefits, this means choosing the maximum amount that can be paid for reaching this purpose. For costs, this means choosing the minimum amount that can be paid for reaching this purpose. The second part consists of cost/benefit criterion that is decided by choosing the project if the net present value of benefit is positive and refusing the project if the net present value is negative [36].

Cost/benefit analysis is used in a diverse array of applications, like global climate policy [36], climate change [37], power generation [38], wind energy [39], technology and environmental policy [40], domestic electricity [41], local air pollution and global climate change [42], and waste reuse project for environmental purposes [43].

Cost/benefit analysis is easy to use, and anyone can understand the results from using this method. It can be used in different locations, scenarios, and applications.

4.2.1.1.2 Cost-Effectiveness Analysis

Cost-effectiveness analysis was improved through the World Health Organization (WHO).This improvement reflects the assessment of the efficiency in different interventions and scenarios. This method works to clarify the intervention scenario and to enhance the effectiveness in every scenario [44]. This method cannot work with cost and benefit, which are used in cost/benefit analysis.

Cost-effectiveness analysis is used in a diverse array of applications like energy production in the EU [45], climate policy [46–49], wind/PV/fuel cell power generation system [50], renewable energy electricity policy [51], new commercial building [52], air quality and greenhouse gases [53], and global warming [54–56].

Cost-effectiveness analysis is similar to cost/benefit analysis because it is easy to understand. Also, it can work with different programs that deal with same disease or goal. Cost-effectiveness analysis like cost/benefit analysis has limitations and drawbacks. The organization of the analysis is not the same for reaching calculations and that impacts the results. For example, some researchers found that it placed the same value on every individual and it did not take into consideration age (infant and middle age assumed equal). Another study found that the calculation of the years of an individual impacted their life.

4.2.1.1.3 Life Cycle Cost Assessment

Life cycle cost assessment works to estimate the cost of the whole life of the product that collaborates with the system through present and future cost. The goal from using this method is to evaluate the total cost of project alternatives and to choose the design that supports the lowest in general and that reflects on quality and function [57].

Life cycle cost assessment can be used in a diverse array of applications like energy building [58–61], alternative fuel [62], environmental analysis [63–65], sustainability [66–68], greenhouse gas emission [69–71], object-oriented framework for highway bridge [72], and solar energy [73].

4.2.1.1.4 Payback Period Analysis

Payback period analysis is the duration of time that is required to get a return on the money that was invested over a certain period of time. A long-term payback period is not favorable. A short-term payback period is more desirable. This method is more important because it determines if the investment or project is acceptable or not.

Payback period analysis can be used in many different applications like evaluation of photovoltaic system [74–78], electricity generation power plant [79, 80], wind energy [81, 82], environmental analysis [83, 84], solar hot water system [85], commercial building application [86–88], and carbon dioxide emission [89, 90].

Payback period analysis has many advantages. For instance, this method is easy to use and calculates the result, giving a more accurate assessment in the final decision for reaching the investment proposal. An assessment of the risk will occur, and the degree of certainty depends on period of the risk. Besides all of these advantages, it has disadvantages. For instance, the calculation for payback and time value of money is not clear in the result. In addition, it focuses a lot of attention on liquidity and leaves off profitability.

4.2.1.1.5 Real Option Analysis

Real option analysis considers alternatives when opportunity is available for business investment by looking at real, tangible assets. Real option analysis is used when there is the ability to expand and cease projects and when many conditions

Table 4.1 Methods used in energy planning with respect to economic analysis from the literature

Type of evaluation	Methods	Reference
Economic analysis	Cost/benefit analysis	[36–43]
	Cost-effectiveness analysis	[44–56]
	Life cycle cost assessment	[57–73]
	Payback period analysis	[74, 90]
	Real option analysis	[91–101]

make it difficult to choose between alternatives. This process will help decision-makers to make decisions accurately.

Real option analysis can be used for different applications like sustainability [91, 92], hydropower energy [93], high-uncertainty technology investment [94, 95], renewable energy [96, 97], carbon emission [98, 99], risk management [100], and challenges in making decisions [101].

Real option analysis is useful in helping decision-makers accurately choose between the best alternatives according to situation.

The table below summarizes the economic analysis with the tool according to the literature review (Table 4.1).

4.2.1.2 Decision Analysis Method

Tools that can be used with decision analysis method are divided into:

Decision trees
Influence diagrams
Multi-attribute utility theory
Analytic hierarchy process (AHP)
Analytic network process (ANP)
PROMETHEE
ELECTRE

4.2.1.2.1 Decision Trees

Decision trees work by finding a course of action or showing a statistical probability. Every branch in the decision tree means the probability of the decision. These branches help to simplify complex decisions, and according to decision trees, the most viable alternative will be selected.

Decision trees can be used in a variety of applications like forecast application [102], cost-effective operation strategy [103], electrical energy consumption [104], solar and wind power [105], renewable energy policy [106, 107], environmental effect [108, 109], building energy [110, 111], enterprise-wide modeling and optimization [112], and program model in energy [113].

There are many advantages in using decision trees. Decision trees are not complicated, are easy to understand, and are simple to execute. Also, the performance will not be affected when the trees have a nonlinear relationship. Decision trees require little effort for data preparation as compared with other methods. The decision tree does have problems when it is supplied with continuous data. For example, it is unstable because when decision trees change the data, this leads to a change in the calculation for future data.

4.2.1.2.2 Influence Diagram

An influence diagram shows problems that need decisions to be made in order to solve them. It shows different shapes and colors for decisions, uncertainties, and objectives as nodes in the network. In the influence diagram, there are four types of nodes that create the decision problem. These nodes explain the situation "what do we do?," "what is the outcome?," and, finally, "how do we like it?."

Influence diagrams work in a diverse set of applications such as life cycle assessment of renewable energy [114], ranking cycle for waste heat recovery [115], organization of renewable energy [116, 117], building energy [118], analysis frameworks [119], sustainable energy system [120], and wind energy [121].

An influence diagram has many advantages. For example, in the case of quantitative information, it simplifies the cause and effect phenomena. Also, the benefit of the model influences the diagram through upkeeping and upgrading. It has a function of open windows instead of black boxes. However, influence diagram has limitations for use. For example, although the model is easy to understand, it is difficult to build the model.

4.2.1.2.3 Multi-attribute Utility Theory (MAUT)

Multi-attribute utility theory (MAUT) works as a tool to solve complicated decision-making problems. This complicated process results from the probability nature of the problem and a multitude of quantitative and qualitative factors. Kenny and Raiffa [122] developed a concept for solving complicated decision problems through multiple attributes and multiple conflicting objectives, which leads to a systematic approach of multiple attribute utility analysis. MAUT solves the problem for decision-makers by simplifying the structure in the form of a simple hierarchy. This process impacts the solution for a large number of uncertainties in both quantitative and qualitative cases [123].

MAUT works in different applications such as energy policy [124, 125], risk analysis [126], power plant [127], climate change mitigation [128], environmental analysis [129], building energy [130], green supply energy management [131], wind energy [132], and decision models for project selection [133].

MAUT has many advantages, and it can participate in the different aspects such as economy and environment. It must have more data than MOP. In addition, it has less difficulty in the computations than MOP [123]. Although MAUT has advantages, it has some limitations. For example, in the program goal, MAUT doesn't have the ability to weigh coefficients and is the reason why many researchers use another methods like AHP. The huge amount of input that is required in every step for reaching accuracy in the decision outcome will lead to intensive data, which may not be found in every step in the process of decision-making [134].

4.2.1.2.4 Analytic Hierarchy Process (AHP)

AHP is used for solving complicated decision-making. There have been many developments in this method by Thomas L. Saaty in the 1970s. It is acceptable in different scientific communities to solve complicated decisions in technical part and environment [135, 136]. Also, this method facilitates the long decision process by dividing it into smaller elements to make the decision process easier [137]. In addition, the pairwise comparison is used to help make decisions, and Satty suggests using a 1–9 scale measurement and eigenvector [137], while Kocaoglu suggests using 100 points between each pair [138].

AHP is successfully used in different applications such as long-term improvement in the national electrical and GHG control panel [139], energy alternatives for the household [140], development of hydrogen technology [141], energy policy planning [142], renewable energy planning [143, 144], transportation fuel policy [145], and environmental impact assessment [146].

The process of AHP has many stages before reaching a decision. The first stage is the target, which is represented by the selection of the best alternative among others. The second stage works to evaluate the criteria according to the alternative. The third stage makes a hierarchy by simplifying a complex problem into a small problem. The fourth stage evaluates if the hierarchy arrangement is suitable or not according to the target. The fifth stage creates an online peer review system. The sixth stage makes the pairwise comparison and calculates the weight of the criteria after that. The seventh and eighth stages examine the consistency. The ninth stage reviews the consistency of the ratio, which must be between 0 and 0.1. After the completion of all of the stages, it must go the tenth stage to select the best alternative that leads to the best development of alternative energy technology [139].

4.2.1.2.5 Analytic Network Process (ANP)

ANP is a tool for making decisions, and it has the flexibility to use interaction and feedback during and between clusters. The feedback is very important for the process of making decisions, and it develops the process of decision in the human society. The framework that contains the cluster of elements has a major effect on creating ANP. That impact is the desired way for reaching the process of deriving ratio scales. ANP was improved by Saaty as a new concept for expansion of

AHP. The advantage of using ANP is to use ratio scales to capture all kinds of interaction [147].

ANP is used in different applications like alternative fuels for electricity generation [148, 149], SWOT analysis [150], selection of photovoltaic solar power plant investment projects [151], sustainable building energy [152], environmental impact [153, 154], strategic analysis for CO2 reduction management [155], and solar energy industry [156].

Although there are advantages in using ANP for different applications, it has some limitations. For example, there are challenges in choosing the correct network structure among other criteria because the different structures impact the result and the experts too. Also, it has difficulties in forming a super-matrix, and all criteria must be in pairwise comparison with respect to other criteria [157].

4.2.1.2.6 PROMETHEE

The PROMETHEE method was developed in 1982 by Brans, and improvements were made to this method during the period between 1985 and 1994 by Brans, Vincke, and Mareschal. This method considers outranking as it works to complete aggregation (MAUT) and it needs additional information. PROMETHEE has three major tools that are used to simplify and solve a problem: PROMETHEE 1 ranking, PROMETHEE 2 complete ranking, and PROMETHEE 3 GAIA plane [158].

PROMETHEE is successfully used in many applications like sustainable energy planning [159, 160], national energy scenarios [161], evaluation of geothermal energy projects [162], evaluation of wind energy [163], decision-making in fuzzy environment [164], distributed residential energy systems [165], assessment of solar thermal technology [166], and chemical emissions on motor vehicles [167].

PROMETHEE has many advantages when it is used. For example, PROMETHEE 1 works to prevent occurring trade-offs between scores on the criteria, which are more likely to happen with AHP. PROMETHEE doesn't need a lot of effort to reach synthesis, and that leads to completion without a lot of effort for each alternative on every criteria. However, PROMETHEE has some limitations. In PROMETHEE 1, the partial ranking, when it prepares to complete the ranking PROMETHEE 2 of the alternative, the specific details are usually lost during the transfer. PROMETHEE doesn't have the ability to build a classical decision tree or another guideline to eliminate the weight that occurs only with a criteria hierarchy [158].

4.2.1.2.7 ELECTRE

The ELECTRE method is part of MCDA, and it was used in the 1960s. This method was discovered by Bernard Roy and his colleague at SEMA Company. This method has the ability to deal with difficult situations in both quantitative and qualitative cases for supplying the order of the alternative [21]. In addition, it works with

Table 4.2 Decision analysis used in energy planning from the literature

Type of evaluation	Methods	Reference
Decision analysis	Decision trees	[102–113]
	Influence diagram	[114–121]
	MAUT	[122–134]
	AHP	[135–146]
	ANP	[147–157]
	PROMETHEE	[158–167]
	ELECTRE	[21, 168–176]

uncertainty and vagueness that lead to the creation of data from predictions and estimations [168].

The ELECTRE method works in different applications like thin-film photovoltaic production processes [169], aid approach for energy planning problems [170], environmental modeling [171], selection for alternative energy [172], promoting electrical efficiency [173], integrated decision aid [174], and assessment of renewable energy sources [175].

The ELECTRE method has advantages. For example, it has the ability to make the decision by selecting the decision parameters and depending on the intervals can ignore the fixed value [176]. However, it has some limitations. For example, sometimes this method is unable to choose the best alternative because it isn't required to finish the task in the system [21].

The table below summarizes the decision analysis with tools according to the literature review (Table 4.2).

4.2.1.3 System Analysis Methods

Tools that can be used with system analysis method are divided into:

Simulation modeling and analysis
System optimization
TOPSIS

4.2.1.3.1 Simulation Modeling and Analysis

Simulation modeling and analysis works in different kinds of application such as building energy performance [177], the dynamic behavior of polymer electrolyte membrane fuel cells [178], system analysis for advanced vehicles [179], emerging technology [180], architecture for sparse sensor networks [181], end-use energy consumption in the residential sector [182], software process simulation [183], and daylight availability and irradiance components from direct and global irradiance [184].

4.2.1.3.2 System Optimization

System optimization can work in different kinds of applications such as energy management system planning [185, 186], stand-alone hybrid solar-wind system [187], photovoltaic power systems [188], advanced alkaline electrolyzers [189], methods applied to renewable and sustainable energy [190], sensitivity analysis of photovoltaic system in residential buildings [191], district heating systems [192], and future energy systems [193].

4.2.1.3.3 TOPSIS

The technique for order of performance by similarity to ideal solution (TOPSIS) is considered a multi-criteria decision analysis. This method was improved by Hwang and Yoon in 1981. TOPSIS works through taking the shortest geometric distance from the positive ideal solution and the longest geometric distance from the negative ideal solution. It works through comparing a set of alternatives by determining the weight for every criterion, normalizing the score for every criterion, and finding the result of geometric distance between every alternative and the best alternative.

TOPSIS can work in a diverse array of applications such as assessing thermal energy storage [194], state-of-the-art survey [195], energy-efficient network selection [196], automotive industry [197], reduction on pollution emission base [198], evaluation and selection of thermal power plant location [199], building energy performance with multi-criteria technique for order preference [200], and the integrated framework for analysis of electricity [201].

TOPSIS has many advantages when it is used. For example, the process is easy to use since the number of steps will stay the same without changing when it has a number of attributes. The disadvantages are that the geometric distance doesn't give attention to the correlation between attributes and it is hard to weigh attributes and maintain consistency of judgment (Table 4.3).

4.2.2 Research Gap Analysis

From the literature review (academic journals, web articles related to energy technology), it has been observed that it is important to focus on the following areas:

- The different procedures and systems that are required for renewable energy for development of resources
- The requirements of using renewable energy to support electrical systems
- Decision-making methodology in energy planning

Table below clarifies the key research areas and findings from the literature review (Table 4.4):

Table 4.3 System analysis used in energy planning from the literature

Type of evaluation	Methods	Reference
System analysis method	Simulation modeling and analysis	[177–184]
	System optimization	[185–193]
	TOPSIS	[194–201]

Table 4.4 Key research area and finding in the literature

Research area	Finding	Literature
Different procedures and systems are required for the development of renewable energy resources	Complicated process of developing renewable energy and increasing demand to have energy and maintain the social, political, environmental, economic, and technical aspects. Minimizing tax, granted loan from the government	[1, 2, 5]
Support energy efficiency system	Geothermal energy resources, seven application areas: energy policy analysis, electrical power planning, technology choice and project appraisal, energy utility operations and management, energy-related environmental policy analysis, energy-related environmental control and management, and miscellaneous category	[5, 7, 16, 21, 35]
Decision-making methodology in energy planning	DA is important to solve complicated processes. DA can be used for strategic or policy decision-making and for solving uncertainties and multiple conflict criteria; energy planning requires multi-criteria to solve complicated processes since one dimension cannot solve these criteria. MCDM applies to different sectors of energy planning	[21–24, 31–35, 47–50, 139–175]

From the research findings in this table, many research gaps have been identified. Many of the research gaps were found from the literature and from other scholars.

These gaps are the need to:

- Find systematic approaches through enhancing electrical systems by depending on geothermal energy resources
- Develop a multi-criteria model for enhancing geothermal energy resources that reflects on better electrical systems
- Collect information from different sectors that can benefit from electrical systems

For finding solutions to these gaps, several questions were used. They are listed below:

- What are the criteria for assessing the support of electrical systems from geothermal energy sources?
- Which geothermal energy resource alternatives have the highest impact for developing the electrical system?

- How can changes in energy resources affect the analysis for making decisions?
- What are the current technologies available for developing and extracting geothermal resources that will be more effective in the electrical system?

4.3 Research Application Background

4.3.1 Importance of Geothermal Energy in Oregon

It is very important for current and future politics to focus on energy safety, energy independence, and minimizing the effect of greenhouse gas emissions. Many countries found that it's necessary to support the use of renewable energy, and they see that geothermal energy has the opportunity to be developed and to be successful. Different applications of technology principles like ground source heat pumps (GSHP) and groundwater heat pumps (GWHP) are used for obtaining the best service to the community [202]. In addition, the increasing demand for energy leads to an increase in the dependence on renewable energy technology. Renewable energy is challenging in terms of how to implement this form of energy with respect to following items: uncertainty in policy design and duration, unclear or inadequate enforcement, and targets that are too hard to reach in some cases. The challenge is to generate the motivation to create goals that will exceed uncertainty in policy design and duration and unclear or inadequate enforcement. The 2007 Oregon's Renewable Portfolio Standard (RPS) legislative objective made it a goal to have 25% of electricity come from renewable energy by 2025, and that goal has led to exploring what options exist for renewable energy resources. The demand for electricity is expected to reach 7500 MW by 2025. As of 2010, the demand of energy was 5500 MW [203].

The opportunity for success in covering a large part of the electrical system comes from renewable energy. Geothermal energy is one of the highest potential resources to reach the goal of supporting electrical system in Oregon. The report from the Northwest Power and Conservation Council showed that close to 6000 MW of wind power by 2025 will be available. The Western Governors' Association showed that close to 1290 MW of geothermal and 500 MW of solar power by 2025 will be available. According to Daim, Kayakutlu, and Cowan, "the 6000 MW of wind power referred to above would only translate to about 2000 MW of constantly available power" in the Northwest by 2025 [203]. Solar power works only in daylight, and depending on the weather in Oregon, the probability to benefit from solar power is approximately 15%. Geothermal energy has the potential to work all the time and reach the capacity factor of 90% [203]. It is very significant to drive the motivation to use geothermal energy resources, and each driver will clarify on the following items:

- *Cost and risk*: The availability of geothermal energy resources and the knowledge of how to benefit from them reduce the cost of investment for technology, and identifying how these are reflected in different applications minimizes the risk if a project continues over a long period of time.

- *Environmental friendliness*: Geothermal energy is considered friendly to the environment since it doesn't produce carbon emissions in most of the applications that use energy that supports electrical systems.
- *Increasing and changing electricity demand:* Geothermal energy resources in Oregon have the potential to cover a large part of the electricity demand and the systems for electricity if people know how to use the best model for obtaining a high productivity of energy. The availability of geothermal energy resources will make an impact by reducing the load on electricity. As there will be an increase in the load as a result from an increase in population, there is an opportunity to apply this new technology.
- *Uncertainty in fuel prices and growing cost of energy*: Geothermal energy resources can have a constant price over a long period of time, and this impacts the decision-making process with respect to the cost effect. Other sources of energy, like oil, don't have a constant price, and this has an effect on decision-making. This uncertainty in the price creates an inconsistent cost environment.

4.3.1.1 Cost and Risk

The availability of technology can impact and minimize cost. There is a reduction of cost by about 60% for application of geothermal energy resources with low temperatures before 2030. There is no constant price for the cost of geothermal energy because geothermal energy has three types: power plant, district heating, and the direct use of geothermal energy. The cost for each one is different than others. The cost of a geothermal heating system relies on a type of loop system that can be horizontal or vertical. The estimated cost for a home with 25,000 square feet and with a 120,000 BTU load for both cooling and heating ranges from $20,000 to $25,000 for construction. This system minimizes utility bills by 40–60%. This system is considered economical because the payback period is between 2 and 10 years, and the life system for geothermal heating system is between 18 and 23 years. The US government supports improvement for this kind of project through offering a 30% federal tax credit, and many states and companies work to have incentives for this kind of investment [204]. During the construction of geothermal projects, there is still a high risk of failure because it is unknown where the maximum capacity of production can be reached from the drilling and where the drill must be stopped. Also, the investors must invest a lot of money in the project, and they don't know when there will be a return on the investment. In contrast, oil and natural gas are profitable, and investors will know when the return on the investment will be [205].

The cost of a geothermal power plant is considered economical if the impact has been studied over a long period of time because the investment cost is about two-thirds for the project and one-third for the facility. The graph below shows how the investment for a long-term geothermal energy project is better than other renewable energies [206].

4.3.1.2 Environmental Friendliness

Geothermal energy is considered a source of sustainable energy like solar, wind, and biomass. This type of sustainable energy is defined as friendly to the environment since it releases a low emission of greenhouses gases into the atmosphere. Geothermal energy is sustainable and has the potential for production over a long period of time with a constant level of production. The process for taking energy from geothermal sources requires withdrawing the fluid and extracting the heat content. Many parts in the world that use geothermal show no change in the production over the years.

The application of geothermal energy for power generation and direct use will have some effect on the environment; thus the obligation to protect the environment still stands according to United Nations Summits in Rio in 1991, Kyoto in 1997, and Johannesburg in 2001. Any type of technology used for power generation requires many phases of development and production, which include exploration, production tests, construction, and operation. The effect on the environment must not be permanent, including changes to landscape and land use, emissions into the atmosphere, noise, land subsidence, seismicity, and solid waste. Geothermal power generation generates a lower emission of greenhouse gases than other technologies, and geothermal power plants generate lower CO_2 emissions than other technologies. It is clear that geothermal power plants are better for the environment than power plants that require oil, coal, or gas [207]. In Oregon, the type of geothermal power plant is a binary plant, and it is considered friendly to the environment because all of the processes occur in a closed system.

The direct use application of geothermal energy has less impact on the environment than a power plant.

4.3.1.3 Increasing and Changing Electricity Demand

The demand for electricity changed in the last 30 years in the Pacific Northwest, and this change was because of many factors like the price of consumption energy, increasing human population, and construction of new projects as an opportunity to use new technology. All of these factors have contributed to this change in demand, and this change will continue and increase in the future [208]. Geothermal energy will reduce the load on the electrical system.

4.3.1.3.1 Increasing Population and Impact on Electrical System

The population growth in Oregon has increased in the last 3 years since 2014. Population increased in Oregon by 1.1% or by 43,690 people. According to Burchard, "This is up from the 2013 growth rate of 0.9% and higher than the 2014 nationwide growth rate of 0.7%" [209]. The increase in population growth is different from the past. The population increased from 2,927,800 in 1991 to 3,962,710 in

2014, and during this time period, the rate increased by 10.7%, which was more than the national growth rate of 8.6% [209].

Population growth has an impact on the electrical system since the electrical system covers a limited number of people and homes. The growth in population requires the expansion and building of new houses to support the rising population, and this requires a preplan for the electrical system. A plan for a new electrical system needs to identify the future energy capacity to make the plan appropriate for an increasing population. The availability of geothermal energy resources will have positive impact on rising populations in parts of Oregon and will contribute to the reduction of demand on the electrical system.

4.3.1.3.2 The Construction of New Projects for the Opportunity to Use New Technology

A residential energy consumption survey from the US Department of Energy found that every house has the equipment or a device for space heating. More than three quarters of homes have air-conditioning, and most of these homes use both a heating and cooling system during the year. Heating and cooling systems don't have the same source of energy, types of appliances, or distribution systems, and they have a different impact on the environment [210, 211]. In addition, the increase in population leads to new projects that cover for the lack of energy. This has an impact on the use of new technology and the understanding of how it works to best serve the population increase. North America has problems supplying electricity during peak seasons like summer, which results from adding new appliances with capacity loads adding to the currently constant loads like commercial lighting and industrial processes. These new appliances require additional resources of energy, which leads to many problems, such as an increase in the cost, a switch in peak capacity generators, and ways to minimize the demand. There will be blackouts when the supply of electricity is not enough to address the demand for electricity. Therefore, it helps to have several pricing programs to adjust for problems like time of use, critical peak pricing, real-time pricing, and peak time rebate. These programs help to increase the knowledge to decide which strategy is more important for lowering peak time electricity use [212]. The availability of geothermal energy resources will reduce the load on the energy system and decrease the import of energy resources, while at the same time, an increased dependence on geothermal energy resources will match the increasing demand for new projects.

4.3.1.4 Constant Prices Over the Long Term

Oil and energy prices have not been constant since the oil crisis in 1973, and there are many factors that have contributed to the increased fluctuation in these prices. Research studies showed that 95% of crude oil, refined petroleum, and natural gas products do not show consistency in terms of cost. A recent study showed that the price for crude oil is more variable than about 65% of other products [213]. From the research study, it is clear that crude oil products will not generate a consistent price over a long period of time. On the other hand, geothermal energy resources have constant prices over the long term, and this helps in accurate decision-making about what is the requirement of geothermal energy for development.

The price of geothermal heat is considered constant, and this encourages customers to support geothermal heating projects. In addition, geothermal energy is better than tradition fuel like coal, lignite, and fuel oil because it has low initial operation costs and a low selling price [214]. The reason that geothermal energy prices are constant as compared to oil, gas, and natural gas is because geothermal energy resources don't require the large amount of fuel imported from sources outside of Oregon to operate. Although the initial investment for the construction of geothermal power plants is high until the completion of the construction, the size of production and capacity for generating electricity will lead to a modification in the price over the long term [205]. The constant price will help decision-makers decide which factors are necessary for improvement of the production phase and whether to keep the price the same or to modify the price to make it suitable for the process of production.

4.3.2 Potential of Geothermal Energy

There is a lot of research developed to enhance the ability of geothermal energy globally. The Geothermal Energy Association (GEA) data showed a large improvement in geothermal projects by adding 21 new power plants in 2014, which helped to support the electrical grid by adding approximately 610 MW. This improvement in the electrical grid was a large change to add more power plants in 2014 in 1 year compared with 1997. In addition, the global market increased by about 12.8GW to include 40 countries. The data show that the capacity of the global geothermal industry can increase between 14.5 GW and 17.6 GW by 2020. The probability of reaching 27–30 GW by the beginning of 2030 will occur if all countries work to achieve the goal and target of geothermal power development. Forty countries now work to cover the lack of electricity through geothermal power. According to geologic knowledge and technology, communities and countries benefit from 6.5 of total global potential of geothermal power. This knowledge and technology showed that in 2005 more than 160 global geothermal projects were installed adding 4 GW to the electrical grid [215].

Many countries have set goals and targets for future geothermal power use.

According to GEA research, new geothermal projects are planned for the near future. Compared to other countries in the world, the USA dominates the market in the installation of geothermal power plants.

In the USA, attention has been paid to the benefits from the potential use of geothermal energy, and there have been large improvements for obtaining the best service and support to the electrical grid. By the end of 2014, the USA succeeded in installing a net capacity of about 2.7 GW to the grid. The size of production from geothermal power under development is 1250 MW, and there still is a 500 MW delay in the service because geothermal power is waiting for the agreement of power purchase. Many projects were developed after 2005, and these improvements are represented by the addition of 38 geothermal power projects, which have contributed 700 MW to the electrical grid [215].

4.3.2.1 Developing Projects

The amount of developing geothermal projects is different from state to state in the USA, and that is because of many reasons. Many companies made recommendations to the GEA, noting that it isn't a good time to invest in federal or state leasing on on-site locations since there is no economic benefit. These companies will reinvest in the future when the market has more opportunity to invest in geothermal projects. The main reason to consider geothermal energy is that it is more economical than other renewable energy sources like solar and wind and it can replace for oil and gas. Geothermal resources require equipment for discovery, drilling, and extracting, which carries a large financial cost. It is important to invest in the project over the long term for the project to be economical, which sometimes requires putting the project on hold and reinvesting at a later date when the conditions and policies in the market change [215].

4.3.2.2 Global Technology and Manufacturing Development

There are three types of geothermal power technology: dry steam, flash, and binary. Each technology specifically works with one kind of geothermal energy source. Each resource requires a drilling depth in the earth different from other resources because each depth has different temperature. Flash and dry steam technology are more developed than binary since both flash and dry work with high temperatures, which produce higher energy. The percentages for using flash, dry, and binary are 58%, 26%, and 15%, respectively. The remaining 1% is used for back pressure and other types of geothermal technologies [215].

Besides the improvement of global technology, manufacturing also has improved as more companies participated in geothermal energy. The geothermal turbine market contains many companies that supply equipment for working in high-temperature projects like Toshiba, Mitsubishi, and Fuji. An example of a company that provides low-temperature organic Rankine cycle (ORC) solutions is Ormat Technologies Inc. (ORA). Many smaller companies are beginning to contribute to the geothermal market. For example, Ormat manufactures geothermal turbines and covers about 85% of the ORC market. ElectraTherm is considered unique for the design of co-produced fluids geothermal facilities [215].

4.4 Research Approach and Methodology

4.4.1 Introduction

As our project was extensive and reaching a final decision for improvement of geothermal energy was complex, the best method to use was the analytical hierarchy process (AHP). In addition, this method depends on taking surveys from expert panels and analyzing their knowledge in hierarchical decision model (HDM). Also, we chose expert panels who have diversity of knowledge in their field and have the ability to make a decision without looking at the problem from one side. This method identifies each level and evaluates the important action in the final decision [216].

Many developments for the model of decision-making happened after using the analytic hierarchy process method (AHP) created by Thomas L. Saaty in the 1970s, and it is acceptable in different scientific communities to solve complicated decisions from technical and environmental standpoints [135, 136]. Also, this method facilitates the long decision process by dividing the information into smaller elements to make the decision easier [137]. In addition, the pairwise comparison helps in making decisions, and Saaty specifies the use of the 1–9 scale measurement and eigenvector [137], while Kocaoglu specifies the use of 100 points between each pair [138]. The 100 points are more convenient than the 1–9 scale because experts have more flexibility to determine between 100 points, while 1–9 scale isn't as flexible [217]. The AHP model has been used in a lot of studies, and it was used as a basis for data in more than 1000 journal articles and 100 doctoral dissertations [136].

The Research Institute for Sustainable Energy (RISE) in the Engineering and Technology Management Department at Portland State University has successfully made a comprehensive framework to evaluate energy technology and renewable energy by assessing technical, social, political, environmental, and economic criteria. By using these criteria, the hierarchical decision-making (HDM) method will help in the decision-making process for selecting geothermal energy resources that impact and support electrical systems in Oregon.

4.4.2 Research Objective

The objective for the research study is to find the assessment model framework that can best be used to support the electrical system in Oregon by developing geothermal energy sources. The research study works through collaboration utility objectives and goals for filling the present gap that is available and works to create a solution by generating a comprehensive decision-making process to evaluate the best course of action. MCDM is suitable tool to use for the decision-making process. This approach will help to evaluate various decision options that includes a diversity of users and reduces the uncertainty associated with the decision [22–24]. Overall, the research model will increase the knowledge about how to develop geothermal energy sources that will support the electrical system in Oregon including minimizing uncertainties, understanding the potential applications in different areas inside Oregon, and finding the optimum way to reach the goal of the best course of action.

4.4.3 Research Methodology

The purpose of the research study is to improve the model framework for reaching the potential of the electrical system and to expand the model by depending on utility objectives and goals rather than just quantifying variables. Using this approach will help to account for user heterogeneity and will minimize the uncertainty generated from this variable. The result will be an increased knowledge and accuracy about simplifying electrical technology evaluation and planning approaches, which will lead to a better understanding of how to make the best choice in decision-making process.

Decision alternatives in the research model are geothermal energy resources. Every geothermal energy resource alternative consists of different technology, and each one has a different purpose from the other geothermal energy resources. But every geothermal energy resource supports and reduces the load on the electrical system. Using different kinds of knowledge leads to increased information about the research study and then reduces the uncertainty that will happen if they depend on one or two sources of obtaining information. Overall, the research model will give more knowledge to the geothermal field through understanding the problem, finding suitable solutions, and minimizing the uncertainty with respect to all utility objectives and goals.

Levels of research methodology consist of many major phases:

1. Hierarchical Decision Model (HDM)
2. Stage 2: Judgment Quantification
3. Stage 3: Data Collection
4. Stage 4: Data Analysis

4.4.3.1 Hierarchical Decision Model (HDM)

This model is considered a part of the research project aspect of the Research Institute for Sustainable Energy in the Department of Engineering and Technology Management, and HDM supplies a multi-perspective assessment of various energy technologies such as nuclear, wave, geothermal, biomass, petroleum, hydro, wind, solar, biofuel, coal, synfuels, hydrogen, and conservation. The HDM method will clarify the problem and help to decide which decision is most suitable for solving the research problem since most people don't have the ability to solve the complicated process of decision-making without dividing the problem into small parts, which helps to make the right decision with respect to objectives, goals, and criteria. In addition, HDM has ability to observe a large number of alternatives and can analyze the alternatives from different angles. This process of analysis will help to look at the problem in depth and then choose the most suitable decision. HDM methodology is successfully used in different applications like the development of hydrogen energy technology [141], risk analysis in energy policy [218], national emerging technology strategy [219], solar energy technology [135], and long-term improvements in the national electrical system [139].

HDM is a good approach for obtaining the best decisions in geothermal energy resource alternatives. In this research, HDM will break the decision into smaller elements through communication between the mission, objectives, goals, and alternatives. The figure below clarifies the general framework for RISE, which is used by the Department of Engineering and Technology Management at Portland State University (Fig. 4.1).

Intensive literature review was read for the evaluation of geothermal energy resources. The literature review showed that different types of utility work under geothermal energy resources. The table below clarifies the evaluation of geothermal energy resources from the literature review (Table 4.5).

From the literature review, this research is divided into four levels (Fig. 4.2):

1. Mission Statement
2. Utility Objectives Level
3. Utility Goals Level
4. Alternatives Level

4.4.3.1.1 Mission Statement

The purpose of using this methodology is to determine the alternative uses for geothermal energy development that have a high value in terms of overall objectives and goals of the utilities.

4.4.3.1.2 Assessment Variable of Utility Objectives Level

The role and responsibilities for the objective level are clarified in the following sections:

- *Encourage community to support geothermal energy project*: Using geothermal energy projects will make future customer life easier and more convenient; this will encourage customer support for geothermal projects and will increase the adoption and development in this field. The availability of geothermal projects is necessary for supporting the general public and the job sector with more improvement in the operation as compared with other sources of energy.

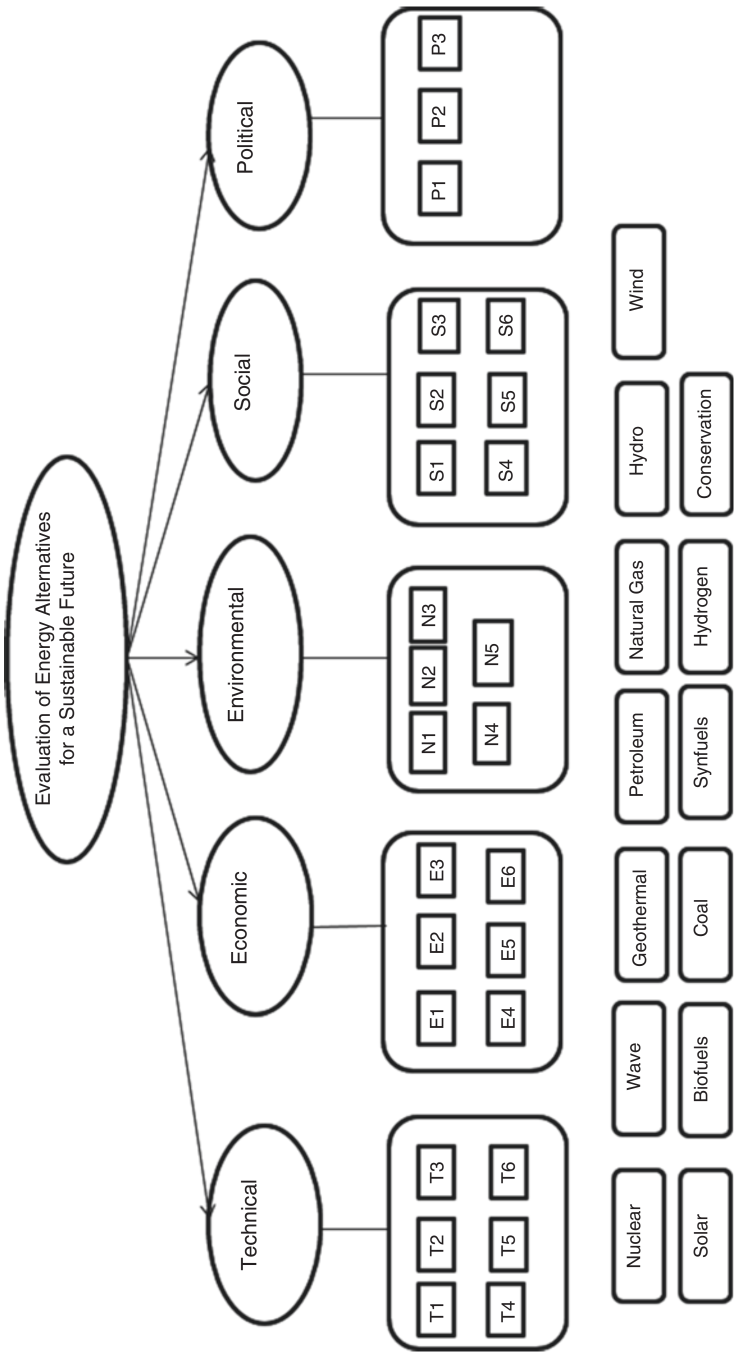


Fig. 4.1 RISE research model (Dundar Kocaoglu, PI, Tugrul U. Daim, Co-PI)

Table 4.5 Evaluation of geothermal energy resource from the literature review

Perspectives	Objectives	Goals	Reference
Social	Encourage community to support geothermal energy project	Create new jobs opportunity	[162, 220–225]
		Social acceptance	[226–228]
Environmental	Minimize environmental impact	GHG emission	[220, 221, 229–233]
		Land requirement	[220, 234–237]
		Seismic activity	[220, 238–242]
		Using the land for other purposes	[220]
Economic	Reduce expense of investment energy projects	Minimize capital cost	[243–248]
		Minimize operation cost	[220, 249–253]
		Economic boost	[254, 255]
Technical	Technical option improvement for geothermal energy projects	Minimizing the demand of critical resources	[256–263]
		Increasing the capacity of the energy system	[264–270]
		Equipment manufacturing development	[262, 271–274]
Political	Minimize the negative impact on the general public	Minimizing noise and odor	[275–279]
		Minimizing property damage for reducing the impact on lifestyle	[280–284]

- *Minimize environmental impact*: Pollution increases from expanding the demand for energy in different sectors, which affects the environment through affecting greenhouse emissions. The availability of geothermal energy will have positive impact on the environment since it doesn't consume a huge amount of fuel as compared with other sources of energy, so it will reduce GHG emissions. In addition, it is possible to drill from one geothermal energy source site and reach other geothermal energy source sites. This has a positive impact on the environment because it reduces the drilling to one site and doesn't affect the other sites and the earth can be used for other purposes. Also, it is possible to create a beautiful landscape in the surrounding areas of geothermal energy sources without creating a negative impact on wildlife.
- *Reduce expense of investment in energy projects*: Increasing population creates challenges to keep up with the demand for energy without blacking out the system. In addition, the size of the financial investment is still large, and the operations of expenses are still very high. Although the investment in geothermal energy projects is not considered competitive as compared with other energy sources, the different technologies that accompany geothermal energy resources will change that if more attention and effort are given to this area of alternative

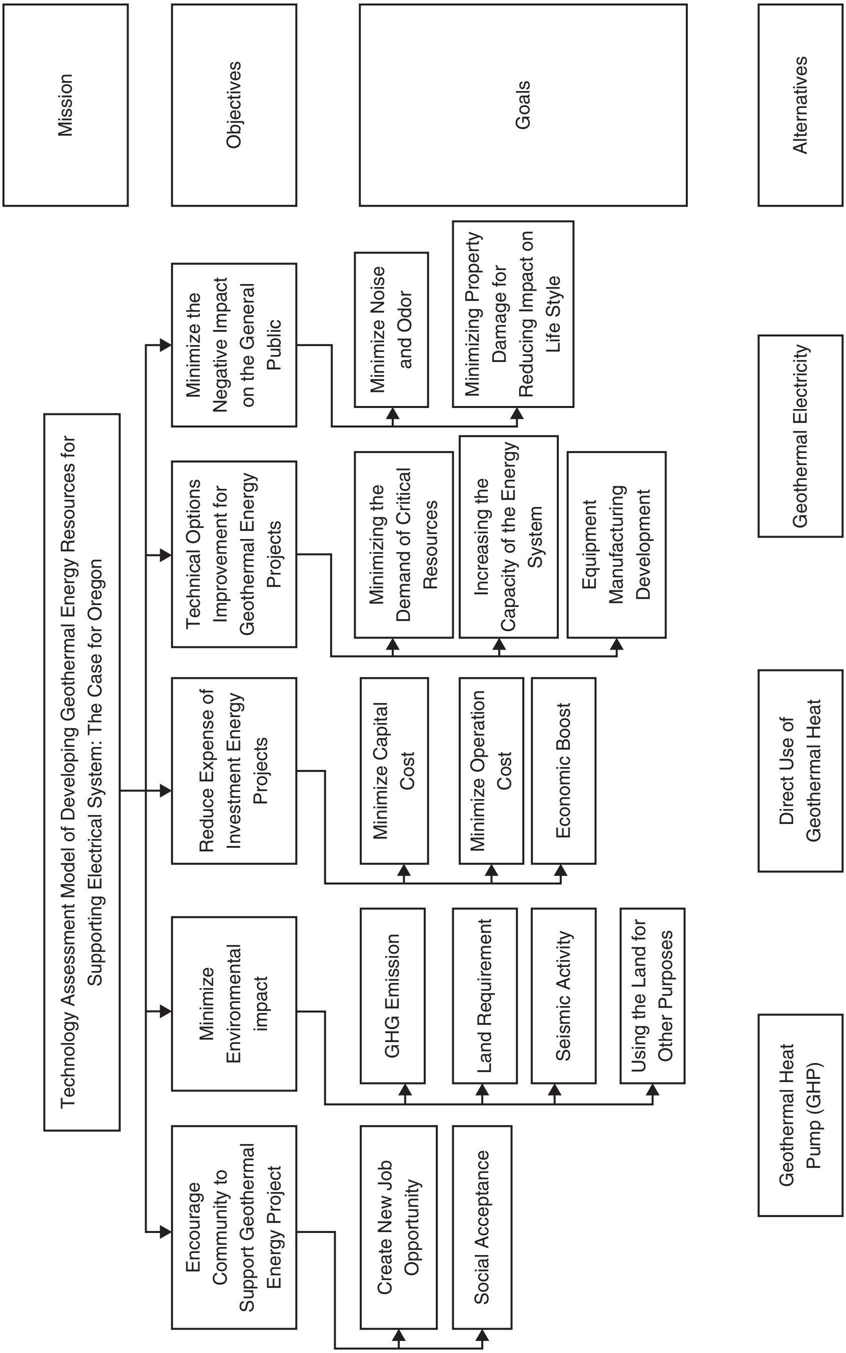


Fig. 4.2 Hierarchical decision model for the research model

energy. The availability of geothermal energy and the knowledge of how to use the resources effectively lead to less dependence on resources from outside state.

- *Technical option improvement for geothermal energy projects*: It is important to understand the technical systems for improving the benefits from geothermal energy. The increasing demand of energy has a negative impact in some areas because not all resources of energy will be enough to cover the demand in the electrical system. Up until recently, some of the challenges facing this alternative energy source were on understanding the concept of geothermal power and its effectiveness without negatively impacting other factors like the environment and the economy. There is the possibility to develop the process in the future by quickly responding to any changes in the market and in the requirements of customers. The ability to have the flexibility to work in any situation with different factors is a key factor for improving geothermal energy projects.
- *Minimize the negative impact on public*: The initiation of geothermal resource projects accompanied by creating a transition line between traditional energy sources and geothermal sources is required for producing energy that supports the electrical system; they also have an impact on public lifestyle and the health system in a community through minimizing demand on the use of traditional power plants and that reduces the level of pollution. Although the impact of geothermal power plants on the environment is initially less than that of power plants for other energy sources, it is important to take into consideration any negative impact on the environment and general public and work to reduce this impact. The objective of reducing the negative impact on the general public and public spaces is to ensure that these geothermal projects don't interact with other projects in the same area because this can lead to conflict. Knowing how to deal with different kinds of projects in the same area is important and has less negative impact on the public.

4.4.3.1.3 Assessment Variable of Utility Goal Level

The role and responsibilities for each goal level are clarified in the following sections. Geothermal energy resources will be evaluated according to the potential for each goal.

Encourage Community to Support Geothermal Energy Project

The utility objectives can be divided into the following utility goals:

- *Create new job opportunity*: Geothermal energy has social implications because it has a large effect on economic development and employment opportunities. When a geothermal power plant is installed, it requires a diversity of skills to complete the construction. This process leads to create indirect jobs, more economic activity, and increased tax revenue. Having a geothermal power plant will create a diversity of job opportunities ranging from exploration and drilling jobs to high-tech manufacturing jobs such as the manufacturing of generators, turbines, and power-conditioning components to maintenance jobs in the power plant itself. These additional jobs and income will support industry employment through local and regional economy. The production of geothermal energy in the USA is $1.5 billion/yr. Garman showed that in 1996 there was close to 12,300 direct jobs and 22,700 indirect jobs in the USA. The electricity sector requires the employment of 10,000 people for the installation and the operation of systems in power plants [220]. This process for creating new job opportunities can work in Oregon and be successful if people know how to benefit from the source of geothermal energy. Many articles show the potential to have new jobs from geothermal energy [162, 221–225].

- *Social acceptance*: In 2006, the BLM managed about 350 geothermal leases, of which 55 were producing geothermal energy from 34 power plants [226]. In 2009, President Obama announced a new energy plan for the USA. The goal from this plan was to increase renewable energy to 10% by 2012 and 25% by 2025. The continual commitment to expand and improve federal lands for the use of geothermal resources has led to an increase in production, and in 2012 his goal was exceeded by 2%; therefore the probability of reaching the 25% by 2025 will be high [227].

The benefit from geothermal energy is to supply a baseload power and to benefit local economies. Direct use application and power plants lead to construction, operations, and maintenance jobs. The power plants also produce tax revenue for federal, tribal, state, and local governments [228].

Minimize Environmental Impact

The utility objectives can be divided into the following utility goals:

- *GHG emission*: Geothermal direct use has less effect on the environment as compared with geothermal power plants. This type is beneficial for states, local communities, agribusinesses, and other industries that require these resources. Also, this type supports the environment since it contains lower levels of gases than the higher-temperature fluids. Most applications of geothermal direct use today work through closed-loop, emission-free system. The carbon dioxide that accompanies geothermal fluids has an advantage to greenhouse application because carbon dioxide is important for the growth of plants. According to Garman, “Geothermally heated livestock facilities make waste management and collection easier for farmers and ranchers. The geothermal water can be used directly for cleaning and sanitizing these facilities, as well as drying the waste” [220]. This concept can work in Oregon. Many articles show the importance of reducing GHG emissions when using geothermal energy resources [221, 229–233].
- *Land requirement*: Geothermal fields require 1–8 acres per megawatt (MW), while nuclear operations need 5–10 acres, and coal operations need 19 acres. Coal power plants need a huge area of land that is used for agricultural purposes for making their fuel. This process for making fuel leads to the movement of

earth, which contributes to the creation of tunnels, waste heaps, and open pits. The process for re-treating the land is complicated and expensive [220].

Geothermal power plants need wells, which require drilling into the ground. The process of drilling will affect the land, but with the advancement in the equipment of drilling, there is less impact on the land. This drilling technology allows several wells to be drilled from one location, and this reduces the impact on the land, access roads, and geothermal fluid piping. A good example of drilling technology is slimhole drilling, which has 4″ to 6″ diameter well, while the traditional has a diameter of 8″ to 12″. Slimhole drilling also minimizes the land used for site preparation and road construction [220]. Many articles show the importance of using geothermal energy resources for keeping land from negative impact of projects [234–237].

- *Seismic activity*: There are benefits from using one location drilling technology where they can also drill several wells from this one location. Even so, land subsidence is the effect that occurs during the drilling process whereby there is an extraction of a large amount of fluid (e.g., water, oil, and geothermal fluid) from beneath the land. The common solution for geothermal power plants is to inject spent geothermal fluids back into a reservoir to avoid subsidence. When they inject the spent resources, the earth will be stable from any subsidence [220]. Many articles show the importance of injecting fluid in the geothermal site to avoid inducing seismic events [238–242].

The probability of seismicity occurrence or earthquake activity will be very high when a large amount of geothermal fluids are withdrawn and injected below the Earth’s surface. The areas with a high frequency of naturally occurring seismic events will be the most affected by the operation of geothermal power plants. If seismic activity occurs, it will be less than magnitude 2.5 on the Richter scale (earthquakes usually cannot be felt under 3.5). In Geysers, California, areas with geothermal fluids have experienced seismic activity [220]. Research studies found that the probability of seismic activity will be high where the location for power plant requires deep drilling (long distance under the surface of the ground), which is what clearly happened in Geysers, California. In Oregon, research studies found that all power plants are binary plants, which do not require the same deep drilling as the location requires in California.

- *Using the land for other purposes*: Geothermal power plants are found in beautiful natural environments, and the power plants don’t affect the landscape because of many factors: geothermal power plants have a small footprint since they don’t require a large amount of land as compared with other sources of energy like coal and nuclear power plants [220].

The impact of minimal land use leads geothermal power plants to mix harmoniously with a diversity of other land uses. That means that when the activity of a power plant is completed, the land can be re-treated and used for livestock grazing or other agriculture purposes. In California, the Imperial Valley hosts 15 geothermal power plants that make 400 MW of electricity, and at the same time, it keeps one of most productive agricultural areas in the world. According to Garman, "one geothermal power plant from the fifteen plants at Salton Sea is neighbor to a national wildlife refuge that shelters hundreds of animal species" [220]. A visitor in this area will not notice anything strange in the landscape even though a geothermal power plant is hosted in this location. This makes a suitable site for injection and production wells, which reduces the negative impact for both scenic and recreational attractions [220]. This type of operation can work in Oregon since it was successful in another area like California.

Reduce Expense of Investment Energy Projects

The utility objectives can be divided into the following utility goals:

- *Minimize capital cost*: One of the challenges to take into consideration is the ability to have a good investment that has potential to cover the requirements of the electrical grid without harm and high initial capital cost. Projects of geothermal energy resources have the potential to reduce the cost of financial investments if the investment is taken over a long period and where the results from these projects will be clear. Geothermal energy resources are very important in supporting the national economy because this leads to a reduced dependence on imported resources like oil. Almost half of the US annual trade deficit will be erased when the USA begins to depend on domestic resources and reduces the dependence on imported oil. Research studies show that there is a potential to benefit from the international market for geothermal energy to enhance domestic economic health and that, in the next 20 years, foreign countries will begin to invest $25–$40 billion for the construction of geothermal power plants. Many states in the USA now are looking for the best way to benefit from geothermal energy. The geothermal power plants in Nevada generate approximately 240 MW of electricity, which saves energy from imported sources by 800,000 tons of coal or 3 million barrels each year. The plants paid $800,000 in 1993 for county taxes and $1.7 million in property taxes. The US Bureau of Land Management also benefited from the lease of the land, which contributed to the increased tax revenue of $20 million each year in rent and royalties from geothermal power plants [220]. This process can be successful in Oregon after making some adjustments to fit with the energy policies there. Many articles show the opportunity of geothermal energy resources to reduce dependence on traditional energy sources [243–248].
- *Minimize operation cost*: Research studies showed the economic impact of geothermal development projects in Siskiyou, Modoc, and Shasta counties in California and Klamath County in Oregon. These projects contribute to an increase of $114 million on the 30-year life span of the projects, which is reflected by an increase in local income and job opportunities through creating new construction projects and in the operation of the power plants [220].

The Geothermal Energy Association found that California has the potential to develop geothermal energy since it has a lot of support. In the short term, geothermal energy can make from 300 to 600 MW and can reach up to 1000 MW when they enhance three locations, the Salton Sea, Northern California, and the Geysers area north of San Francisco, and the total from these locations will be 3600 MW if they know how to fully use and benefit from the technology available today. The Geothermal Resources Council lists the importance of geothermal sitings for development and the companies that can do this operation [220]. This process can be successful in Oregon if researchers put their efforts into reaching the best way to do this process. Many articles show the potential of geothermal energy increasing in the future [249–253].

- *Economy boost*: Geothermal projects have the potential to enhance the economies through increased tax revenues, the creation of new businesses and local jobs, and enhanced community involvement. Many articles show the importance of geothermal energy to enhance the economic sector [254, 255].

Technical Option Improvement for Geothermal Energy Projects

The utility objectives can be divided into the following utility goals:

- *Minimizing the demand of critical resources*: The increase in human population has led to an increased demand on critical resources like oil, water, coal, etc. Over time, it has been observed that there are many challenges with these increases since the cost of these resources has risen, which has affected different sectors like social, environmental, and economic. Continuing to use these resources without looking to find alternative solutions is a large problem, and it will have a negative impact on all aspects of society and the environment [256–263]. The availability of geothermal energy resources is important to cover and reduce the dependence on critical resources, such as oil, natural gas, coal, etc. It is important to know how to find the best methods for the maximum benefit of geothermal energy resources.
- *Increasing the capacity of the energy system*: The availability of geothermal energy resources will minimize the load on the electrical system and simplify the challenges associated with increased energy load, especially during peak periods of demand of electricity like severe winter and summer periods. There are many applications of geothermal energy resources, which can support the electrical system since geothermal energy covers large areas like bathing and swimming, agriculture, the industrial process, snow melting and cooling [264], electrical systems [265–267], and large buildings [268–270]. The diversity of different applications and the increased capacity of geothermal energy resources are significant in supporting the electrical system and in avoiding blackouts during peak demand period.
- *Equipment manufacturing development*: Even though there is a variety of variable geothermal energy equipment in the market, we still need more development to increase the geothermal electrical, and for that we need to develop the technologies for use in manufacturing of the equipment. It is important for increasing the capacity of electrical systems to make new developments in equipment manufacturing. The increase in population living in different areas will

create more demand for energy, so the construction of new projects like geothermal energy resources will require the development of equipment manufacturing. Many articles show the importance of equipment manufacturing development on the energy system [262, 271–274].

Minimize the Negative Impact on the General Public

The utility objectives can be divided into the following utility goals:

- *Minimizing noise and odor***:** It is important for the success of geothermal energy projects that geothermal energy resources work without negatively impacting the general public by avoiding and reducing noise and odor as quickly as possible. If the geothermal energy industry has the ability to deal with and avoid both noise and odor, there will be more support for these projects. Many articles show the importance to construct projects without annoying the public [275–279].
- *Minimizing property damage for reducing the impact on lifestyle*: The construction of new projects creates new transmission lines for connecting with the energy system. These connections will change the pathways, which will require redrawing new paths for residents and commercial activities. The construction of new projects will disturb movements of the general public and local businesses, so it is necessary in the construction of geothermal energy projects to build the plant in the right place. With the installation of new projects, it is important to avoid any conflicts or obstacles to the movement of residential and commercial activities. Many articles show the importance of building new projects without disturbing the activities of the general public and local businesses [280–284].

4.4.3.1.4 Geothermal Energy Resources Alternatives

To gain the best support from the electrical system in Oregon, it is important to simplify geothermal energy resources and to benefit from the application of technology. Research studies show that geothermal energy resources can be simplified by the application of technology in three different ways: geothermal electricity, direct use of geothermal heat, and geothermal heating pumps. Each application is clarified in the following sections:

Geothermal Electricity

This type of technology produces electricity through depending on the heat that comes from the water inside of the Earth. This method brings the sources of geothermal energy to the surface by drilling in wells of different depths and then converting the extracted heat from the earth into electricity. There are three different types of power plants that produce electricity: flash, dry steam, and binary power plants. These plants process geothermal resources by taking the hot water and steam from the earth and converting it to electricity before returning the water back to the earth [7, 9, 285, 286].

Flash Power Plant

This type of plant depends on geothermal fluid that has temperature of more than 360 °F (182 °C) to produce electricity. The plant uses steam vapor to run the turbine, and if the fluid temperature decreases, the process will be repeated to obtain more energy [287, 288].This type of power plant is used in areas such as China and the Philippines [11, 289–292].

Dry Steam Power Plant

This type of plant depends on the steam that is available below the Earth, which goes directly into the turbine to produce electricity. This type of power plant is very old and has been used in Italy since 1904 [287]. Today, steam power technology is available in many areas. The largest location, with 20 plants, that uses this type of technology to produce electricity is at Geysers in Northern California [254, 293].

Binary Power Plant

This type of plant depends on a geothermal area that has a moderate water temperature of less than 400 °F, from which it produces electricity. The process of operation works through the transference of heat from hot geothermal fluid to a secondary fluid with a much lower boiling point temperature by using a heat exchanger. This creates flash water that becomes a vapor, which runs the turbine. This type of plant is better for the environment because the process takes place in a closed-loop system. In the future, most of the geothermal power plants constructed will be binary plants [286]. This type of plant is used in many areas like Nevada, Idaho, and New Zealand [294–299]. There is the potential to increase the use of the binary power plant in Oregon, but so far the Oregon Institute of Technology in Klamath Falls is the only place that has the ability to run this type of power plant [300, 301]. Many projects were constructed, and in Malheur County, the possibility of a successful binary power plant was high because the area has a temperature between 311 ° F and 320 ° F, which encouraged the development of geothermal energy. By 2014, this temperature increased to 368 ° F because of the use of geothermal technologies [302].

Direct Use of Geothermal Heat

This type of technology uses the heat directly from the earth without taking support from power plants and heating pumps. Geothermal resources use water that has a variation of temperature from low to moderate (68–302 °F) [303]. It is used in many applications like space heating and cooling, food preparation, spas and hot spring bathing, greenhouses, industrial business, and agriculture. There are many sectors that use direct heating from geothermal resources in many locations in the USA. There is a capacity of about 470 MW in direct use technology [285]. In addition, it is considered cheap energy as compared with traditional energy because it reduces the cost by 80% as compared with fossil fuel. This energy is very clean and doesn't affect the environment. This type of energy is very successful in the ten western states of the

USA that use this type of energy, as was found from a survey of more than 9000 thermal wells and springs. From the 9000, 900 of these wells and springs have a low to moderate temperature, which is suitable for direct use of geothermal heating. The Office of Energy Efficiency and Renewable Energy (EERE) supports the operation of geothermal energy processes at the Geo-Heat Center at the Oregon Institute of Technology in Klamath Falls, Oregon, and provides information to students and faculty [304]. This type of technology can be applied in many areas like Romans in the past, such as in Belgium and in Pompeii and Tuscany in Italy [285, 305, 306].

Geothermal Heat Pump (GHP)

This type of technology works when the temperature is constant between 10 ft. and 300 ft. under the Earth. Also, there are no limitations to using this technology because it can be used everywhere in the world because it doesn't need drilling and rock excavation equipment for extracting the resources from the earth. It uses covered pipes under the earth that circulate water or other liquids, and it can be designed using different shapes like horizontal or vertical. This system is considered environmentally successful as it is suitable for both heating and cooling system. For cooling in the summer, it takes the heat from the building by using a pipe loop to exchange the heat with the earth, and in the winter the process is reversed. This type of energy minimizes power use by 30–60% as compared with traditional equipment that consumes a large amount of electricity in heating and cooling buildings [284, 302] . In the USA there are nearly 50,000 geothermal heat pumps constructed each year, and there are two kinds of geothermal heat pump systems—the closed-loop and the open-loop systems [274, 307]. The closed-loop system includes the "horizontal" (this type of construction is very efficient for residential usage, and it works at a depth of 4 feet), the "vertical" (this type of construction works with large commercial buildings and schools, and it works at a depth between 100 and 400 feet), and the "pond/lake" (this type of construction works in a location that has enough body of water; the cost will be low, and it needs a depth of 8 feet to protect from freezing) [308]. The open-loop system depends on wells and works like a heat exchanger by circulating the water from the ground to the heating/cooling system and then back into the ground. This system works with clean water [308]. In Oregon, all applications using the geothermal heat pump work with the closed-loop system. The open loop system does not qualify to be used [309].

These types can be used in different applications for residential and commercial buildings. The best type to use depends on many factors like weather, the situation of the soil, the available land, and the cost of installation at the location [308].

4.4.3.2 Stage 2: Judgment Quantification

This level depends on the quantification of expert judgments for data collection purposes. The performance of expert judgment must have the ability to make a hierarchy of decisions on different levels. The procedure for judgment quantification is divided into four steps:

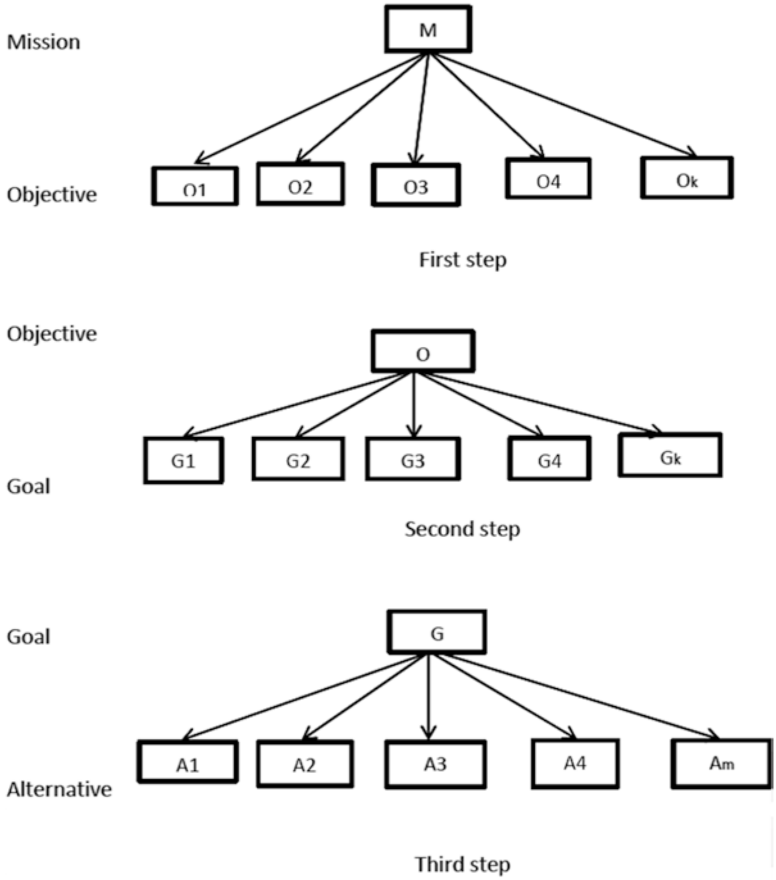


Fig. 4.3 Relationship between each step

- Mission (what business do we want to be in)
- Objective (what achievements should we have in order to satisfy our mission)
- Goals (what are the targets to reach in order to fulfill our objectives)
- Alternatives (what projects should we have in order to development) (Fig. 4.3)

The graph below clarifies the relationship between each step.

The research model employs the pairwise comparison method. The ratio scale for the pairwise comparison requires decision-makers to allocate 100 points between each pair. As the number of variables increases in each step, different judgment quantifications are required for that process. The pairwise comparison method is a solution that simplifies the complicated process of decision-making into small sets, which contributes to easier decision-making. The table below clarifies the process of judgment quantification methods in the research model (Table 4.6).

Table 4.6 Judgment quantification methods in the research model

Hierarchy level	Area specialist	Judgment quantification method	Ratio scale
Second level	Importance of utility objective with relation to mission	Pairwise comparison	Constant sum method
Third level	Importance of utility goals with relation to objective	Pairwise comparison	
Fourth level	Importance of alternative with relation to goal	Pairwise comparison	

4.4.3.3 Stage 3: Data Collection

All of the procedures of judgment quantification are going to be calculated through expert panels. Thus the research model requires experts from different organizations.

Expert panel will concentrate on determining utility goals under utility objectives:

1. Objectives level—Expert panel must have a general understanding of the wide range of utility operations and objectives.
2. Goals level—Encourage the community to support geothermal energy project for the improvement of public affairs. The expert panel must have experience in public affairs.
3. Goals level—Minimize environmental impact. Expert panel must have experience and knowledge of environmental and wildlife protection.
4. Goals level—Reduce the expense of investment energy projects. Expert panel must have experience in planning and assessment management and power policy and rates.
5. Goals level—Improve the technical system for geothermal energy projects. Expert panel must have experience in power, transition, and distribution services.
6. Goals level—Minimize the negative impact on the general public. Expert panel must have experience in agency compliance and governance.
7. Alternatives level—Expert panel must have experience in the fields of engineering, project management, and technologies.

The general criteria for the expert panel selection include the following:

- Relevant expertise within the research area
- Availability and willingness to participate
- Balanced perspectives and biases

4.4.3.4 Stage 4: Data Analysis

The results of judgment quantification from the expert panels will be counted to determine each energy alternative resource as related to the mission. The results of the data analysis will come from formula below:

Table 4.7 Inconsistency analysis method for research model

Panel	Research area	Expert inconsistency
Experts panel members	Utility objective	Inconsistency analysis
	Encourage community to support geothermal energy projects	
	Minimize environmental impact	
	Reduce expense of investment in energy projects	
	Technical option improvement for geothermal energy projects	
	Minimize the negative impact on general public	
	Alternatives level	

Mission: The selection of the geothermal energy resource that is successful to cover the utility objectives and goals.
Objectives: Utility objective k with relation to the missionO_k, i.e., $k = 1,\ldots,k$.
Goals: Utility goal I with relation to the objectiveG_{Ik}, i.e., $I = 1,\ldots,L$.
Alternative: Geothermal energy resource alternatives A_m,i.e., $m = 1,\ldots,M$.
$V(O_k)$: The formula of relationship between the utility objective and the mission.
$V(G_{Ik})$**:** The formula of relationship between utility goal I and objective k.
$V(A_{mIk})$: The formula of relationship between geothermal energy resource alternatives m to goal I with respect to objective k.
$V(EEV_m)$: The formula of geothermal energy resource alternatives m to the mission.

The research model will work with the inconsistency analysis method that depends on the results from the expert panels. The table below shows how inconsistency analysis works with the research model (Table 4.7).

4.4.4 Establishment of the Expert Panels

Decision analysis is one of the more important aspects for simplifying the problem, and that is the reason for using this method. Model development is a requirement for optimizing one or more objectives that are impacted by physical, structural, and policy constraints in a static or deterministic setting [310]. One of the challenges in using the model is to find the right experts and how to reach the best results from probability and evaluation toward the mission. The procedure for selecting the experts requires strict rules to ensure that those experts have an interest in and relationship to this specific study. This will help to provide better opinions, feedback, and judgments in the different research areas, [310] such as developing national technology policy [311], multiple prospective and decision modeling [312], medicine [313], decision-making for elderly persons [314], medical and health care [315], psychological characteristics and strategies [316], and technology evaluation and acquisition strategies [317].

It is very important before building expert panels to talk with experts and to understand their knowledge and opinions about the problems set before them in the study. This process, like literature reviews, helps to find which experts will participate in the panel. The number of experts who will participate in the panel depends on the objective and the analysis that will follow.

An expert is a person who depends on his/her knowledge, experience, and opinion to give his/her feedback to make the best choice in the decision-making process [318, 319]. It is important to use expert judgment in the analysis of the decision model in case of design issues that may affect the results of the research. To create an expert panel, it is necessary to establish two criteria: expert panels must have balance in the diversity of knowledge or experience, and they must be unbiased because that will have negative impact on the analysis of the research study. In addition the researchers must know who is suitable as an expert and how many experts are required by looking at the size of the research and the analysis required. The researchers are required to make guidelines as to how to select the experts and how to decide the qualifications of the experts who will be considered for the panels. As a result of these guidelines, experts are chosen according to the following:

- *Relevant expertise within the research area*: Experts must have knowledge and experience in this field. The panel must have diversity of knowledge and not be limited by one expert because experts must be able to make decisions that require diversity of knowledge, experience, and information.
- *Availability and willingness to participate*: The people who choose to be experts for the panels must have the ability to give their opinions and feedback without external pressure to make decisions. They can end their participation as panelists whenever they like, so they have the freedom to explain and express their ideas in the way they like.
- *Balanced perspectives and biases*: In the selection of the expert panels, it is important to choose experts from different organizations who do not know each other. Although there is an advantage to people who work together and understand each other well, this selection will lead to biases toward one decision, which will not be good for the hierarchy decision-making process. This process of decision-making will have a positive impact on the result because no one panelist will affect another in providing feedback on the hierarchy of decisions. In addition, the process must work to prevent occurring conflicts, which will have a negative impact on the result.

Experts will help to do more than one job during their participation as panelists in the research model, which can be summarized in the following points:

- Examining the research model to see if it needs to be re-edited or if more criteria need to be added
- Giving feedback for judgment quantification to all levels of the model
- Checking the final research of the model

To create the expert panels for the research model, the following steps are required:

- Identify expert requirements: According to the research and literature review, the panels require experts who have knowledge in the development of geothermal energy resources; in the development of technology for obtaining the best service; in renewable energy projects; in power generation; in the environmental, social, and economic sectors; and in academics in relation to this field.
- Make a list of names of all expert panelists and the research study specialization of each one on the panel. A collection of a list of all of the names that will come from literature review that includes government reports, reports from the state about this field of geothermal energy resources, and reports of renewable energy projects.
- Invitation process: On the invitation, ask experts if they agree to participate in the model, and send an email to all experts.

4.4.5 Pairwise Comparisons

The pairwise comparisons are used for identifying the number of comparisons required for the decision element. The formula used for number of comparison is (N)and N is calculated by ($n = \frac{N \times (N-1)}{2}$). For instance, if the model has 6 elements,the number of pairwise comparisons will be $6 \times \frac{5}{2}$; therefore the result will be 15comparisons in the decision. If more elements participate, more numbers of pairwise comparisons will be obtained, and the complexity of the decision analysis will increase.

4.4.6 Inconsistency

In the research model, the expert panels will use the constant sum method for obtaining accurate values. This process requires the experts to choose one from two pairs in the decision, and the total of both pairs is 100 points. It is important to examine any mistakes that may be committed by the experts during the comparison between the pairs of the decision. Therefore it is important to measure the inconsistency of the variance from the relative value of the decision variable [320].

A mistake in judgment occurs because humans cannot always make the right decisions. Some inconsistencies in judgment aren't too big so they can be measured and ignored, while other inconsistencies can create problems and cannot be solved and answered. The range of inconsistency cannot exceed 0.1 (≤ 0.1). If an expert has an inconsistency greater than 0.1, the calculation must be repeated to find where the mistake is, and the process of deciding between the pairs must be repeated once again. The process of repeating the calculation continues until the result reaches under or equal to 0.1.

The process for calculating inconsistencies is clarified in the steps that follow. The decision variable for n will become $n!$, and it is simplified with vectors r_1, r_2, r_3,…., r_n. For example, 5! will become 120 orientations like ABCD ABDC ACBD ACDB,……., DBCA. The same value in the result will occur if all experts have the same idea. Each panelist has different opinions, so the result will not be the same. This inconsistency is used in the HDM methodology for obtaining the variance by calculation [138]. The formula of inconsistency is clarified below:

Let

r_{ij} is the relative value of the i^{th} element in the j^{th} orientation for an expert
$\bar{r}_i$ is the mean relative of the i^{th} element

Inconsistency for the i^{th} element is

$$\frac{1}{n!}\sum_{n!}^{j=1}\left(\bar{r}_i - r_{ij}\right)^2 \text{ for } i = 1,2,\ldots,n$$

Inconsistency of the expert for n element decision variable is:

$$\frac{1}{n}\sum_{n}^{i=1}\frac{1}{n!}\sqrt{\sum_{n!}^{j=1}\left(\bar{r}_i - r_{ij}\right)^2}$$

4.5 Result and Data Analysis

This part will explain the judgment quantification results, experts' inconsistencies, and the areas of disagreement between the experts on the panel. A pairwise comparison method software was used for analyzing the results of the quantified expert judgment. As explained in the previous chapters, the value of disagreement among the group will be less than or equal to 0.1.

4.5.1 Expert Panel

The seven expert panel members have expertise in the geothermal technologies associated with geothermal energy projects. Based on the list of alternatives on the survey questionnaire, they noted which alternative is more convenient in the decision-making process with respect to the mission of our project, objective, and goals. The panel was comprised of experts from the following organizations: two were from government agencies, one from university, and four from nongovernment organizations. The table below explains the experts and which institutions they are working at (Table 4.8).

Table 4.8 Expert panel and institutions

Expert	Affiliation	Institution
Expert 1	Oregon Department of Energy Geothermal Energy Council	Government
Expert 2	Energy Trust of Oregon	Nongovernment organization
Expert 3	Oregon Environmental Council	Nongovernment organization
Expert 4	Oregon Public Utility Commission	Government
Expert 5	Renewable Northwest	Nongovernment organization
Expert 6	Oregon State University	Academia
Expert 7	AltaRock Energy, Inc.	Nongovernment organization

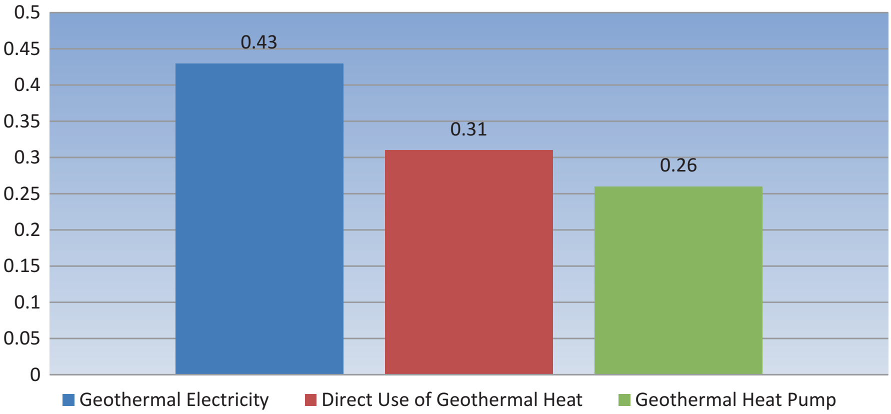


Fig. 4.4 The global weight of alternative geothermal energy technology

4.5.1.1 Expert Panel Results

The seven expert panel members were asked to use the online survey questionnaire link that included instructions about how to use the hierarchical decision model (HDM) to evaluate different criteria that affect geothermal energy with respect to our goal that was mentioned in the mission (Technology Assessment Model of Developing Geothermal Energy Resources for Supporting the Electrical System in Oregon). The figure below shows the contribution results from the expert panel .

The results in Fig. 4.4 show that "geothermal electricity," with a rating of 43%, was ranked as the most important alternative with respect to mission, objectives, and goals. "Direct use of geothermal heat" was ranked as the second most important alternative with 31%, and the "geothermal heat pump" was ranked as the least important alternative with 26% for developing geothermal energy sources in Oregon.

4.5.1.2 Analysis of Expert Panel Results

The individual expert opinions about the relative importance in weight of each alternative contributed to finding the most important alternative with respect to mission statement. The mean of seven experts is shown in Table [1]. All experts have knowledge and experience in geothermal energy, and they gave their judgment in the questionnaire survey. The results of the comparison are among the acceptance level of consistency in their judgment, and consistency level must be less than or equal to 0.1. The results showed that the mean level of disagreement was 0.095 between the experts that participated in questionnaire of survey. At the same time, the individual expert's judgments were among the acceptable range, which is 0–0.03. The table below shows the individual expert judgment for each alternative. All individual inconsistencies are within the acceptable level or range (Fig. 4.5 and Table 4.9).

From the results in the table above, the majority of the experts chose geothermal electricity as the most important electricity alternative. The reason for this is that electricity is used in a variety of different applications like heating, cooling, industry, medical, and so forth, and the population of people and their demand for electricity are always increasing.

The outcome analysis of the results in Appendix C showed that in terms of objectives, minimizing environmental impact was rated at the highest value at 0.26 with respect to the mission. Within the category of minimizing environmental impact, seismic activity and GHG emissions had higher values as well because they require more attention and work to reduce the negative impact from the process of geothermal energy activities.

A numerical analysis was also made to know what are the most important objectives through looking at different expert segments (background of the organization, position, and education) and identify if this result of analysis will affect decision-making or not.

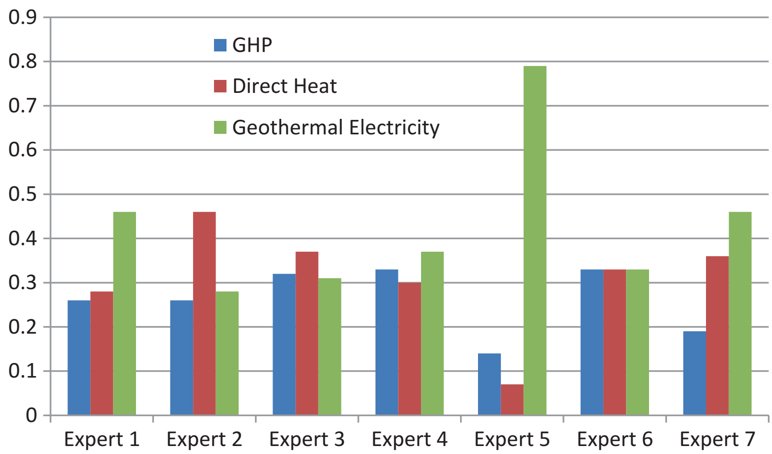


Fig. 4.5 Individual expert judgment for each alternative

Table 4.9 Individual expert judgment for each alternative

Expert	GHP	Direct heat	Geothermal electricity	Inconsistency
Expert 1	0.26	0.28	0.46	0
Expert 2	0.26	0.46	0.28	0.01
Expert 3	0.32	0.37	0.31	0.02
Expert 4	0.33	0.3	0.37	0.02
Expert 5	0.14	0.07	0.79	0.02
Expert 6	0.33	0.33	0.33	0.01
Expert 7	0.19	0.36	0.46	0.03
Mean	0.26	0.31	0.43	
Disagreement	0.095			

Table 4.10 Importance of objectives from different characteristics of the experts

Characteristics of experts		Importance of objectives	
		Preference choice #1	Preference choice #2
Background of organization	Utility	Minimize environmental impact	Reduce expense of investment energy cost
	Consulting	Minimize environmental impact	Technical option improvement for geothermal energy projects
	Research lab	Reduce expense of investment energy cost	Technical option improvement for geothermal energy projects
	University	Reduce expense of investment energy cost	Minimize the negative impact on the general public
Experts positions	Management	Minimize environmental impact	Reduce expense of investment energy cost
	Planning	Reduce expense of investment energy cost	Minimize the negative impact on the general public
	Policy	Reduce expense of investment energy cost	Technical option improvement for geothermal energy projects
	Environment	Minimize environmental impact	Minimize the negative impact on the general public
Education	Bachelor's degree	Minimize environmental impact	Reduce expense of investment energy cost
	Master's degree	Minimize environmental impact	Technical option improvement for geothermal energy projects
	Ph.D. degree	Reduce expense of investment energy cost	Encourage community to support geothermal energy project

Table 4.10 shows that minimizing environmental impact and reducing expense of investment energy cost are the most important objectives for all experts either as their first choice or their second most important choice.

Table 4.11 analyzes the input from the experts. As mentioned before, all of the experts were from different organizations, and the results of the input showed that while not all of them selected the same objectives as the most important, the majority of the experts rated a reduction in the expense of investment energy projects as

Table 4.11 Identifying the important objectives made by the experts

Importance of objectives		
	Preference choice # 1	Preference choice #2
Reduce expense of investment energy projects	3	2
Technical option improvement for geothermal energy projects	2	1
Minimize environmental impact	2	0
Minimize the negative impact on the general public	1	2
Encourage community to support geothermal energy project	0	2

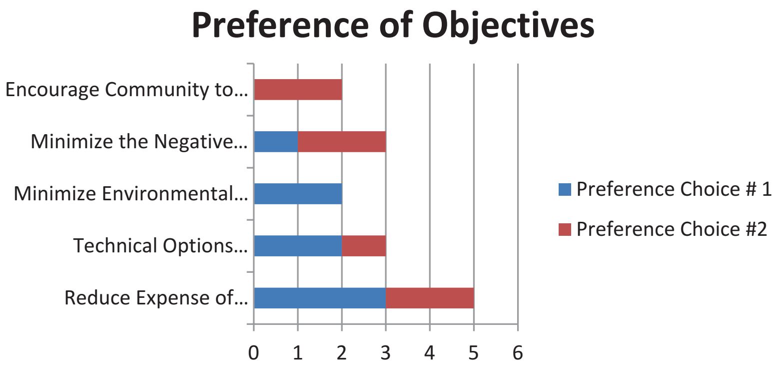


Fig. 4.6 Preference of objectives

the most important factor and ranked this as first or second. The table below clarified this process of selection (Fig. 4.6).

As expected, minimizing environmental impact is the most important objective for Oregon since Oregon encourages all investment in renewable energy projects to serve and protect the environment. All of the experts chose the most important out of 14 designated goals and then ranked these selections from one to four, one being the highest and four the lowest. Creating new job opportunities and minimizing noise and odor were ranked the highest among the goals. Table 4.12 identifies the important goals made by the experts.

From Table 4.12, the majority of the experts chose minimizing noise and odor, creating new job opportunity, and social acceptance as the most important goals for this research study in Oregon (Fig. 4.7).

To have more understanding of the most important goals for improvement of geothermal energy sources, different perspectives of experts' characteristics were analyzed. Table 4.13 explained the most important goals from different perspectives of experts.

Most of the experts chose geothermal electricity and the direct use of geothermal heat as the most important alternative for developing geothermal energy sources in

Table 4.12 Identifying the important goals chosen by the experts

Importance of goals				
	Preference choice # 1	Preference choice # 2	Preference choice # 3	Preference choice # 4
Minimize noise and odor	4	2	1	0
Create new job opportunity	2	3	0	0
Social acceptance	1	1	1	2
Minimizing property damage for reducing impact on lifestyle	0	1	1	0
Equipment manufacturing development	0	1	1	1
Minimize capital cost	0	0	3	2
Minimize operation cost	0	0	1	0
Minimizing thedemand of critical resources	0	0	1	0
Seismic activity	0	0	0	2
Economic boost	0	0	0	1

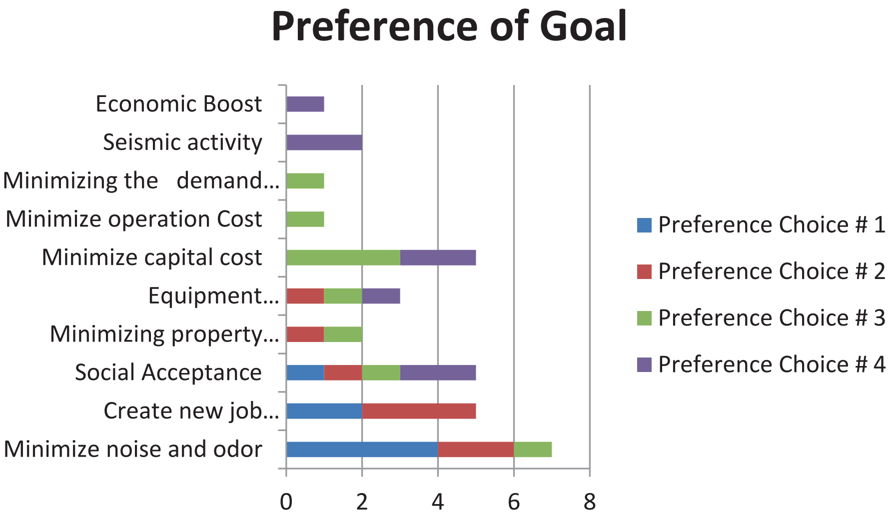


Fig. 4.7 Preference of goal

Oregon. Table 4.14 explains the most important feature of each goal for every alternative of geothermal energy that was chosen by the experts.

Table 4.14 shows that the most important features for geothermal energy projects were creating new job opportunities and social acceptance. More focus is needed around the research of geothermal energy sources in the geothermal field and for making the geothermal energy alternatives successful in Oregon (Fig. 4.8).

Table 4.13 Importance of goals from different characteristics of the experts

Characteristics of experts		Importance of goals			
		Preference choice #1	Preference choice #2	Preference choice #3	Preference choice #4
Background of organization	Utility	Minimize noise and odor	Social acceptance	Minimize capital cost	Seismic activity
	Consulting	Create new job opportunity/minimize noise and odor	GHG emission	Minimizing the demand of critical resources	Economic boost
	Research lab	Minimize noise and odor	Create new job opportunity	Minimize capital cost	Increasing the capacity of the energy system
	University	Create new job opportunity	Increasing the capacity of the energy system	Seismic activity	Social acceptance/economic boost/minimize capital cost/minimize operation cost
Experts positions	Management	Minimize noise and odor	Minimize capital cost	Social acceptance	Create new job opportunity
	Planning	Minimize noise and odor	Create new job opportunity	Social acceptance	Equipment manufacturing development
	Policy	Minimize noise and odor	Create new job opportunity	Minimize capital cost	Increasing the capacity of the energy system
	Environment	Minimize noise and odor	Create new job opportunity	Minimizing the demand of critical resources	Economic boost
Education	Bachelor's degree	Social acceptance	Minimize noise and odor	Minimize capital cost	Seismic activity
	Master's degree	Minimize noise and odor	Create new job opportunity	Equipment manufacturing development	Minimize capital cost
	Ph.D. degree	Create new job opportunity	Minimize noise and odor	Minimize capital cost	Increasing the capacity of the energy system

Table 4.14 The most important features for geothermal energy alternatives that were chosen by the experts

Alternative			
	GHP	Direct heat	Geothermal electricity
Create new job opportunity	1	2	6
Social acceptance	3	4	4
GHG emission	3	4	6
Land requirement	4	3	5
Seismic activity	4	6	4
Using the land for other purposes	3	2	6
Minimize capital cost	1	3	5
Minimize operation cost	2	3	6
Economic boost	2	2	5
Minimizing thedemand of critical resources	2	5	5
Increasing the capacity of the energy system	3	3	6
Equipment manufacturing development	2	2	5
Minimize noise and odor	3	4	6
Minimizing property damage for reducing impact on lifestyle	3	4	7

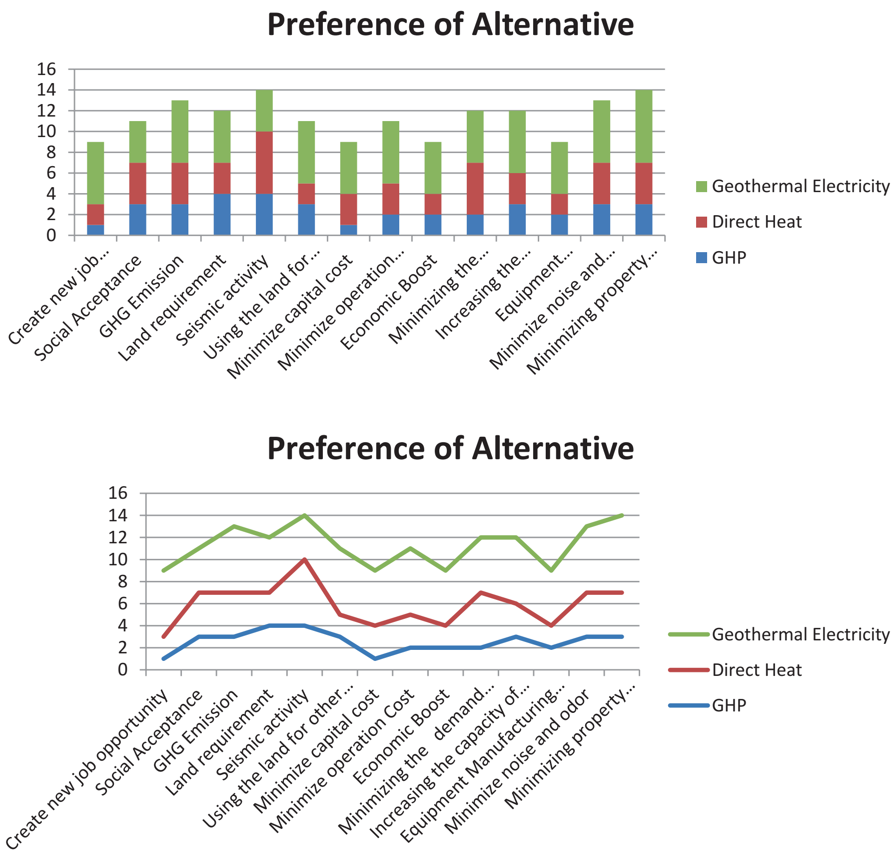


Fig. 4.8 Preference of alternatives

Table 4.15 Different characteristics of experts for geothermal energy alternatives

Characteristics of experts		Alternative		
		GHP	Direct heat	Geothermal electricity
Background of organization	Utility	GHG emission	Minimize capital cost	Equipment manufacturing development
	Consulting	Seismic activity	Minimizing the demand of critical resources	Minimize noise and odor
	Research lab	Seismic activity	Seismic activity	Increasing the capacity of the energy system
	University	Seismic activity/ GHG emission/ create new job opportunity	Minimize capital cost/minimize operation cost/ economic boost	Minimizing the demand of critical resources/ equipment manufacturing development
Experts positions	Management	Social acceptance	Minimize capital cost	Equipment manufacturing development
	Planning	Land requirement	Create new job opportunity	Using the land for other purposes
	Policy	Seismic activity	Seismic activity	Increasing the capacity of the energy system
	Environment	Using the land for other purposes	Minimizing the demand of critical resources	Increasing the capacity of the energy system
Education	Bachelor's degree	Using the land for other purposes	Minimize operation cost	Minimizing the demand of critical resources
	Master's degree	Seismic activity	Minimizing the demand of critical resources	Equipment manufacturing development
	Ph.D. degree	Seismic activity	Seismic activity	Increasing the capacity of the energy system

To know which alternative is the most successful with features (goals) for development of geothermal energy, different perspectives of experts' characteristics were analyzed. Table 4.15 explained this process.

From Table 4.15, most experts which have different perspectives of characteristics preferred to choose features of environment as the highest rank. Technical features were ranked also as one of the most important for achieving the best benefits of geothermal energy.

In order to understand why there was a difference between what objectives, goals, and alternatives each expert on the panel deemed important and ranked the most highly, the discussion in the discussion section will help to understand their thoughts about the future of geothermal energy and their recommendations for improvement in this sector of renewable energy. All explanations for objectives, goals, and alternatives will be expounded in the discussion part.

4.5.2 Criterion-Related Validity

Managers from different organizations in the Pacific Northwest, who are specialists in renewable energy, environment, and geothermal energy, participated in evaluating the criterion-related validity. Experts were asked to give their judgment in a survey questionnaire about the research study. All of the experts agreed that the methodology was a good approach for reaching a decision. They also agreed that all of the nodes that were applied in the HDM methodology that are based off in real life require more attention. This process will lead to more development of geothermal energy sources in Oregon. Also, the experts confirmed that the development of geothermal energy technology will grow quickly if there is more attention and focus on the criteria that were used in the methodology. We held a face-to-face meeting with the expert panel to hear their thoughts on what is required for more development in the future. Experts agreed that by applying this model in the future for another state and by adding more criteria, this model will be useful for determining what will be required for greater improvement in the geothermal field.

4.5.3 Summary of the Study

A hierarchical decision model (HDM) methodology was used in this research study to reach the value for the technology assessment model of developing geothermal energy sources for supporting the electrical system. This methodology (HDM) was applied to Oregon as a case study. The result of the data analysis in this research process is summarized in the following points:

1. The objective from the research study was to develop an assessment model framework that can be used for supporting cost-effective renewable energy in Oregon by the development of geothermal energy sources. This research study was done by using the HDM model and consisted of four levels: mission, objectives, goals, and alternatives.
2. Seven experts agreed to give their judgment and evaluate different nodes in objectives, goals, and alternatives.
3. The results of this research study were discussed with the experts to get their feedback and learn from them what requirements are necessary for improvement in the geotechnical energy sector for future research. The experts agreed that this methodology is a good approach to help reach the right decision since this methodology (HDM) divides the problem into small sets, which will make the decision process easier.

4.6 Discussion

This part will explain all of the data collection and the final results from the experts' participation in this research study and analyze the results according to the feedback from the experts. The discussion with the experts helped in understanding what drove their choices. This discussion provides insight, and a better understanding of the participation results in this research study of geothermal energy sources in Oregon.

4.6.1 Results

4.6.1.1 Evaluation of the Objectives

The HDM showed that minimizing environmental impact is the most important objective with respect to the mission of developing geothermal energy sources in Oregon. Reducing the expense of investment in geothermal energy projects was ranked second after minimizing environmental impact, and this result showed that for geothermal energy projects to be successful, it is important to reduce the investment cost. The more the cost of investment of geothermal energy projects is reduced, the faster the improvement in technology will occur. Technical option improvement for geothermal energy projects and minimizing the negative impact on the general public had the same value and were ranked third. Lastly, encouraging the community to support geothermal energy projects had the lowest value, and all these results were discussed with experts.

Getting feedback from experts and analyzing the results from their participation showed the importance of having projects that focus on developing geothermal energy sources in Oregon and benefit from improvement and progress in technology that serves this type of renewable energy. As mentioned above, minimizing the environmental impact and reducing the expense of investment in energy projects are the most important objectives, and the experts from different organizations explained why focusing on these objectives is important for the success of geothermal energy projects in Oregon. The results from the data collection from the survey showed that the experts preferred reducing the expense of investment in energy projects as one of the most important objectives. Experts explained that the reason for this preference was that geothermal energy is still expensive and there is a lack of research in the field about how to create and benefit from improvements in this alternative energy form. This is the reason why geothermal energy projects are still expensive; there is not a huge amount of research available for developing the geothermal energy sources. Right now, geothermal energy research has problems with how to reach deep drilling at a cheaper cost. Meanwhile, researchers still have difficulties estimating how long the investment will last and how many additional funds will be required, so the experts found that the best thing to make geothermal energy projects successful is to focus on the economics of the projects because the price of other renewable energies like solar and wind is still cheaper.

Minimizing environmental impact was ranked as the most important objective for developing geothermal energy sources in Oregon, and this result was discussed with the expert panel in order to clarify their preference for this objective. Experts found that environmental issues are important because Oregon has a strong environmental ethic at some sites. These sites are located on protected public land, especially some sites near volcanoes, and others are located in national parks. In addition, public policy wants to keep Oregon away from any impact from poor water quality, chemical, and air pollution that can happen during the construction of geothermal energy projects. At the same time, experts encouraged investment in geothermal energy projects since geothermal energy is good for the environment compared with other sources of energy like the coal and oil industries. Geothermal energy is the best source of energy for both environmental and product of environment. There is much progress happening in the environmental sector. Oregon has achieved many things like working to have clean air and water, getting a healthy climate, working to have sustainable food, and making a beautiful landscape through reducing pollution. For these reasons, experts chose minimizing environmental impact as the most important objective.

Technical option improvement for geothermal energy projects was ranked as the third most important objective for developing geothermal energy sources in Oregon. Experts found that while there is still more effort needed for obtaining more improvements, the size of improvements is slow because the achievements in the field of geothermal energy are so expensive. To accelerate the size of improvement and to get a more efficient system in the geothermal field, more support from the government and public policy is required. Also, there are many failures that need to be fixed, such as the problem of heat transfer because a piece of equipment does not match the thermal properties during the construction and this process of construction impacts system efficiency. In addition, the field of geothermal energy is still not as sophisticated as other alternative energy sources so the field of geothermal energy needs more attention and research to be competitive with other renewable energies like solar, wind, etc. The price of solar and wind is cheap compared with geothermal energy, which is still expensive. Researchers are now focusing on developing low-temperature geothermal sites, which carry a marginal cost. As the price of geothermal energy goes down, the prospective risk will go down too. For this reason, experts chose technical option improvement for geothermal energy projects as one of the most important objectives.

Minimizing the negative impact on the general public was ranked also as the third most important objective for developing geothermal energy sources in Oregon. This result was discussed with experts for why they chose minimizing the negative impact on the general public as one of the important factors. Experts found that the success of any renewable energy project depends on the acceptance from the community who live around the construction of renewable energy projects. This is because ongoing operations of renewable energy create a large amount of waste. If these inconveniences to the community nearby the geothermal energy projects are during construction phase only, it may be easier to "sell" the idea of geothermal energy if the community knows the size of the benefit that will come from this project. If the issue is ongoing past the construction phase, the community nearby will terminate this project if they believe that the impact on their health will be negative.

It is important to benefit from the technology available today since the technology works to serve the community, and while there are many improvements in this sector, the developers still need to be aware of these issues. For this reason, it is important to focus on minimizing the negative impact on the general public, and they need to work on changing the community's perception of geothermal energy sites or reduce these projects near communities.

Encouraging community to support geothermal energy projects was evaluated as the least important objective for developing geothermal energy sources in Oregon. This result was discussed with the experts for why they chose encouraging community to support geothermal energy projects as the least important factor. In fact, not all of the experts ranked encouraging community to support geothermal energy projects as the least valuable; some experts ranked it as second in importance and some the third. The reason for disagreement about this value was that some experts considered geothermal energy as only one type of renewable energy and that a community that is educated about the value of energy can understand that renewable energy is beneficial to society, so this is the reason why the experts chose encouraging community support of geothermal energy as the lowest value. Some experts chose encouraging community to support geothermal energy projects as one of the important objectives. Those experts believe that it is important to educate the community about geothermal projects, and people might express concern for environmental issues; therefore the process of educating the community about geothermal energy projects will hopefully over time create ongoing support and understanding about the process of geothermal energy and anything related to land use. People have very strong opinions about geothermal energy projects, and there are some challenges associated with geothermal energy projects or normal development that potentially can create a negative impact on the community. If people do not understand what the source of negative impact is or how it is caused, there may be a backlash that is disproportionate to the benefits of geothermal energy. People must understand that green projects are not always impact-free. For this reason, encouraging community to support geothermal energy projects is so important for successful investment in geothermal projects.

4.6.1.2 Evaluation of the Goals

The success of developing geothermal energy sources in Oregon requires knowing what the most important objectives and goals are. These objectives and goals will work with technology alternatives, and with this work comes greater improvements resulting in more successful geothermal energy projects. The HDM showed that minimizing noise and odor was ranked the most important goal with a value of 0.73. Creating new job opportunity was ranked as the second most important goal with a value of 0.59, and minimizing capital cost was ranked the third with a value of 0.51. The results of these goals were discussed with experts to ask why they ranked these goals as the most important.

Experts found that minimizing noise and odor is important because communities usually complain about noise, and although there are many types of geothermal plants, equipment still generates noise. Technology that accompanies geothermal energy projects is required for making equipment less noisy. There is a need for greater improvement in running the station smoothly so that it won't disturb the community nearby. If geothermal energy projects do not minimize noise and odor, geothermal energy sources will not improve nor be accepted by local communities, which will keep geothermal energy limited only to a few sites. This is the reason why some experts chose minimizing noise and odor as the most important goal. Experts found also creating new job opportunity as one of the most important factors for successful geothermal energy projects in Oregon since geothermal projects will improve the economy and more job opportunities will be available for the people. Meanwhile, more public dollars will be available, and job opportunity is beneficial in terms of economic and environmental value. Bringing these two things together from a public policy standpoint is beneficial for society as a whole. Geothermal energy projects need different job skills during discovery, construction, and maintenance after the completion of geothermal energy projects, and these skills already exist. Staff can already do this kind of work, and this level of worker skill set leads to better and cleaner energy power.

Minimizing capital cost was found to be one of the most important goals chosen by the experts because the investment in geothermal energy projects is so expensive. Right now, most research on geothermal energy in Oregon focuses on low-temperature geothermal projects since these projects are less expensive and require less funding than research focusing on high-temperature geothermal projects. These high-temperature projects require a lot of funding because the deep drilling needed for reaching high-temperature projects will carry greater risk and may not find a good source of geothermal energy. For this reason, experts are more willing to find the best way to generate geothermal energy through the development of technology at a lower cost. The development of improved equipment manufacturing is in the middle of the most important goals because the experts found that their national laboratories are putting in a lot of effort to produce better equipment. Lately, many small manufacturing companies are merging with big companies. Even though big companies in the USA specialize in geothermal equipment and are motivated to improve the equipment to be used in geothermal energy, the technology for updating the equipment and the systems in the USA is not the same as for the international market. The international market has created better improvements in geothermal equipment than the USA.

4.6.1.3 Evaluation of Alternative

The success of geothermal energy projects depends on developing the technology that works within the geothermal field to obtain greater benefits from alternative geothermal energy. The HDM showed that geothermal electricity was ranked the most important alternative with a value of 0.43, direct use of geothermal heat was ranked the second important alternative with a value of 0.31, and GHP was ranked the least important alternative with a value 0.26. These results were discussed with the experts to understand why they ranked the alternatives of geothermal energy the way that they did.

Geothermal electricity was ranked as the most important alternative for developing geothermal energy sources in Oregon. Experts explained that geothermal electricity was the most important resource for supplying more electricity to Oregon. At the same time, communities are increasing in population, and more new buildings are constructed as compared with previous years. Therefore, the growth of communities requires planning for a greater capacity of electricity. Also, having electricity generated from a geothermal field will not harm the environment, and it will bring a good amount of electricity to the community, and there are many places like Klamath Falls that already have geothermal electricity that is of great value. This is the reason why the experts encouraged the use of geothermal electricity to improve the geothermal field in Oregon.

Experts ranked direct use of geothermal heat as the second important alternative for developing geothermal energy sources in Oregon. Direct use of geothermal heat is considered the best option economically, but it cannot work everywhere so direct use of geothermal heat is limited to certain geographic areas. Direct use for geothermal heat works well within a large building area but not within a small building area, and for this reason direct use of geothermal heat sources is only available as local resources for large buildings. At the same time, electrical heat is oftentimes less efficient or there are many heat applications that depend on natural gas. A huge amount of natural gas is used for heating applications, including industrial processes. For this reason, direct use of geothermal heat is more efficient and can supply a large number of buildings with heating. Experts encouraged developing the direct use of geothermal heat because it is not only more efficient but will also not harm the environment.

Geothermal heat pumps (GHPs) were ranked the least important alternative for developing geothermal energy sources in Oregon. The USA has a national history of failure in both the technical and the economic sector for using GHP. GHP is more in efficient homes that use a ductless heating system, but there is a problem with how to connect GHP with home buildings. Recently, GHP has become more successful in regulating temperature. While energy efficiency for the heat pump is going up and the prices for the heat pump are going down, experts chose GHP as the least important alternative because GHP needs more research and professional geothermal experts to improve the technology to gain better efficiency from GHP.

4.6.2 Challenges Accompanying Geothermal Energy Projects

Even though geothermal energy projects are a good investment and are economically, politically, environmentally, technically, and socially beneficial, there are many challenges that still accompany geothermal energy from discovering sources and the construction of sites to the continued maintenance of the sites after construction. In order to gain better efficiency from geothermal energy projects in Oregon, many improvements are required to expand the use of geothermal energy, and the process of improvement requires focusing on solving the obstacles that accompany geothermal fields, and these obstacles are explained below.

The cost of geothermal energy projects is still high as compared with other renewable energies like wind, solar, and so forth. Geothermal energy projects are considered expensive because even though the investors spend a huge amount of money for exploration and trying to locate right resources of geothermal energy, they may not get the right resources and may ultimately lose their investment. The problem of cost will be solved if researchers know how to find the right location, manage the exploration of resources, and estimate the drilling for required depth. Right now, many researchers are trying to find a critical plan for the resources of geothermal energy projects because the initial start-up cost of an investment in the geothermal field is still high, and this scares many investors. For this reason, experts found that reducing the cost of investment in geothermal energy projects will generate more investors in this sector of renewable energy, and investment will also be cheaper when more researchers are available for the development of geothermal energy.

Public relations and awareness are two of the biggest challenges because most people do not even know what geothermal energy is, and even when they are told about geothermal energy, they do not think geothermal is necessary like solar, wind, etc. At the same time, people are afraid of the seismic activity that can happen during the construction of geothermal projects because this issue is one of the factors that need to be heavily managed. For this reason, greater education and awareness are needed in the community to make them understand what the benefits from geothermal projects are and to clarify the ways or methods that will be used to manage seismic activity if that happens during construction.

There is also a lack of information in the research of geothermal energy in Oregon as compared with California and Nevada. In addition, the level of professional people in Oregon is limited although good researchers are available at the Oregon Institute of Technology (OIT). Researchers still have difficulties in estimating the cost for long-term investment. Oregon still needs more support to increase the progress in the technology for achieving a higher efficiency of geothermal energy projects.

Regulatory issues are one of the main factors that are holding geothermal energy back. Public policy works to protect the environment from any negative impact, so for this reason the power of renewable policy over the long term is stronger in Oregon than California. As mentioned before, Oregon has strong environmental ethics, and these ethical issues prevent the development of research in the geothermal field since ethical considerations restrict the research and discovery of geothermal sources in some locations.

4.6.3 Opportunity for Successful Geothermal Energy Projects in the Future

Even though geothermal energy projects are accompanied by some obstacles that can make the improvement of the geothermal field very slow in Oregon, there are many opportunities to make the geothermal field successful especially with more progress in the research of geothermal energy technology. Oregon can take advantage of the research in the geothermal field to achieve more efficiency in this field of renewable energy and have the opportunity for better improvement of geothermal energy projects in the future.

Oregon needs to focus on the economic prospective and support the adoption of geothermal energy projects with financial investment research, community outreach, and environmental protection. This support will make geothermal energy projects successful since the price of other renewable energies like solar, wind, etc. is still cheaper. For this reason, experts chose reducing the expense of investment in energy projects as one of the most important objectives in successful development of geothermal energy sources in Oregon. In California, there is a lot of research done with deep drilling in the geothermal field, and this research will help Oregon. Right now, geothermal energy with technology today looks very good. Over the past few years, technology has improved within power plants, and geothermal energy is one of the least expensive renewable energies if people are looking at the investment as a long-term one. Researchers in geothermal field have done some recent work with enhanced geothermal system (EGS) in Oregon, and there are many attempts from researchers in geothermal field to produce big EGS. If big EGS happened, this good technology will be available in Oregon.

Compared with other states, Oregon is ready now for improvement, and Oregon is already an ideal spot for both direct use of geothermal heat and GHP. If technology develops a little bit better right now, the power production will be reliable as well. Now is the best time for developing geothermal energy sites and working to manage the cost of geothermal energy. In addition, if the climate crisis continues, geothermal energy will be a good resource since additional resources will be required for reducing the negative impact on the climate and geothermal energy sources are a good candidate for solving this issue. It is important for Oregon to keep developing more research into geothermal energy sources to be ready for any crisis in the climate.

Researchers need support from public policy to be able to move forward. Encouraging new associations to participate in the research of geothermal energy sources is very important in Oregon, and all utilities are interested in geothermal energy projects that will lead to achieve full benefit from geothermal field in Oregon.

4.7 Limitations and Future Research

4.7.1 Assumptions and Limitations of the Research Model

A number of expert panelists who have the knowledge to and who can supply the data validation of the outcome will contribute to building and evaluating the research model. This process of evaluation will have a positive impact on the development of the model because the model will be more accurate in the decision-making process. In addition, there are many other factors that can be used to improve the research model. These factors contribute in different ways: relevant expertise within the research area, the availability and willingness to participate, and balanced perspectives and biases. All of these factors were discussed in the previous chapters. Even though these factors are important and must be applied and used in the panel to have an accurate outcome, it is still a challenge to generate the best result without biases. For solving this process of uncertainty in the decision-making, different procedures and methods will be used in the research model to create validity measures. All of this process for this research study was discussed in previous chapters. Using suitable tools and techniques and selecting the right experts to provide feedback will reduce the ambiguity in some parts of the research. Having accurate information will lead to different perspectives for better decision-making.

In general, the outcome of the research model is dependent on the context and is time dependent. That means any change in the future in terms of any driver such as the technical, economic, social, political, and environmental sectors will have a large effect on the electrical system. In addition, any change will be impacted by the changes in the utility goals and objectives, which are represented by the decisions made about the development of geothermal energy resource alternatives in Oregon. From this, it is clear that it's hard to predict future changes, and this affects the decision-making process.

The value of geothermal energy resources relies on the market, the technology, and the variability of utility available in Oregon. For example, the demand for geothermal energy in the market is not stable, and that is because of many factors like the availability of suitable technology that contributes to use the source of geothermal energy and the price of using source of geothermal as compared with other energy sources. All of these factors participate in changing the value of geothermal energy in the market. In addition, these factors can change at any time. For example, the value of geothermal energy resources will not be the same area to area. When the research model applies the process to another region other than Oregon, the decision-making process will be significantly different. It is clear that the research model was created to support the electrical system in Oregon. The research model can be developed and used in other regions by changing it according to the market requirements, the available technology, the utilities, and the possibility for success. Finally, the research model can be applied to all types of geothermal electricity plants (dry steam, flash steam, and binary). These types of geothermal electricity plants were discussed in the previous chapters on the comparisons of which technology is the best for generating electricity. Unlike the previously mentioned technologies, the research model works to support the electrical system through depending on the geothermal process that uses the heat pump, direct use of geothermal heat, and geothermal electricity.

4.7.2 Expected Contributions

The expected contribution of the research model will lead to better knowledge and more accuracy in the decision-making process. The following steps outline expected project contributions. First, the research model will contribute to the evaluation of geothermal energy resource alternatives with respect to the effect on the utility objectives and goals. From the literature review, it is clear that no research model can work with more than one dimension (economic, technical, social, political, and environmental) and go in detail for each aspect (utility objective and goals). Utility objectives and goals are very important in the process of decision-making because they constitute the variables in the research model, which requires a trade-off in the analysis of decision process. This trade-off makes decisions easy to take in the field. In addition, the literature review showed that it's important to have diversity in the use of geothermal energy resources in different applications as was mentioned in the previous chapters. The literature review also showed the effect of this diversity in terms of supporting the electrical system and how the successful use of technologies and alternative sources of geothermal energy in different regions in the world can also be successfully used in Oregon. From the literature, it is important to have a connection between utility objectives and goals for geothermal energy resource alternatives, as this will increase the level of knowledge and understanding for creating accurate decisions in the field, and to gain greater benefits from geothermal energy sources.

The HDM model is important to use for finding which geothermal energy resource alternative is the best with respect to utility objectives and goals. The HDM method depends on judgments that require increased knowledge and understanding of the important criteria in the decision-making process and provide feedback from the experts to generate a more accurate decision. The HDM method has the ability to deal with multiple perspectives and to analyze each perspective with respect to utility objectives and goals, which helps in obtaining a better decision.

The decision to use alternative sources of geothermal energy is a good investment, and the probability of success is very high if these types of projects are considered a long-term investment. There are many criteria (technical, environmental, social, economic, and political) that are changing with the times that will have an impact on these types of investments over the long term. It will require a recalculation and updating of the materials and equipment that are used in these investments, which will have an impact on the whole electrical system.

In general, the research model will contribute to an increased level of knowledge for using geothermal energy resource alternatives and to knowing which decision is suitable for reaching the full benefit from this source of energy. In addition, the research model will help to build the right structures for developing a strategy that will improve the decision-making process. The outcome from the model will be the best way to support the electrical system in Oregon.

4.7.3 Future Research

This research study focuses on the use of one of the alternative sources of geothermal energy for supporting electrical system. The purpose of this case study is to evaluate the electrical system in Oregon because of the many criteria that have been already discussed in the previous chapters. The hierarchical decision model (HDM) method was used for this purpose. This method has the ability to expand the research because this method depends on the collection of information from the literature review. In addition, this information increases the ability to know what the requirements are for developing the model in future research because our case study is about the state of Oregon. The requirements for developing geothermal energy alternatives in this state are different from other regions, and all of the used utility objectives and goals are for Oregon. There is no guarantee that these utility objectives and goals can be successful if applied to other locations around the world for supporting electrical systems because not everything that we found in the literature can be successfully used in Oregon. The utility objectives and goals in the research model are matched with the requirements for development of geothermal energy resources in Oregon. The research model can be improved for use in future research for other regions, and from this research model, one can look for what is not necessary, what is missing, and what is required to keep from the criteria that were used in the Oregon case study.

The research model may or may not change in future work because this research was built with the dependence on the current research from the literature review and the current market and end use. That means the utility objectives and goals can change, and the selection of geothermal energy resource alternatives can change depending on the technology available in the market and the diffusion of end use.

For future research, it is important to create a diversity of scenarios to look at how each scenario interacts in the research model, how this impacts the utility objectives and goals, and what is the outcome from the process of scenario analysis in the decision-making process. From that, scenario analysis is necessary to calculate the impact for future work, and the importance of the analysis for each scenario creates a better development of the model. The development of the model will be perfected if the scenarios are discussed with the experts to know which criteria are necessary for the development of the model, and from this information the best outcome is reached for end use, which leads to the improvement of the electrical system in Oregon.

Sensitivity analysis is necessary in the research model for understanding better decision choices according to the utility goals and objectives. This will help to create different scenarios for future planning and will help to estimate the best way to deal with each scenario if it is applied in the real world and what the outcome will be based on the chosen decision.

The research model can be connected with an optimization program for gaining the best benefits from geothermal energy resources as output for future research.

Appendices

Appendix A: Instruments for the Invitation of Experts

Appendix A1: The Invitation of Experts for Participation in My M.S. Thesis Research

Dear ………………………,

My name is Ahmed Alshareef and I am an M.S. student from the Department of Engineering and Technology Management at Portland State University. I am writing to invite you to participate in my research study called "Technology Assessment Model of Developing Geothermal Energy Resources for Supporting Electrical System: The Case for Oregon." This research study is being conducted in partial fulfillment of the requirements for a master's degree in engineering and technology management at Portland State University.

You're eligible to be in this study because you are an expert from either academia or industry and have enough experience to provide feedback on the criteria in the model I am researching.

Your participation in my research is important to developing a framework, measurement system, and metric for reaching the best benefit of geothermal energy resources. My research looks at the problem from different perspectives and dimensions with respect to utility objectives and goals.

The proposed research model that I developed requires participation of experts who have knowledge and opinions in the topic area of geothermal energy resources. Participation in the online survey/evaluation will take approximately 30 min to complete. This will help to further construct the model and establish a weight for selecting elements that require further development.

If you decide to participate in this study, you will make judgments on different criteria, using paired comparison between two elements, deciding which element is more important between the two. Remember, this is completely voluntary. You can choose to be in the study or not.

If you'd like to participate or have any questions about the study, please email or contact me at aalsha2@pdx.edu or call me at (503) 867–9279.

If you have any concerns or problems about participating in this study or your rights as a research subject, please contact the **PSU Office of Research Integrity**, 1600 SW 4th Ave., Market Center Building Ste. 620, Portland, OR, 97201 (phone (503) 725–2227 or 1 (877) 480–4400).

Thank you very much.

Sincerely,

Ahmed Alshareef
M.S. Student
Department of Engineering and Technology Management
Portland State University

Appendix A2: Informed Consent Form

Informed Consent Template: Online Survey Consent

You are invited to participate in a research study entitled "Technology Assessment Model of Developing Geothermal Energy Resources for Supporting Electrical System." The study is being conducted by me, Ahmed Alshareef, a graduate student from the Department of Engineering and Technology Management at Portland State University. The study is under the supervision of my advisor, Tugrul Daim.

The purpose of this research study is to examine which technologies are important for developing geothermal energy. Your participation in the study will contribute to a better understanding of the different criteria with more knowledge to know which criteria in the model require developing and more research work to cover it from a different perspective. This project is being conducted in partial fulfillment of the requirements for an M.S. degree under the supervision of Dr. Tugrul U. Daim. You are invited as a potential participant due to your expertise in the area of energy sector due to your qualification and professional experience. You are free to contact the investigator at the above address and phone number to discuss the study. You must be at least 18 years old to participate.

If you agree to participate, the evaluation will take approximately 30 min of your time, and you will complete an activity about Developing Geothermal Energy Resources for Supporting Electrical System.

There are no known risks for participating and all the information will be kept in my laptop, and I will destroy the information after 1 year of graduation. There are no costs for participating, nor will you personally benefit from participating. Your name and email address will be collected during the data collection phase for tracking purposes only. Identifying information will be stripped from the final dataset.

Your participation in this study is voluntary. You may decline to answer any question and you have the right to withdraw from participation at any time. Withdrawal will not affect your relationship with Portland State University in any way. If you do not want to participate, either simply stop participating or close the browser window. I may send study reminders about participation in the study. If you do not want to receive any more reminders, you may email me at aalsha2@pdx.edu.

If you have any questions about the study or need to update your email address, contact me, Ahmed Alshareef, at 503–867-9279 or send an email to aalsha2@pdx.edu. You may also contact my advisor, Tugrul Daim, at ji2td@pdx.edu.

If you have questions about your rights or are dissatisfied at any time with any part of this study, you can contact the Human Subjects Research Review Committee at hsrrc@pdx.edu, Market Center Building, 6th Floor, 1600 SW 4th Ave., Portland, OR 97201.

If you agree to participate, click on the following link [HTTP://LINK TO STUDY URL].

Thank you.

Please print a copy of this document for your records.

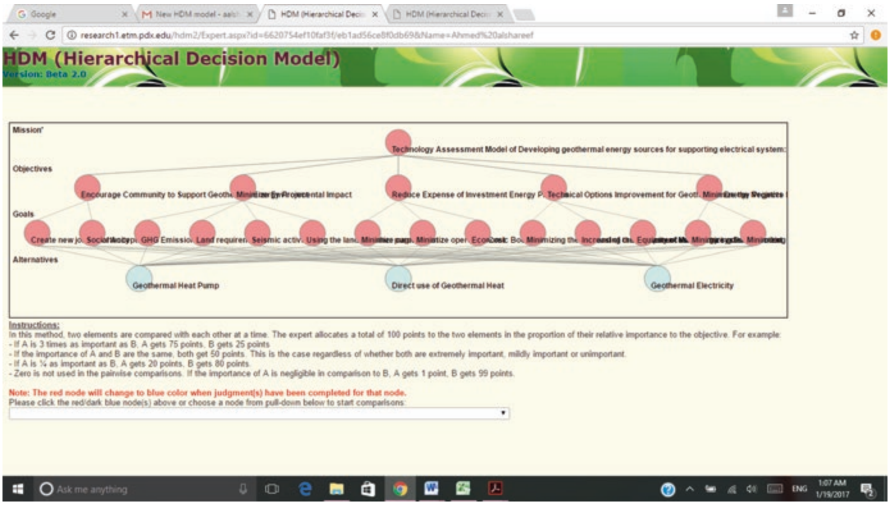
Appendix A3: Content Web Survey

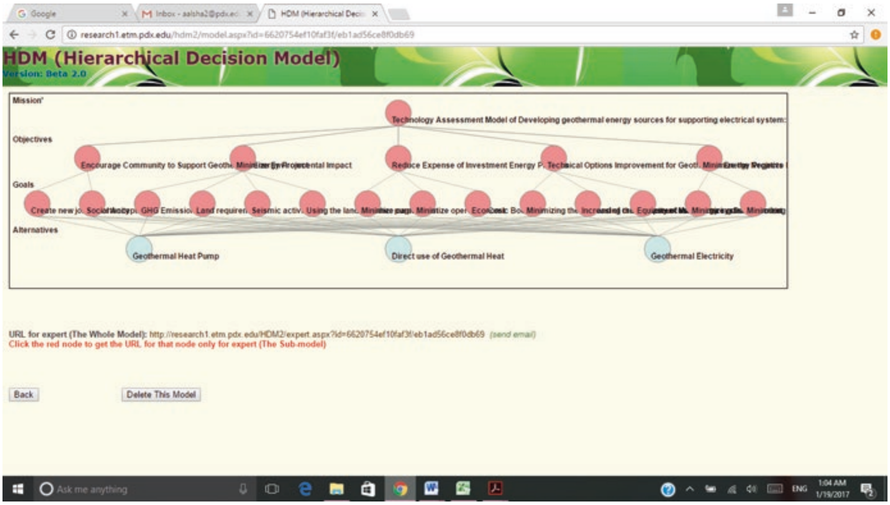
Dear ……..,

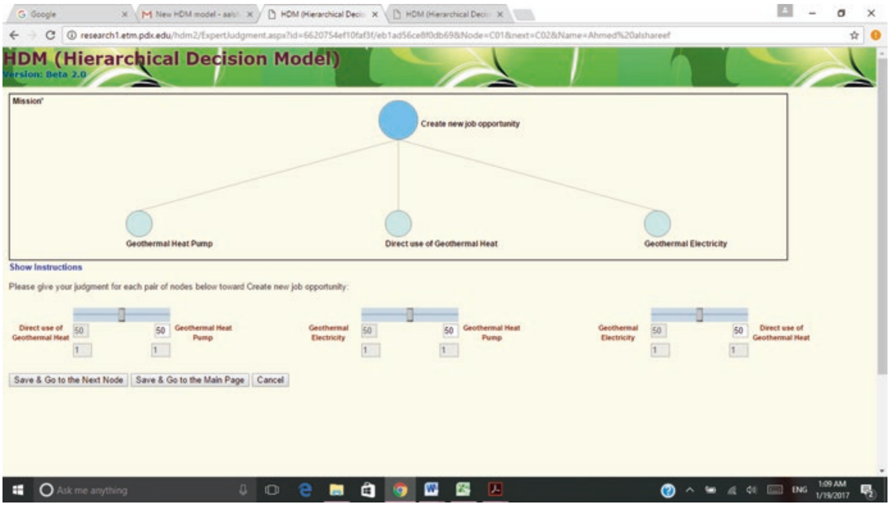
Thank you so much for accepting the invitation to complete the survey for my thesis research (Technology Assessment Model of Developing Geothermal Energy Resource for Supporting Electrical System). I have attached the link of the survey, the instructions, and the explanation of the research. You can see the details of each node in the model of the survey by pointing your cursor over the node. Each node had been explained in the instruction document.

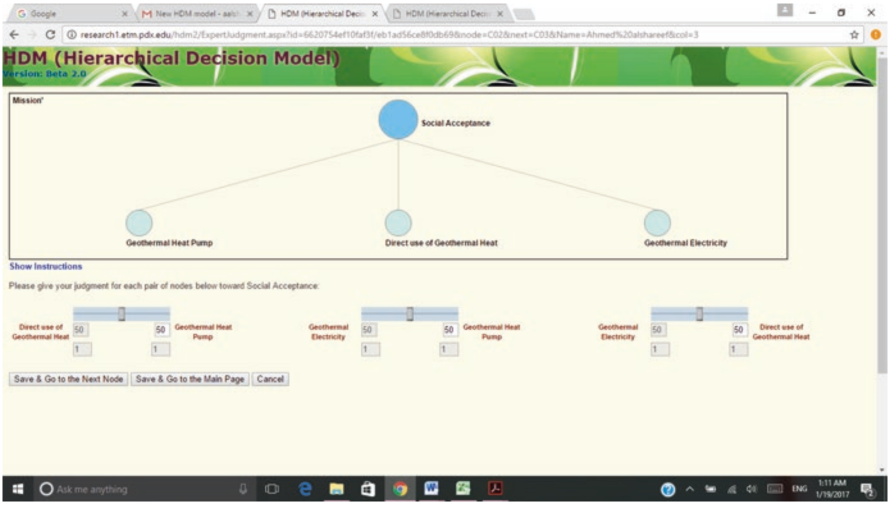
Thank you very much.
Sincerely,
Ahmed Alshareef
M.S. Student
Department of Engineering and Technology Management
Portland State University

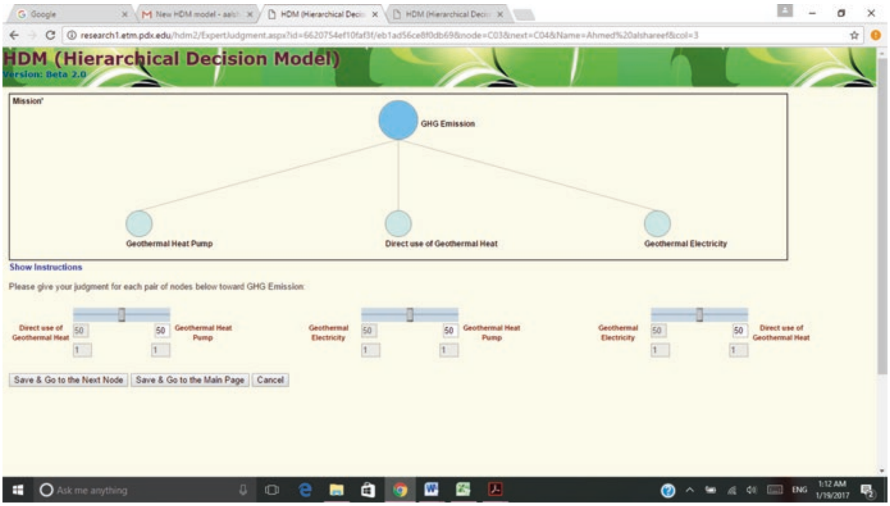
Appendix A4: Content Questionnaire Survey

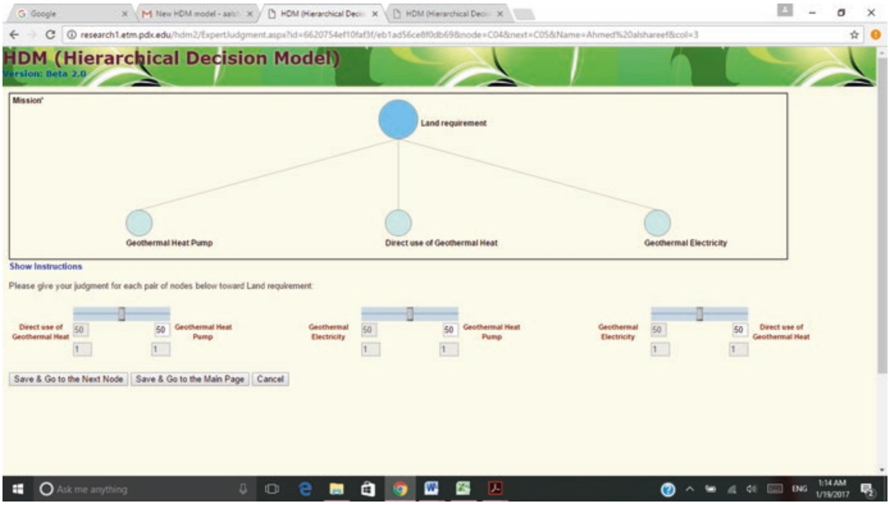


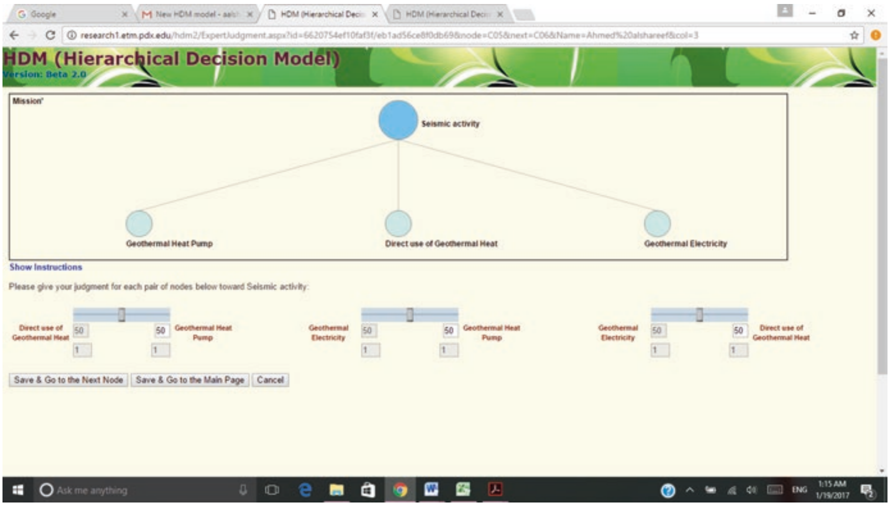

HDM (Hierarchical Decision Model)
Version: Beta 2.0
Mission
Objectives
Goals
Alternatives
Technology Assessment Model of Developing geothermal energy sources for supporting electrical system
Geothermal Heat Pump
Direct use of Geothermal Heat
Geothermal Electricity
Click the red node to get the URL for that node only for expert (The Sub-model)
Back
Delete This Model

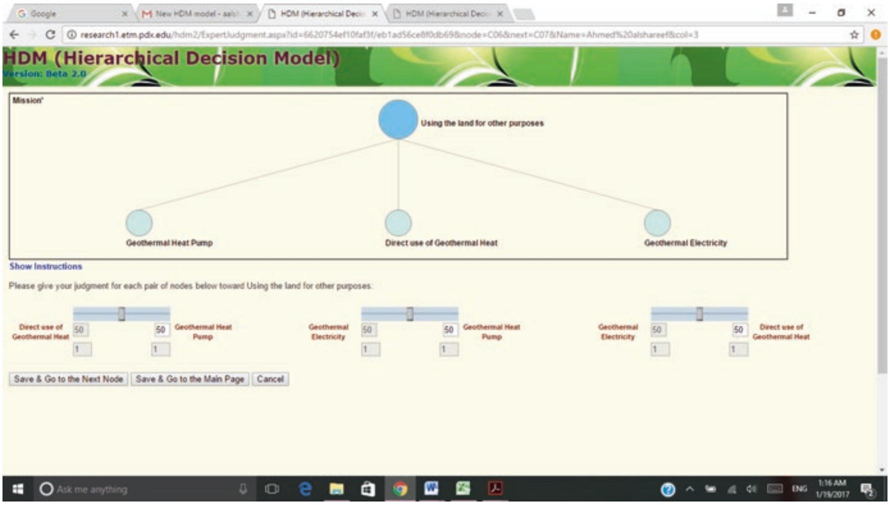

HDM (Hierarchical Decision Model)
Version: Beta 2.0
Mission
Create new job opportunity
Geothermal Heat Pump
Direct use of Geothermal Heat
Geothermal Electricity
Show Instructions
Please give your judgment for each pair of nodes below toward Create new job opportunity:
Save & Go to the Next Node
Save & Go to the Main Page
Cancel

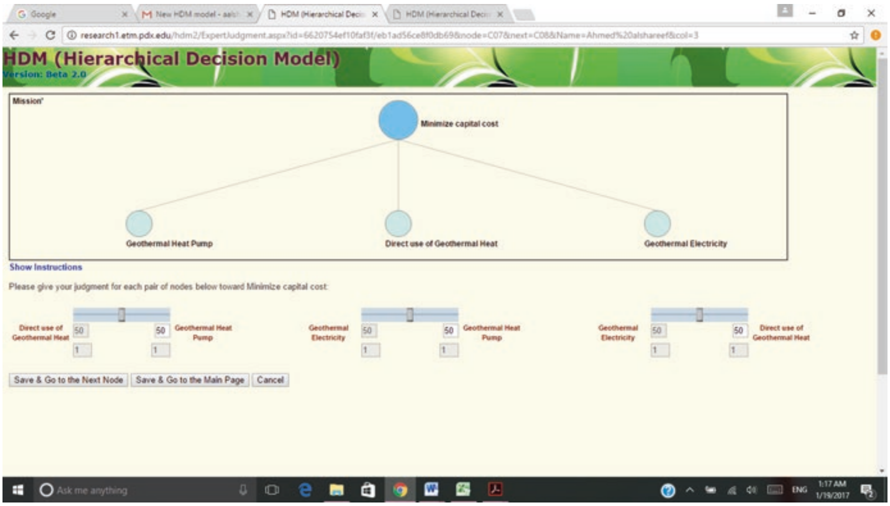

HDM (Hierarchical Decision Model)
Version: Beta 2.0
Mission
Social Acceptance
Geothermal Heat Pump
Direct use of Geothermal Heat
Geothermal Electricity
Show Instructions
Please give your judgment for each pair of nodes below toward Social Acceptance:
Direct use of Geothermal Heat
Geothermal Heat Pump
Geothermal Electricity
Geothermal Heat Pump
Geothermal Electricity
Direct use of Geothermal Heat
Save & Go to the Next Node
Save & Go to the Main Page
Cancel

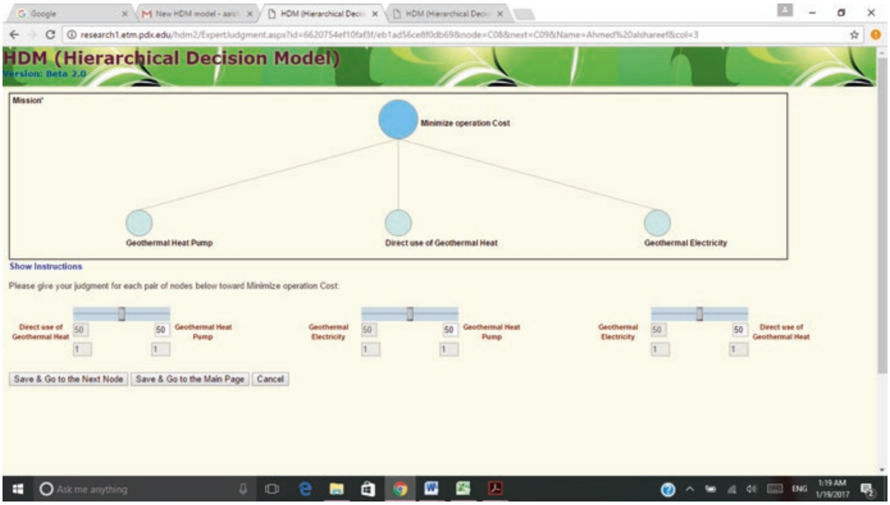

HDM (Hierarchical Decision Model)
Version: Beta 2.0
Mission
GHG Emission
Geothermal Heat Pump
Direct use of Geothermal Heat
Geothermal Electricity
Show Instructions
Please give your judgment for each pair of nodes below toward GHG Emission:
Direct use of Geothermal Heat
Geothermal Heat Pump
Geothermal Electricity
Geothermal Heat Pump
Geothermal Electricity
Direct use of Geothermal Heat
Save & Go to the Next Node
Save & Go to the Main Page
Cancel

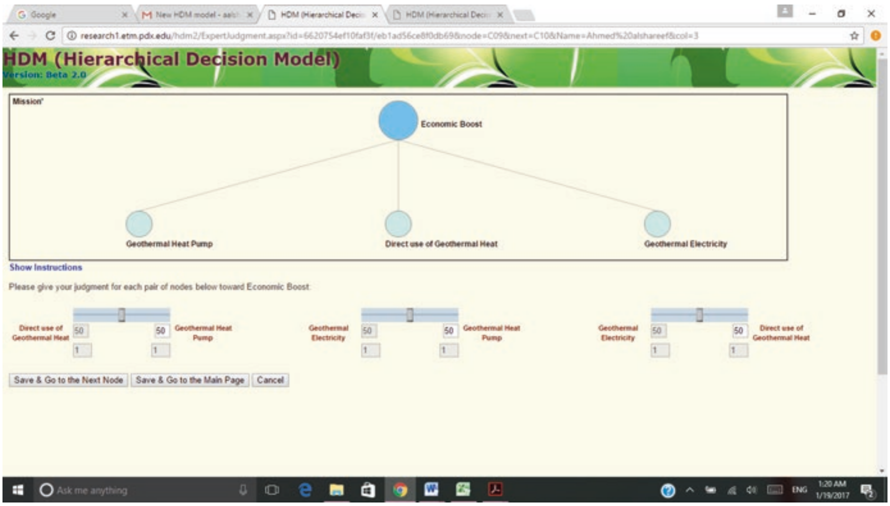

HDM (Hierarchical Decision Model)
Version: Beta 2.0
Mission
Land requirement
Geothermal Heat Pump
Direct use of Geothermal Heat
Geothermal Electricity
Show Instructions
Please give your judgment for each pair of nodes below toward Land requirement
Direct use of Geothermal Heat
Geothermal Heat Pump
Geothermal Electricity
Save & Go to the Next Node
Save & Go to the Main Page
Cancel

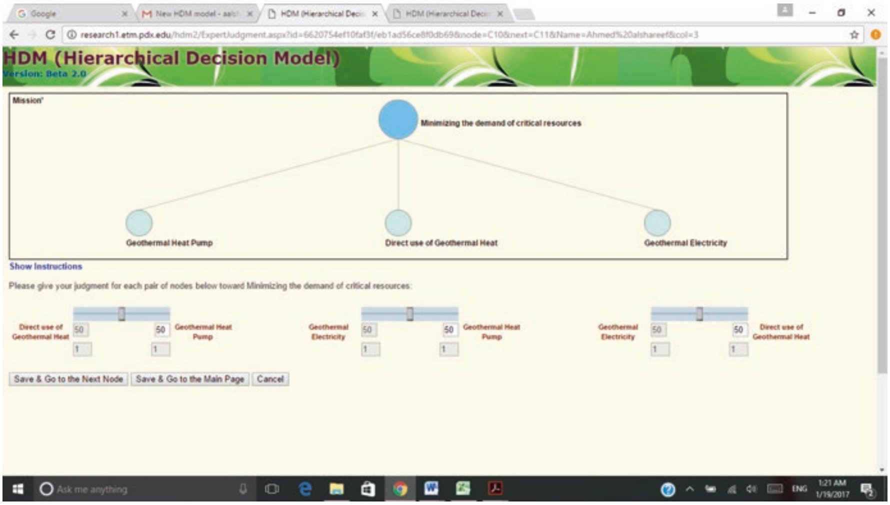

HDM (Hierarchical Decision Model)
Version: Beta 2.0
Mission
Seismic activity
Geothermal Heat Pump
Direct use of Geothermal Heat
Geothermal Electricity
Show Instructions
Please give your judgment for each pair of nodes below toward Seismic activity
Direct use of Geothermal Heat
Geothermal Heat Pump
Geothermal Electricity
Save & Go to the Next Node
Save & Go to the Main Page
Cancel

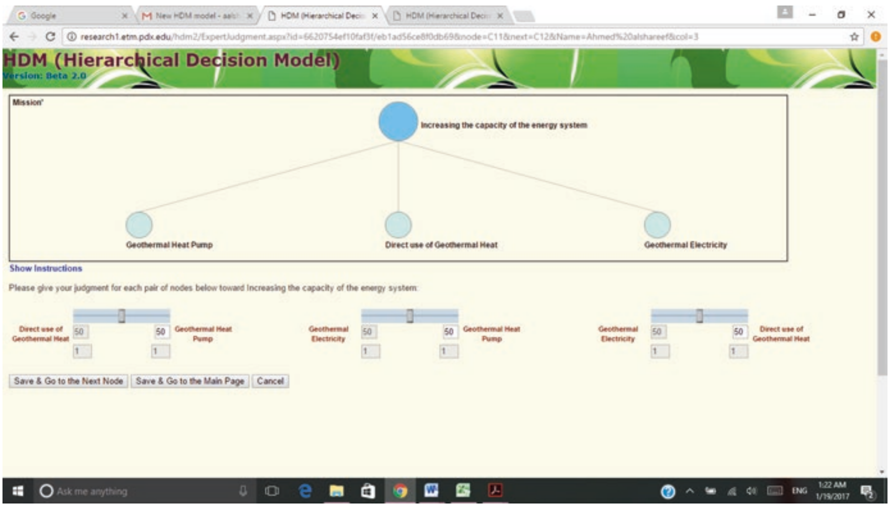

HDM (Hierarchical Decision Model)
Version: Beta 2.0
Mission'
Using the land for other purposes
Geothermal Heat Pump
Direct use of Geothermal Heat
Geothermal Electricity
Show Instructions
Please give your judgment for each pair of nodes below toward Using the land for other purposes:
Direct use of Geothermal Heat
Geothermal Heat Pump
Geothermal Electricity
Geothermal Heat Pump
Geothermal Electricity
Direct use of Geothermal Heat
Save & Go to the Next Node
Save & Go to the Main Page
Cancel

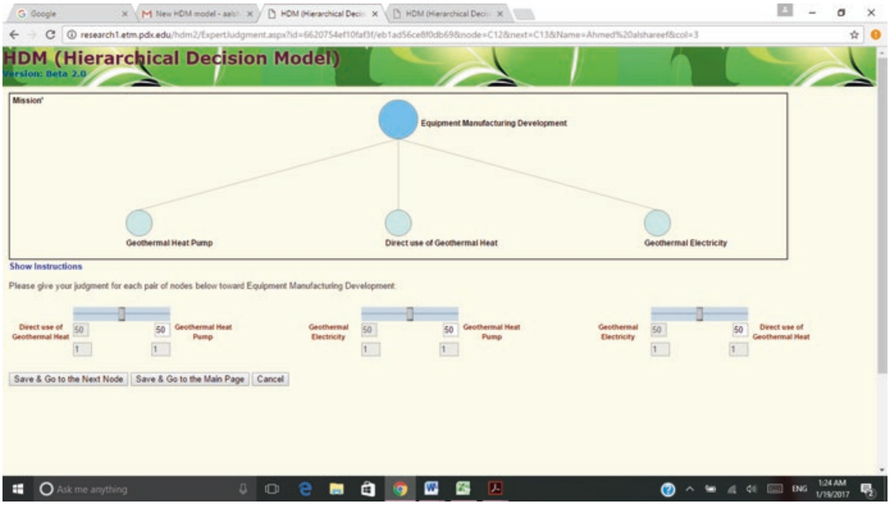

HDM (Hierarchical Decision Model)
Version: Beta 2.0
Mission'
Minimize capital cost
Geothermal Heat Pump
Direct use of Geothermal Heat
Geothermal Electricity
Show Instructions
Please give your judgment for each pair of nodes below toward Minimize capital cost:
Direct use of Geothermal Heat
Geothermal Heat Pump
Geothermal Electricity
Geothermal Heat Pump
Geothermal Electricity
Direct use of Geothermal Heat
Save & Go to the Next Node
Save & Go to the Main Page
Cancel

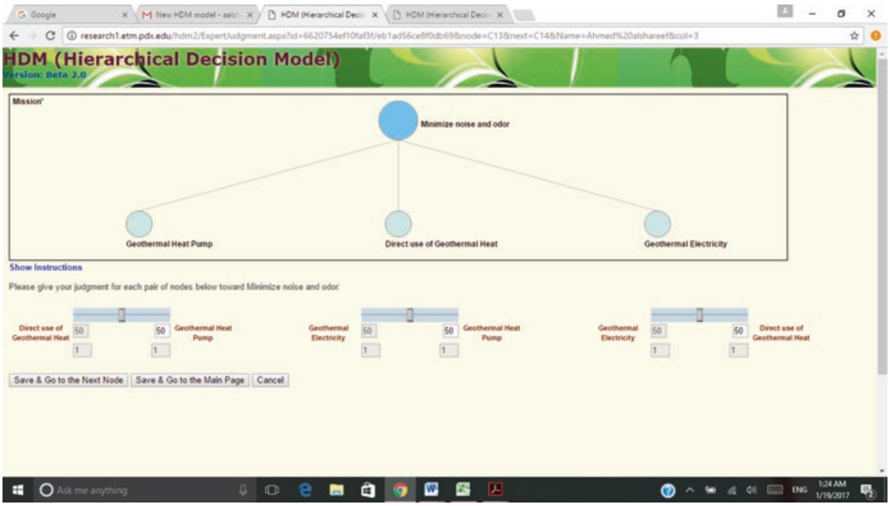

HDM (Hierarchical Decision Model)
Mission
Minimize operation Cost
Geothermal Heat Pump
Direct use of Geothermal Heat
Geothermal Electricity
Show Instructions
Please give your judgment for each pair of nodes below toward Minimize operation Cost
Direct use of Geothermal Heat
Geothermal Heat Pump
Geothermal Electricity
Geothermal Heat Pump
Geothermal Electricity
Direct use of Geothermal Heat
Save & Go to the Next Node
Save & Go to the Main Page
Cancel

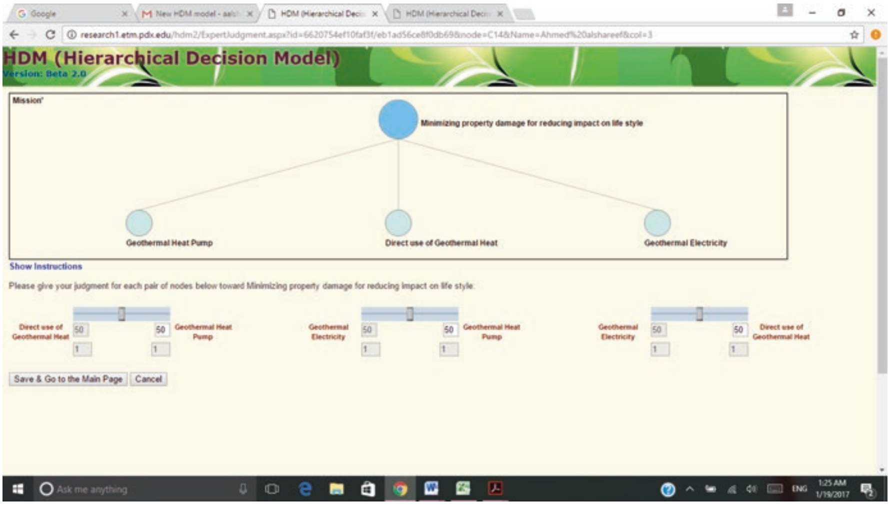

HDM (Hierarchical Decision Model)
Mission
Economic Boost
Geothermal Heat Pump
Direct use of Geothermal Heat
Geothermal Electricity
Show Instructions
Please give your judgment for each pair of nodes below toward Economic Boost
Direct use of Geothermal Heat
Geothermal Heat Pump
Geothermal Electricity
Geothermal Heat Pump
Geothermal Electricity
Direct use of Geothermal Heat
Save & Go to the Next Node
Save & Go to the Main Page
Cancel

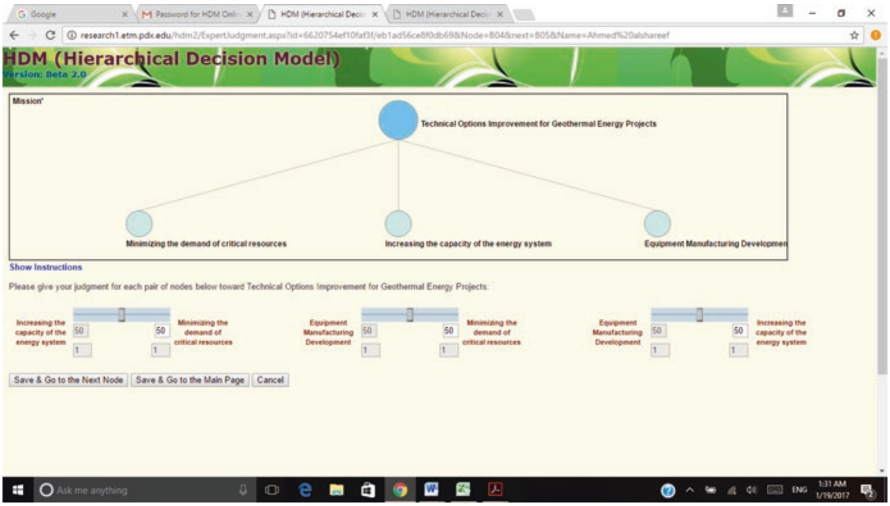

HDM (Hierarchical Decision Model)
Version: Beta 2.0
Mission
Minimizing the demand of critical resources
Geothermal Heat Pump
Direct use of Geothermal Heat
Geothermal Electricity
Show Instructions
Please give your judgment for each pair of nodes below toward Minimizing the demand of critical resources:
Direct use of Geothermal Heat
Geothermal Heat Pump
Geothermal Electricity
Save & Go to the Next Node
Save & Go to the Main Page
Cancel

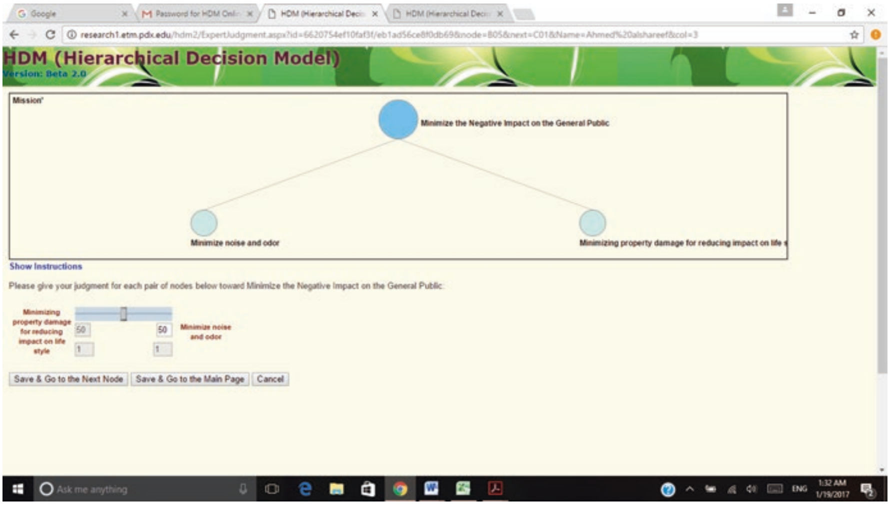

HDM (Hierarchical Decision Model)
Version: Beta 2.0
Mission
Increasing the capacity of the energy system
Geothermal Heat Pump
Direct use of Geothermal Heat
Geothermal Electricity
Show Instructions
Please give your judgment for each pair of nodes below toward Increasing the capacity of the energy system:
Direct use of Geothermal Heat
Geothermal Heat Pump
Geothermal Electricity
Save & Go to the Next Node
Save & Go to the Main Page
Cancel

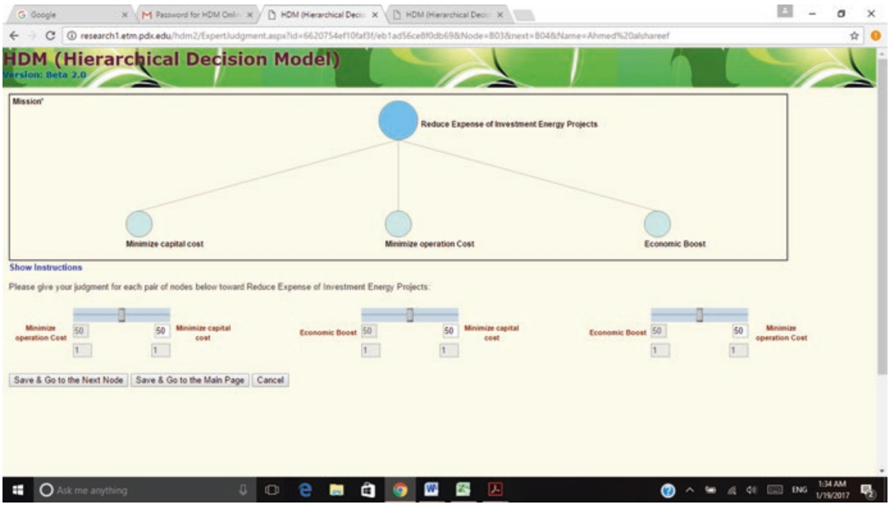

HDM (Hierarchical Decision Model)
Version: Beta 2.0
Mission
Equipment Manufacturing Development
Geothermal Heat Pump
Direct use of Geothermal Heat
Geothermal Electricity
Show Instructions
Please give your judgment for each pair of nodes below toward Equipment Manufacturing Development
Direct use of Geothermal Heat
Geothermal Heat Pump
Geothermal Electricity
Geothermal Heat Pump
Geothermal Electricity
Direct use of Geothermal Heat
Save & Go to the Next Node
Save & Go to the Main Page
Cancel

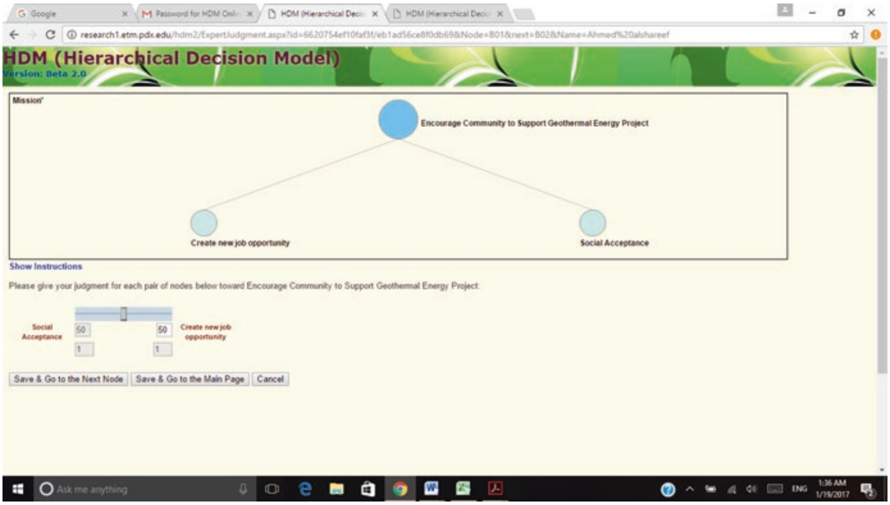

HDM (Hierarchical Decision Model)
Version: Beta 2.0
Mission
Minimize noise and odor
Geothermal Heat Pump
Direct use of Geothermal Heat
Geothermal Electricity
Show Instructions
Please give your judgment for each pair of nodes below toward Minimize noise and odor
Direct use of Geothermal Heat
Geothermal Heat Pump
Geothermal Electricity
Geothermal Heat Pump
Geothermal Electricity
Direct use of Geothermal Heat
Save & Go to the Next Node
Save & Go to the Main Page
Cancel

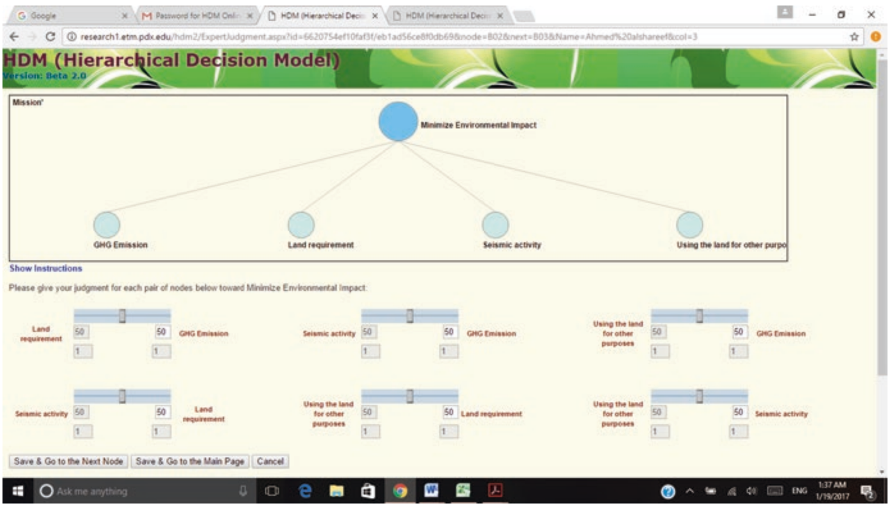

HDM (Hierarchical Decision Model)
Version: Beta 2.0
Mission
Minimizing property damage for reducing impact on life style
Geothermal Heat Pump
Direct use of Geothermal Heat
Geothermal Electricity
Show Instructions
Please give your judgment for each pair of nodes below toward Minimizing property damage for reducing impact on life style
Direct use of Geothermal Heat
Geothermal Heat Pump
Geothermal Electricity
Geothermal Heat Pump
Geothermal Electricity
Direct use of Geothermal Heat
Save & Go to the Main Page
Cancel


HDM (Hierarchical Decision Model)
Version: Beta 2.0
Mission
Technical Options Improvement for Geothermal Energy Projects
Minimizing the demand of critical resources
Increasing the capacity of the energy system
Equipment Manufacturing Developmen
Show Instructions
Please give your judgment for each pair of nodes below toward Technical Options Improvement for Geothermal Energy Projects
Increasing the capacity of the energy system
Minimizing the demand of critical resources
Equipment Manufacturing Development
Minimizing the demand of critical resources
Equipment Manufacturing Development
Increasing the capacity of the energy system
Save & Go to the Next Node
Save & Go to the Main Page
Cancel


HDM (Hierarchical Decision Model)
Version: Beta 2.0
Mission
Minimize the Negative Impact on the General Public
Minimize noise and odor
Minimizing property damage for reducing impact on life s
Show Instructions
Please give your judgment for each pair of nodes below toward Minimize the Negative Impact on the General Public:
Minimizing property damage for reducing impact on life style
50
50
Minimize noise and odor
1
1
Save & Go to the Next Node
Save & Go to the Main Page
Cancel

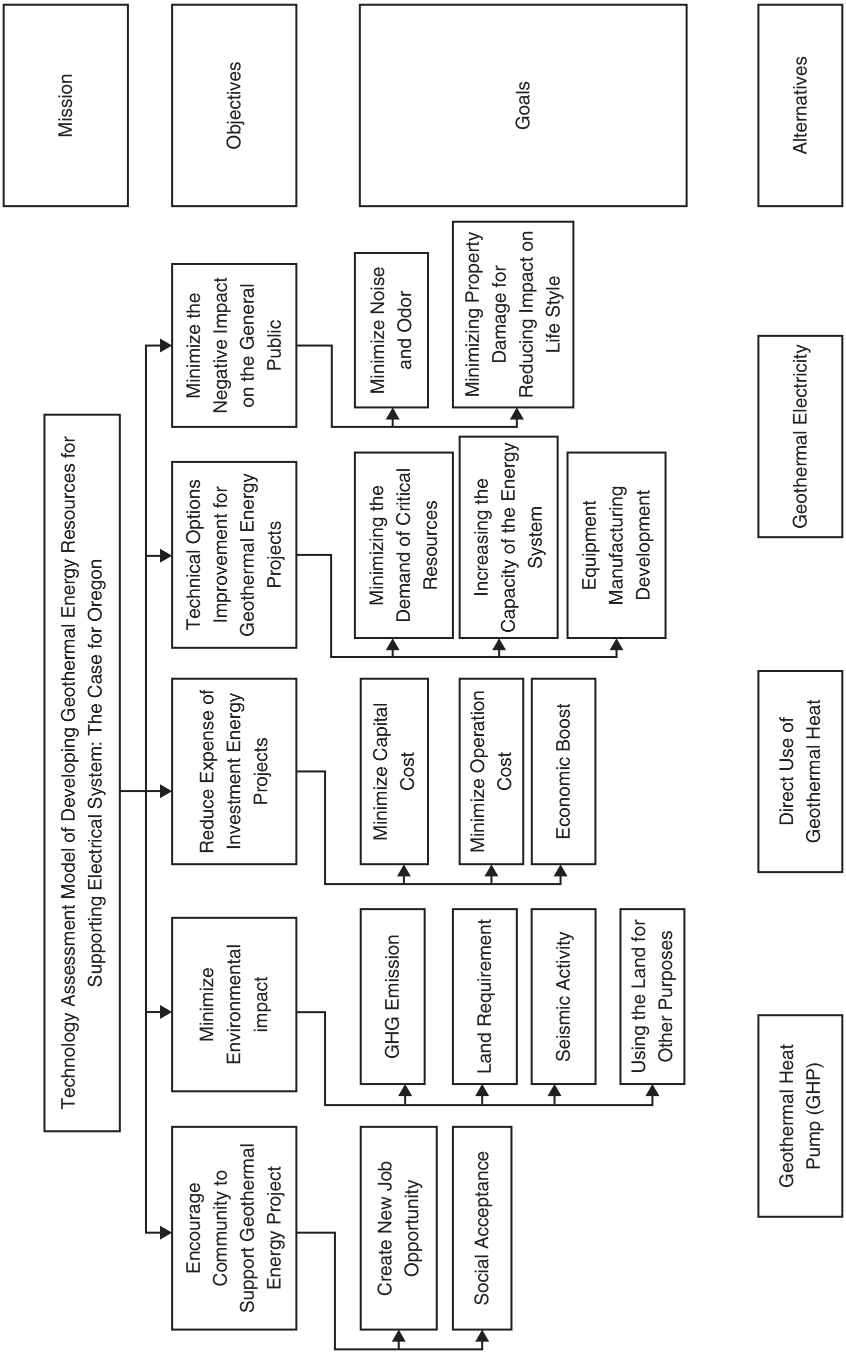

HDM (Hierarchical Decision Model)
Version: Beta 2.0
Mission
Reduce Expense of Investment Energy Projects
Minimize capital cost
Minimize operation Cost
Economic Boost
Show Instructions
Please give your judgment for each pair of nodes below toward Reduce Expense of Investment Energy Projects:
Minimize operation Cost
Minimize capital cost
Economic Boost
Minimize capital cost
Economic Boost
Minimize operation Cost
Save & Go to the Next Node
Save & Go to the Main Page
Cancel





Appendix A5: Content Instructions and Explanation of Nodes

The figure below shows the proposed research model. This figure will be used to establish the weight of each element and analyze the model.


Mission
Objectives
Goals
Alternatives
Technology Assessment Model of Developing Geothermal Energy Resources for Supporting Electrical System: The Case for Oregon
Minimize the Negative Impact on the General Public
Technical Options Improvement for Geothermal Energy Projects
Reduce Expense of Investment Energy Projects
Minimize Environmental impact
Encourage Community to Support Geothermal Energy Project
Minimize Noise and Odor
Minimizing Property Damage for Reducing Impact on Life Style
Minimizing the Demand of Critical Resources
Increasing the Capacity of the Energy System
Equipment Manufacturing Development
Minimize Capital Cost
Minimize Operation Cost
Economic Boost
GHG Emission
Land Requirement
Seismic Activity
Using the Land for Other Purposes
Create New Job Opportunity
Social Acceptance
Geothermal Electricity
Direct Use of Geothermal Heat
Geothermal Heat Pump (GHP)

Based on a comprehensive literature review and by validating the proposed research model with my advisor Dr. Tugrul U. Daim, this research model will be used for asking experts to establish their weighted output relative to geothermal energy resources. The data collection will be created from this research model to establish the final results of this study.

All the development of the proposed research model will stay in the same frame of the human subject research, and it will not change the HSRRC application. In addition, the goal and objective of the research will be kept from any change.

The objective of the proposed research is to develop the assessment model framework that can be used for supporting cost-effective renewable energy in Oregon by the development of geothermal energy sources. A mission-oriented model, hierarchical decision-making (HDM), will be used to determine the goal that represents the case for Oregon.

HDM is the approach that will be used for analyzing the research objective and criteria used to inform decision about how to inform geothermal energy since HDM works with complicated processes and looks at the problem from different perspectives. All the development occurred to the proposed research model works through criteria, sub-criteria, and alternatives, and this research model comes from a comprehensive review of literature.

The purpose of the data collection is to ensure the relative importance of decision elements through a numerical quantification process. Using the pairwise comparison method between two elements to evaluate distributional balance is necessary in order to know which element is more important than another. A pairwise comparison will use 100 points scale to make the balance. Defining each element will be clarified below.

Encourage community to support geothermal energy project: Using geothermal energy project will make future customer life easier and more convenient; the result of using these geothermal energy projects will encourage customers to support geothermal projects. Also, it will increase the adoption and development of geothermal energy.

Minimize environmental impact: Using geothermal energy will have a positive impact on the environment since it does not consume a huge amount of fuel.

Reduce expense of investment energy projects: Different technologies that accompany geothermal energy resources will change the expenses of investment if more attention and effort are given to this area of alternative energy.

Technical option improvement for geothermal energy projects: There is a possibility to develop the process in the future by quickly responding to any changes in the market and in the requirements of customers.

Minimize the negative impact on the general public: Reducing the negative impact on the general public and public spaces ensures that these geothermal projects do not interact with other projects in the same area.

Create new job opportunity: When geothermal energy resources are constructed, this construction will require a diversity of skills to complete.

Social acceptance: The continued commitment to expand and improve federal lands for the use of geothermal resources will lead to an increase in production.

GHG emissions: Due to lower GHG emissions, geothermal energy projects have less impact on the environment compared with other sources of energy.

Land requirement: Geothermal fields require fewer acres compared with other sources of energy.

Seismic activity: While the extraction of geothermal energy can lead to seismic activity, this event would most likely be less than magnitude of 2.5 on the Richter scale (earthquakes usually cannot be felt under 3.5).

Using the land for other purposes: When the activity of a power plant is completed, the land can be rehabilitated and used for livestock grazing or other agriculture purposes.

Minimize the capital cost: Projects of geothermal energy resources have the potential to reduce the cost of investments if the investments are made over a long period.

Minimize operation cost: Geothermal projects can increase the energy production and reduce the cost.

Economy boost: "Geothermal projects have the potential to enhance the economies through increased tax revenues, the creation of new businesses and local jobs, and enhanced community involvement" [321].

Minimizing the demand of critical resources: Geothermal projects reduce the demand on traditional resources like oil, coal, and natural gas.

Increasing the capacity of the energy system: Using geothermal energy resources will minimize the load on the electrical system and will simplify the challenges associated with increased energy load.

Equipment manufacturing development: In spite of the variety of geothermal energy equipment in the market, this equipment still needs more development to increase the geothermal energy efficiency, and for that technologies will need to be developed to be used in the manufacturing of this equipment.

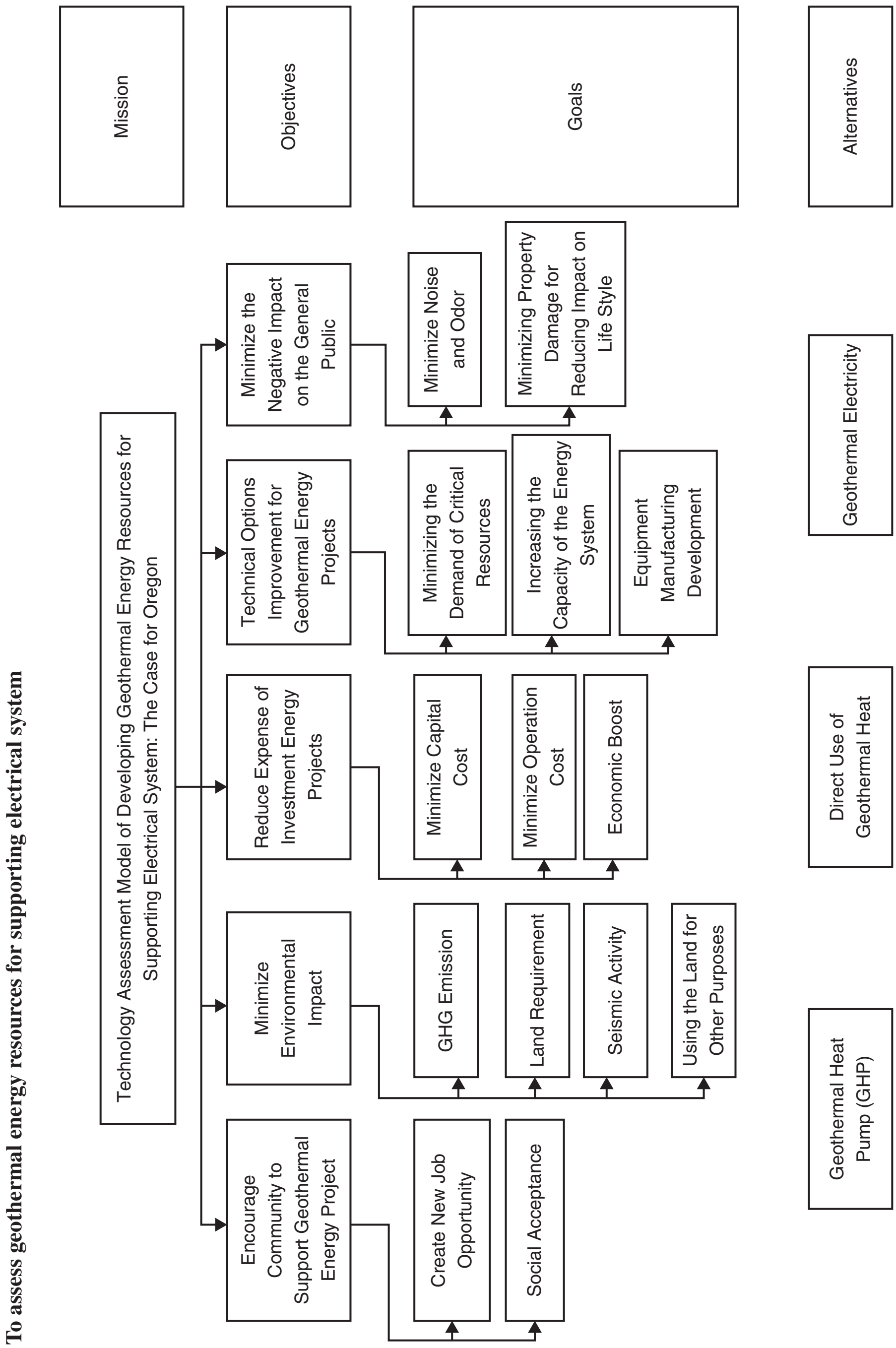
Minimize noise and odor: It is important for geothermal energy projects to work without negatively impacting the general public by avoiding and reducing noise and odor as quickly as possible.

Minimizing property damage for reducing impact on lifestyle: It is important for geothermal energy projects to minimize the routes to and from the site to avoid any conflicts or obstacles to the movement of residential and commercial activities.

Geothermal heat pump: "Is a central heating and/or cooling system that transfers heat to or from the ground. Geothermal heat pumps use the natural insulating properties of the earth from just a few feet underground to as much as several 100 feet deep, offering a unique and highly efficient renewable energy technology for heating and cooling" [322].

Direct use of geothermal heat: "refers to the immediate use of the energy for both heating and cooling applications. It is the use of underground hot water to heat buildings, …and for many other applications. District heating applications use networks of piped hot water to heat buildings in whole communities" [323].

Geothermal electricity: "Geothermal power plants use steam produced from reservoirs of hot water found a few miles or more below the Earth's surface to produce electricity. The extremely high temperatures in the deeper geothermal reservoirs are used for the generation of electricity. The steam rotates a turbine that activates a generator, which produces electricity" [324].


To assess geothermal energy resources for supporting electrical system
Mission
Objectives
Goals
Alternatives
Technology Assessment Model of Developing Geothermal Energy Resources for Supporting Electrical System: The Case for Oregon
Encourage Community to Support Geothermal Energy Project
Minimize Environmental Impact
Reduce Expense of Investment Energy Projects
Technical Options Improvement for Geothermal Energy Projects
Minimize the Negative Impact on the General Public
Create New Job Opportunity
Social Acceptance
GHG Emission
Land Requirement
Seismic Activity
Using the Land for Other Purposes
Minimize Capital Cost
Minimize Operation Cost
Economic Boost
Minimizing the Demand of Critical Resources
Increasing the Capacity of the Energy System
Equipment Manufacturing Development
Minimize Noise and Odor
Minimizing Property Damage for Reducing Impact on Life Style
Geothermal Heat Pump (GHP)
Direct Use of Geothermal Heat
Geothermal Electricity

The mission of this model is to assess geothermal energy resources for supporting the electrical system. This process will require weighting objectives, criteria, and alternatives. A pairwise comparison is required for this purpose to rate criteria (objectives) with respect to each other. As the model is built based on HDM, "a pairwise comparison helps you work out the importance of a number of options relative to one another. This makes it easy to choose the most important problem to solve, or to pick the solution that will be most effective. It also helps you set priorities where there are conflicting demands on your resources. The tool is particularly useful when you don't have objective data to use to make your decision" [325]. This process for technology assessment model of developing geothermal energy resources requires having a scale with 100 points distributed between these main criteria. The criteria with high points result from experts choosing this criterion, while the criteria with low points result from few experts choosing this criterion. Also, the score of 0 will not be valid and the score for this situation must be at least 1 point.

This is an example of how to weight, evaluate, and compare:

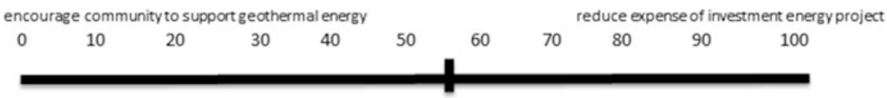
Considering two objectives, "Objective *A*" and "Objective "*B*," choose the point value that you think is necessary. Since the system is based on 100 points, this can be weighted as *A* = 55 and *B* = 45.

1.1 100 points must be distributed between the following pairs of geothermal energy objectives to reflect your judgment on their relative importance to the overall goal for this study.

The importance of encouraging community to support geothermal energy to minimize the environment impact:

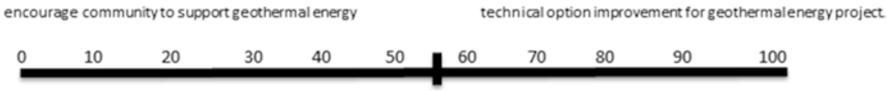
1.2 100 points must be distributed between the following pairs of geothermal energy objectives to reflect your judgment on their relative importance to the overall goal for this study.

The importance of encouraging community to support geothermal energy to reduce expense of investment energy project:



1.3 100 points must be distributed between the following pairs of geothermal energy objectives to reflect your judgment on their relative importance to the overall goal for this study.

The importance of encouraging community to support geothermal energy to technical option improvement for geothermal energy project:

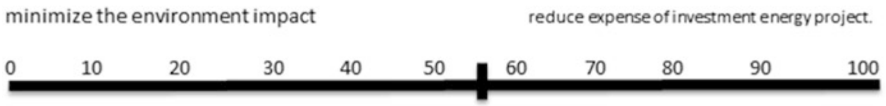


1.4 100 points must be distributed between the following pairs of geothermal energy objectives to reflect your judgment on their relative importance to the overall goal for this study.

The importance of encouraging community to support geothermal energy to minimize the negative impact on general public:

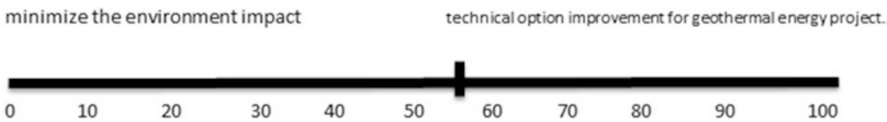
1.5 100 points must be distributed between the following pairs of geothermal energy objectives to reflect your judgment on their relative importance to the overall goal for this study.

The importance of minimizing the environment impact to reduce expense of investment energy project:



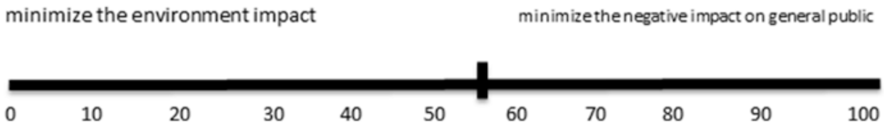
1.6 100 points must be distributed between the following pairs of geothermal energy objectives to reflect your judgment on their relative importance to the overall goal for this study.

The importance of minimizing the environment impact to technical option improvement for geothermal energy project:



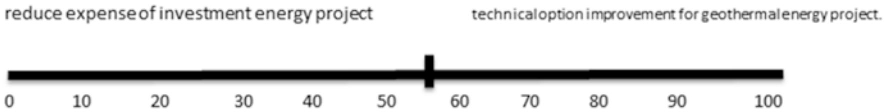
1.7 100 points must be distributed between the following pairs of geothermal energy objectives to reflect your judgment on their relative importance to the overall goal for this study.

The importance of minimizing the environment impact to minimize the negative impact on general public:



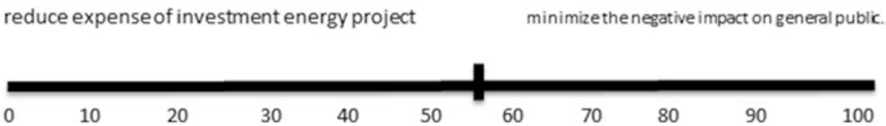
1.8 100 points must be distributed between the following pairs of geothermal energy objectives to reflect your judgment on their relative importance to the overall goal for this study.

The importance of reducing expense of investment energy project to technical option improvement for geothermal energy project:



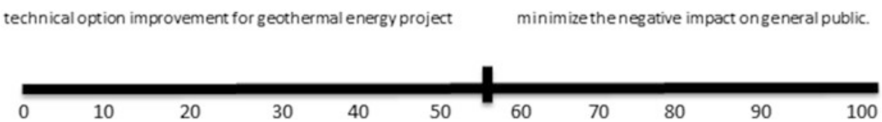
1.9 100 points must be distributed between the following pairs of geothermal energy objectives to reflect your judgment on their relative importance to the overall goal for this study.

The importance of reducing expense of investment energy project to minimize the negative impact on general public:



1.10 100 points must be distributed between the following pairs of geothermal energy objectives to reflect your judgment on their relative importance to the overall goal for this study.

The importance of technical option improvement for geothermal energy project to minimize the negative impact on general public:



Appendix B: Judgment Quantifications

Appendix B1: Judgment Quantification for the Objectives Level with Respect to the Mission

The table below shows the ratio of judgment quantification, as explained in the example: using CS 70 and IC 30, this will be written as CS/IC = 70, and 30 will not appear in the table.

Encourage community to support geothermal energy projects, CS
Minimize environmental impact, EI
Minimize investment cost, IC
Technical option improvement for geothermal energy projects, TI
Minimize the negative impact on the general public, NI

	CS/EI	CS/IC	CS/TI	CS/NI	EI/IC	EI/TI	EI/NI	IC/TI	IC/NI	TI/NI
Expert 1	50	50	50	50	40	40	60	50	75	75
Expert 2	42	42	18	42	46	50	44	35	60	63
Expert 3	10	55	75	40	80	75	80	20	20	49
Expert 4	18	21	58	50	71	74	86	65	39	60
Expert 5	50	50	70	70	20	20	70	50	70	80
Expert 6	59	50	32	51	41	62	34	89	52	18
Expert 7	70	35	80	45	50	75	35	40	45	20

Appendix B2: Judgment Quantification for the Goals Level with Respect to Objectives

The table below shows the ratio of judgment quantification, as explained in the example: using JO 70 and SC 30, this will be written as JO/SC = 70, and 30 will not appear in the table.

Encourage Community to Support Geothermal Energy Projects

Create new job opportunity: JO
Social acceptance: SC

	JO/SC
Expert 1	60
Expert 2	40
Expert 3	70
Expert 4	12
Expert 5	90
Expert 6	67
Expert 7	75

Minimize Environmental Impact

GHG emission: GE
Land requirement: LR
Seismic activity: SA
Using the land for other purposes: UL

	GE/LR	GE/SA	GE/UL	LR/SA	LR/UL	SA/UL
Expert 1	50	75	75	75	75	50
Expert 2	72	55	78	50	32	63
Expert 3	99	50	90	10	40	50
Expert 4	70	10	75	10	45	80
Expert 5	50	80	60	89	20	10
Expert 6	43	22	16	29	50	71
Expert 7	5	30	85	15	50	85

Reduce Expense of Investment Energy Projects

Minimize capital cost: CC
Minimize operation cost: OC
Economic boost: EB

	CC/OC	CC/EB	OC/EB
Expert 1	50	80	80
Expert 2	58	84	66
Expert 3	70	25	20
Expert 4	80	95	95
Expert 5	95	90	70
Expert 6	50	50	50
Expert 7	65	60	75

Technical Option Improvement for Geothermal Energy Projects

Minimizing the demand of critical resources: CR
Increasing the capacity of energy system: CS
Equipment manufacturing development: ED

	CR/CS	CR/ED	CS/ED
Expert 1	40	50	60
Expert 2	35	15	31
Expert 3	90	70	20
Expert 4	50	80	95
Expert 5	25	50	70
Expert 6	31	38	66
Expert 7	25	30	25

Minimize the Negative Impact on the General Public

Minimize noise and odor: NO
Minimizing property damage for reducing impact on lifestyle: PD

	NO/PD
Expert 1	50
Expert 2	66
Expert 3	80
Expert 4	75
Expert 5	99
Expert 6	50
Expert 7	90

Appendix B3: Judgment Quantification for the Alternatives Level with Respect to Goals

The table below shows the ratio of judgment quantification, as explained in the example: using GE 70 and DH 30, this will be written as GE/DH=70, and 30 will not appear in the table.

Geothermal electricity: GE
Direct use of geothermal heat: DH
Geothermal heat pump: GH

Alternatives: create new job opportunity

	GH/DH	GH/GE	DH/GE
Expert 1	60	40	25
Expert 2	29	71	91
Expert 3	65	40	39
Expert 4	65	35	30
Expert 5	90	10	5
Expert 6	50	50	50
Expert 7	20	15	50

Alternatives: social acceptance

	GH/DH	GH/GE	DH/GE
Expert 1	60	60	50
Expert 2	30	48	77
Expert 3	30	40	56
Expert 4	60	50	20
Expert 5	50	20	10
Expert 6	50	50	50

	GH/DH	GH/GE	DH/GE
Expert 7	50	50	50

Alternatives: GHG emission

	GH/DH	GH/GE	DH/GE
Expert 1	50	35	35
Expert 2	42	67	68
Expert 3	25	85	70
Expert 4	70	50	30
Expert 5	80	10	1
Expert 6	50	50	50
Expert 7	50	50	50

Alternatives: land requirement

	GH/DH	GH/GE	DH/GE
Expert 1	50	50	50
Expert 2	53	65	51
Expert 3	50	25	40
Expert 4	70	50	70
Expert 5	80	13	5
Expert 6	50	50	50
Expert 7	10	10	10

Alternatives: seismic activity

	GH/DH	GH/GE	DH/GE
Expert 1	75	90	75
Expert 2	45	62	69
Expert 3	49	50	50
Expert 4	50	50	50
Expert 5	50	50	50
Expert 6	50	50	50
Expert 7	5	5	50

Alternatives: using the land for other purposes

	GH/DH	GH/GE	DH/GE
Expert 1	50	50	50
Expert 2	50	35	35
Expert 3	60	70	60
Expert 4	75	50	20
Expert 5	50	20	10
Expert 6	50	50	50
Expert 7	10	5	50

Alternatives: minimize capital cost

	GH/DH	GH/GE	DH/GE
Expert 1	40	40	50
Expert 2	22	22	72
Expert 3	60	30	20
Expert 4	40	70	70
Expert 5	50	20	10
Expert 6	50	50	50
Expert 7	30	30	35

Alternatives: minimize operation cost

	GH/DH	GH/GE	DH/GE
Expert 1	50	50	50
Expert 2	37	26	54
Expert 3	61	25	20
Expert 4	30	50	60
Expert 5	75	10	5
Expert 6	50	50	50
Expert 7	35	20	30

Alternatives: economic boost

	GH/DH	GH/GE	DH/GE
Expert 1	50	25	25
Expert 2	30	33	64
Expert 3	65	60	60
Expert 4	65	50	30
Expert 5	50	40	30
Expert 6	50	50	50
Expert 7	10	5	40

Alternatives: minimizing the demand of critical resources

	GH/DH	GH/GE	DH/GE
Expert 1	50	50	50
Expert 2	50	67	68
Expert 3	30	60	80
Expert 4	50	15	15
Expert 5	50	40	25
Expert 6	50	50	50
Expert 7	30	30	50

Alternatives: increasing the capacity of the energy system

	GH/DH	GH/GE	DH/GE
Expert 1	40	20	25
Expert 2	50	63	63
Expert 3	50	30	15
Expert 4	50	30	20
Expert 5	80	1	1
Expert 6	50	50	50
Expert 7	50	50	50

Alternatives: equipment manufacturing development

	GH/DH	GH/GE	DH/GE
Expert 1	25	10	25
Expert 2	26	28	54
Expert 3	60	40	30
Expert 4	70	50	35
Expert 5	70	30	1
Expert 6	50	50	50
Expert 7	50	5	15

Alternatives: minimize noise and odor

	GH/DH	GH/GE	DH/GE
Expert 1	50	10	10
Expert 2	43	65	76
Expert 3	55	30	30
Expert 4	50	50	50
Expert 5	70	20	11
Expert 6	50	50	50
Expert 7	50	50	50

Alternatives: minimizing property damage for reducing impact on lifestyle

	GH/DH	GH/GE	DH/GE
Expert 1	25	25	50
Expert 2	50	50	50
Expert 3	50	25	20
Expert 4	50	50	50
Expert 5	50	20	10
Expert 6	50	50	50
Expert 7	30	20	40

Appendix C: Calculations (Overall Weight)

Objectives		Goals			GHP		Direct heat		Geothermal electricity	
			Local	Global	Local	Global	Local	Global	Local	Global
Encourage community to support geothermal energy project	0.17	Create new job opportunity	0.59	0.1	0.25	0.025	0.3	0.04	0.45	0.045
		Social acceptance	0.41	0.07	0.29	0.02	0.32	0.022	0.39	0.027
Minimize environmental impact	0.26	GHG emission	0.3	0.078	0.3	0.023	0.3	0.023	0.4	0.03
		Land requirement	0.2	0.053	0.28	0.014	0.3	0.016	0.42	0.02
		Seismic activity	0.32	0.083	0.34	0.028	0.36	0.03	0.3	0.024
		Using the land for other purposes	0.18	0.046	0.29	0.013	0.27	0.012	0.44	0.02
Reduce expense of investment energy projects	0.21	Minimize capital cost	0.51	0.107	0.23	0.024	0.33	0.036	0.44	0.047
		Minimize operation cost	0 28	0.059	0.22	0.013	0.29	0.018	0.49	0.028
		Economic boost	0.21	0.044	0.27	0.012	0.3	0.014	0.43	0.018
Technical option improvement for geothermal energy projects	0.18	Minimizing the demand of critical resources	0.28	0.05	0.27	0.013	0.35	0.018	0.38	0.019
		Increasing the capacity of the energy system	0.39	0.07	0.24	0.016	0.23	0.017	0.53	0.037
		Equipment manufacturing development	0.33	0.06	0.22	0.013	0.22	0.014	0.56	0.033
Minimize the negative impact on the general public	0.18	Minimize noise and odor	0.73	0.131	0.27	0.035	0.27	0.036	0.46	0.06
		Minimizing property damage for reducing impact on lifestyle	0.27	0.049	0.23	0.011	0.29	0.014	0.48	0.022
						0.26		0.31		0.43

Appendix D: Objectives Weight for Different Characteristics of Experts

Objectives weight for different characteristics of experts: background of organization

Objectives and goals	Utility	Consulting	Research lab	University
Encourage community to support geothermal energy project	0.15	0.16	0.25	0.16
Create new job opportunity	0.43	0.65	0.9	0.67
Social acceptance	0.57	0.35	0.1	0.33
Minimize environmental impact	0.28	0.34	0.12	0.16
GHG emission	0.23	0.5	0.31	0.1
Land requirement	0.2	0.2	0.23	0.18
Seismic activity	0.46	0.19	0.05	0.46
Using the land for other purposes	0.11	0.11	0.42	0.26
Reduce expense of investment energy projects	0.19	0.17	0.28	0.31
Minimize capital cost	0.56	0.35	0.86	0.33
Minimize operation cost	0.33	0.29	0.08	0.33
Economic boost	0.11	0.36	0.06	0.33
Technical option improvement for geothermal energy projects	0.18	0.19	0.26	0.1
Minimizing the demand of critical resources	0.21	0.47	0.21	0.2
Increasing the capacity of the energy system	0.38	0.25	0.57	0.51
Equipment manufacturing development	0.41	0.28	0.22	0.29
Minimize the negative impact on the general public	0.2	0.14	0.08	0.27
Minimize noise and odor	0.77	0.65	0.99	0.5
Minimizing property damage for reducing impact on lifestyle	0.23	0.35	0.01	0.5

Objectives weight for different characteristics of experts: background of organization

		Utility			Consulting			Research lab			University		
	Alternatives	GHP	Direct heat	Geo. elect.	GHP	Direct heat	Geo. elect.	GHP	Direct heat	Geo. elect.	GHP	Direct heat	Geo. elect.
Goals	Create new job opportunity	0.21	0.43	0.35	0.33	0.21	0.47	0.15	0.03	0.82	0.33	0.33	0.33
	Social acceptance	0.31	0.36	0.33	0.32	0.375	0.315	0.14	0.11	0.75	0.33	0.33	0.33
	GHG emission	0.36	0.32	0.31	0.305	0.395	0.3	0.07	0.01	0.91	0.33	0.33	0.33
	Land requirement	0.3	0.37	0.32	0.275	0.3	0.42	0.14	0.04	0.82	0.33	0.33	0.33
	Seismic activity	0.23	0.42	0.34	0.51	0.285	0.205	0.33	0.33	0.33	0.33	0.33	0.33
	Using the land for other purposes	0.24	0.27	0.49	0.405	0.32	0.27	0.14	0.11	0.75	0.33	0.33	0.33
	Minimize capital cost	0.21	0.45	0.33	0.25	0.27	0.49	0.14	0.11	0.75	0.33	0.33	0.33
	Minimize operation cost	0.19	0.37	0.43	0.275	0.24	0.48	0.11	0.04	0.85	0.33	0.33	0.33
	Economic boost	0.2	0.34	0.44	0.325	0.25	0.425	0.28	0.24	0.48	0.33	0.33	0.33
	Minimizing the demand of critical resources	0.23	0.31	0.44	0.29	0.465	0.245	0.27	0.22	0.51	0.33	0.33	0.33
	Increasing the capacity of the energy system	0.31	0.3	0.38	0.18	0.185	0.635	0.02	0.01	0.98	0.33	0.33	0.33
	Equipment manufacturing development	0.21	0.24	0.53	0.195	0.22	0.585	0.18	0.03	0.79	0.33	0.33	0.33
	Minimize noise and odor	0.33	0.38	0.27	0.17	0.155	0.68	0.19	0.09	0.72	0.33	0.33	0.33
	Minimizing property damage for reducing impact on lifestyle	0.26	0.33	0.39	0.165	0.3	0.53	0.14	0.11	0.75	0.33	0.33	0.33

Objectives weight for different characteristics of experts: position

Objectives, and goals	Management	Planning	Policy	Environment
Encourage community to support geothermal energy project	0.18	0.135	0.25	0.13
Create new job opportunity	0.49	0.53	0.9	0.7
Social acceptance	0.51	0.47	0.1	0.3
Minimize environmental impact	0.28	0.175	0.12	0.5
GHG emission	0.22	0.26	0.31	0.61
Land requirement	0.26	0.2	0.23	0.03
Seismic activity	0.41	0.35	0.05	0.26
Using the land for other purposes	0.11	0.19	0.42	0.1
Reduce expense of investment energy projects	0.21	0.255	0.28	0.08
Minimize capital cost	0.53	0.44	0.86	0.25
Minimize operation cost	0.36	0.33	0.08	0.13
Economic boost	0.11	0.23	0.06	0.62
Technical option improvement for geothermal energy projects	0.16	0.21	0.26	0.12
Minimizing the demand of critical resources	0.27	0.16	0.21	0.65
Increasing the capacity of the energy system	0.44	0.38	0.57	0.07
Equipment manufacturing development	0.29	0.46	0.22	0.28
Minimize the negative impact on the general public	0.17	0.225	0.08	0.17
Minimize noise and odor	0.72	0.58	0.99	0.8
Minimizing property damage for reducing impact on lifestyle	0.28	0.42	0.01	0.2

Objectives weight for different characteristics of experts: position

	Alternatives	Management			Planning			Policy			Environment		
		GHP	Direct Heat	Geo. Elect	GHP	Direct Heat	Geo. Elect.	GHP	Direct Heat	Geo. Elect.	GHP	Direct Heat	Geo. Elect.
Goals	Create new job opportunity	0.23	0.27	0.49	0.28	0.505	0.205	0.15	0.03	0.82	0.35	0.23	0.43
	Social acceptance	0.37	0.26	0.36	0.275	0.455	0.265	0.14	0.11	0.75	0.21	0.46	0.34
	GHG emission	0.33	0.25	0.4	0.345	0.39	0.26	0.07	0.01	0.91	0.35	0.53	0.12
	Land requirement	0.27	0.37	0.35	0.375	0.325	0.295	0.14	0.04	0.82	0.22	0.27	0.51
	Seismic activity	0.35	0.35	0.3	0.34	0.385	0.27	0.33	0.33	0.33	0.33	0.34	0.33
	Using the land for other purposes	0.26	0.29	0.44	0.295	0.295	0.405	0.14	0.11	0.75	0.48	0.31	0.21
	Minimize capital cost	0.26	0.39	0.35	0.225	0.45	0.32	0.14	0.11	0.75	0.25	0.16	0.6
	Minimize operation cost	0.23	0.35	0.4	0.26	0.36	0.375	0.11	0.04	0.85	0.22	0.15	0.63
	Economic boost	0.21	0.25	0.54	0.255	0.41	0.325	0.28	0.24	0.48	0.45	0.3	0.25
	Minimizing the demand of critical resources	0.21	0.29	0.49	0.365	0.37	0.26	0.27	0.22	0.51	0.25	0.6	0.16
	Increasing the capacity of the energy system	0.23	0.24	0.52	0.36	0.36	0.28	0.02	0.01	0.98	0.21	0.15	0.64
	Equipment manufacturing development	0.19	0.17	0.63	0.245	0.39	0.36	0.18	0.03	0.79	0.31	0.21	0.48
	Minimize noise and odor	0.25	0.25	0.49	0.335	0.41	0.25	0.19	0.09	0.72	0.25	0.22	0.54
	Minimizing property damage for reducing impact on lifestyle	0.2	0.36	0.43	0.33	0.33	0.33	0.14	0.11	0.75	0.19	0.17	0.63

Objectives weight for different characteristics of experts: education

Objectives and goals	Bachelor's degree	Master's degree	Ph.D. degree
Encourage community to support geothermal energy project	0.1	0.17	0.21
Create new job opportunity	0.12	0.61	0.78
Social acceptance	0.88	0.39	0.22
Minimize environmental impact	0.47	0.26	0.14
GHG emission	0.15	0.38	0.2
Land requirement	0.07	0.23	0.2
Seismic activity	0.68	0.27	0.26
Using the land for other purposes	0.09	0.12	0.34
Reduce expense of investment energy projects	0.18	0.18	0.3
Minimize capital cost	0.7	0.42	0.6
Minimize operation cost	0.28	0.32	0.21
Economic boost	0.02	0.26	0.19
Technical option improvement for geothermal energy projects	0.12	0.2	0.18
Minimizing the demand of critical resources	0.36	0.3	0.2
Increasing the capacity of the energy system	0.59	0.26	0.54
Equipment manufacturing development	0.05	0.44	0.26
Minimize the negative impact on the general public	0.12	0.19	0.17
Minimize noise and odor	0.75	0.72	0.75
Minimizing property damage for reducing impact on lifestyle	0.25	0.28	0.25

Objectives weight for different characteristics of experts: education

	Alternatives	Bachelor's degree			Master's degree			Ph.D degree		
		GHP	Direct heat	Geo. elect.	GHP	Direct heat	Geo. Elect.	GHP	Direct heat	Geo. elect.
Goals	Create new job opportunity	0.31	0.19	0.5	0.245	0.3825	0.375	0.24	0.18	0.575
	Social acceptance	0.35	0.17	0.48	0.2975	0.415	0.29	0.235	0.22	0.54
	GHG emission	0.41	0.18	0.41	0.325	0.3925	0.28	0.2	0.17	0.62
	Land requirement	0.43	0.33	0.25	0.255	0.3475	0.3925	0.235	0.185	0.575
	Seismic activity	0.33	0.33	0.33	0.35	0.375	0.2775	0.33	0.33	0.33
	Using the land for other purposes	0.42	0.13	0.46	0.2775	0.33	0.39	0.235	0.22	0.54
	Minimize capital cost	0.36	0.47	0.18	0.1975	0.36	0.4475	0.235	0.22	0.54
	Minimize operation cost	0.24	0.48	0.28	0.22	0.2825	0.4925	0.22	0.185	0.59
	Economic boost	0.39	0.19	0.42	0.2175	0.3375	0.4425	0.305	0.285	0.405
	Minimizing the demand of critical resources	0.13	0.13	0.74	0.29	0.4375	0.2725	0.3	0.275	0.42
	Increasing the capacity of the energy system	0.22	0.18	0.6	0.27	0.2725	0.4575	0.175	0.17	0.655
	Equipment manufacturing development	0.42	0.19	0.39	0.155	0.2475	0.5975	0.255	0.18	0.56
	Minimize noise and odor	0.33	0.33	0.33	0.2525	0.2825	0.465	0.26	0.21	0.525
	Minimizing property damage for reducing impact on lifestyle	0.33	0.33	0.33	0.2	0.3175	0.48	0.235	0.22	0.54

References

1. Beck, F., & Martinot, E. (2004). Renewable energy policies and barriers. *Encyclopedia of Energy, 5*(7), 365–383.
2. Zhe, W., Yiru, W., Chuan, H., Jianhui, Y., & Hao, Z. (2009). Development status of China's renewable energy power generation. In*Sustainable Power Generation and Supply, 2009. SUPERGEN'09. International Conference* (pp. 1–5).
3. Wiser, R. H., & Pickle, S. J. (1998). Financing investments in renewable energy : the impacts of policy design. *Renewable and Sustainable Energy Reviews, 2*(4), 361–386.
4. DiPippo, R. (1991). Geothermal energy electricity generation and environmental impact. *Energy Policy, 19*(8), 798–807.
5. Sawyer, S. W. (1982). Leaders in change: Solar energy owners and the implications for future adoption rates. *Technological Forecasting and Social Change, 21*(3), 201–211.

6. Energy.gov, Geothermal | Department of Energy. (2015). [Online]. Available: http://www.energy.gov/science-innovation/energy-sources/renewable-energy/geothermal. Accessed 25 Jun 2015.
7. Barbier, E. (2002). Geothermal energy technology and current status: an overview. *Renewable and Sustainable Energy Reviews, 6*(1), 3–65.
8. Oregon.gov, Geothermal Energy Geothermal Energy. (2015). [Online]. Available: http://www.oregon.gov/energy/renew/geothermal/pages/geo_index.aspx. Accessed 25 Jun 2015.
9. Union of Concerned Scientists, 'How Geothermal Energy Works. (2015). [Online]. Available: http://www.ucsusa.org/clean_energy/our-energy-choices/renewable-energy/how-geothermal-energy-works.html#.VYukZ_lVikp. Accessed 25 Jun 2015.
10. Lsa.colorado.edu, Geothermal Energy, 2015. [Online]. Available: http://lsa.colorado.edu/essence/texts/geothermal.html. Accessed 25 Jun 2015.
11. Bertani, R. (2005). World geothermal power generation in the period 2001–2005. *Geothermics, 34*(6), 651–690.
12. Bertani, R. (2012). Geothermal power generation in the world 2005–2010 update report. *Geothermics, 41*, 1–29.
13. 2013 Annual US geothermal power production and development report, Geothermal Energy Association, Washington, D.C, 2013.
14. Lund, J. W. (January 2003). Direct-use of geothermal energy in the USA. *Applied Energy, 74*(1), 33–42.
15. Lund, J. W. (1997). Geothermal research at the Geo-Heat Center Oregon Institute of Technology. In*Energy Conversion Engineering Conference, 1997. IECEC-97., Proceedings of the 32nd Intersociety* (Vol. 3, pp. 1820–1825).
16. Lund, J. W., & Freeston, D. H. (2001). World-wide direct uses of geothermal energy 2000. *Geothermics, 30*(1), 29–68.
17. Eia.gov. (2015). [Online]. Available: http://www.eia.gov/state/analysis.cfm?sid=OR. Accessed 25 Jun 2015.
18. U.S.Department of Energy, EERE Investments in Oregon, 2013.
19. Petty, S., Nordin, Y., Glassley, W., Cladouhos, T. T., & Swyer, M. (2013). Improving geothermal project economics with multi-zone stimulation: results from the Newberry Volcano EGS demonstration. In*Proceedings of the 38th Workshop on Geothermal Reservoir Engineering* (pp. 11–13). Stanford.
20. Hull, D. A., Bowen, R. G., Blackwell, D. D., & Peterson, N. V. (1977). Preliminary Heat-Flow Map and Evaluation of Oregon's Geothermal Energy Potential. *The Ore Bin, 39*(7), 109–123.
21. Pohekar, S. D., & Ramachandran, M. (2004). Application of multi-criteria decision making to sustainable energy planning—a review. *Renewable and Sustainable Energy Reviews, 8*(4), 365–381.
22. Wang, J. J., Jing, Y. Y., Zhang, C. F., & Zhao, J. H. (2009). Review on multi-criteria decision analysis aid in sustainable energy decision-making. *Renewable and Sustainable Energy Reviews, 13*(9), 2263–2278.
23. Løken, E. (2007). Use of multicriteria decision analysis methods for energy planning problems. *Renewable and Sustainable Energy Reviews, 11*(7), 1584–1595.
24. Mendoza, G. A., & Martins, H. (2006). Multi-criteria decision analysis in natural resource management: a critical review of methods and new modelling paradigms. *Forest Ecology and Management, 230*(1), 1–22.
25. Energy Challenges for Oregon and the Nation, National Ocean Industrial Association.
26. Adams, S., & Anderson, S. (2009). ''Portland Plan''. In*City of Portland Bureau of Planning and Sustainability, Portland*.
27. State of Oregon Biennial Energy Plan 2015–2017, Oregon Department of Energy, Salem, Oregon, 2015.
28. Samouilidis, J. E., & Mitropoulos, C. S. (1982). An aggregate model for energy costs: national product interdependence. *Energy Economics, 4*(3), 199–206.

29. Bopp, A., & Lady, G. M. (1982). On measuring the effects of higher energy prices. *Energy Economics, 4*(4), 218–224.
30. Meier, P., & Mubayi, V. (1983). Modelling energy-economic interactions in developing countries: A linear programming approach. *European Journal of Operational Research, 13*(1), 41–59.
31. Beccali, M., Cellura, M., & Mistretta, M. (2003). Decision-making in energy planning. Application of the Electre method at regional level for the diffusion of renewable energy technology. *Renewable Energy, 28*(13), 2063–2087.
32. San Cristóbal, J. R. (2011). Multi-criteria decision-making in the selection of a renewable energy project in Spain: the Vikor method. *Renewable Energy, 36*(2), 498–502.
33. Kaya, T., & Kahraman, C. (2011). Multicriteria decision making in energy planning using a modified fuzzy TOPSIS methodology. *Expert Systems with Applications, 38*(6), 6577–6585.
34. Beccali, M., Cellura, M., & Ardente, D. (1998). Decision making in energy planning: the ELECTRE multicriteria analysis approach compared to a fuzzy-sets methodology. *Energy Conversion and Management, 39*(16), 1869–1881.
35. Zhou, P., Ang, B. W., & Poh, K. L. (2006). Decision analysis in energy and environmental modeling: An update. *Energy, 31*(14), 2604–2622.
36. Lind, R. C. (1995). Intergenerational equity, discounting, and the role of cost-benefit analysis in evaluating global climate policy. *Energy Policy, 23*(4), 379–389.
37. Maddison, D. (1995). A cost-benefit analysis of slowing climate change. *Energy Policy, 23*(4), 337–346.
38. Diakoulaki, D., & Karangelis, F. (2007). Multi-criteria decision analysis and cost–benefit analysis of alternative scenarios for the power generation sector in Greece. *Renewable and Sustainable Energy Reviews, 11*(4), 716–727.
39. Snyder, B., & Kaiser, M. J. (2009). Ecological and economic cost-benefit analysis of offshore wind energy. *Renewable Energy, 34*(6), 1567–1578.
40. Jaffe, A. B., Newell, R. G., & Stavins, R. N. (2005). A tale of two market failures: Technology and environmental policy. *Ecological Economics, 54*(2), 164–174.
41. Clinch, J. P., & Healy, J. D. (2001). Cost-benefit analysis of domestic energy efficiency. *Energy Policy, 29*(2), 113–124.
42. Bollen, J., van der Zwaan, B., Brink, C., & Eerens, H. (2009). Local air pollution and global climate change: A combined cost-benefit analysis. *Resource and Energy Economics, 31*(3), 161–181.
43. Molinos-Senante, M., Hernández-Sancho, F., & Sala-Garrido, R. (2011). Cost–benefit analysis of water-reuse projects for environmental purposes: a case study for Spanish wastewater treatment plants. *Journal of Environmental Management, 92*(12), 3091–3097.
44. Mehta, S., & Shahpar, C. (2004). The health benefits of interventions to reduce indoor air pollution from solid fuel use: a cost-effectiveness analysis. *Energy for Sustainable Development, 8*(3), 53–59.
45. Kovacevic, V., & Wesseler, J. (2010). Cost-effectiveness analysis of algae energy production in the EU. *Energy Policy, 38*(10), 5749–5757.
46. Bassi, A. M., & Yudken, J. S. (2011). Climate policy and energy-intensive manufacturing: A comprehensive analysis of the effectiveness of cost mitigation provisions in the American Energy and Security Act of 2009. *Energy Policy, 39*(9), 4920–4931.
47. Jackson, T. (1995). Joint implementation and cost-effectiveness under the Framework Convention on Climate Change. *Energy Policy, 23*(2), 117–138.
48. Berndes, G., & Hansson, J. (2007). Bioenergy expansion in the EU: cost-effective climate change mitigation, employment creation and reduced dependency on imported fuels. *Energy Policy, 35*(12), 5965–5979.
49. Zomer, R. J., Trabucco, A., Bossio, D. A., & Verchot, L. V. (2008). Climate change mitigation: A spatial analysis of global land suitability for clean development mechanism afforestation and reforestation. *Agriculture, Ecosystems & Environment, 126*(1), 67–80.
50. Nelson, D. B., Nehrir, M. H., & Wang, C. (2006). Unit sizing and cost analysis of stand-alone hybrid wind/PV/fuel cell power generation systems. *Renewable Energy, 31*(10), 1641–1656.

51. Carley, S. (2009). State renewable energy electricity policies: An empirical evaluation of effectiveness. *Energy Policy, 37*(8), 3071–3081.
52. Kneifel, J. (2010). Life-cycle carbon and cost analysis of energy efficiency measures in new commercial buildings. *Energy and Buildings, 42*(3), 333–340.
53. Amann, M., Bertok, I., Borken-Kleefeld, J., Cofala, J., Heyes, C., Höglund-Isaksson, L., Klimont, Z., et al. (2011). Cost-effective control of air quality and greenhouse gases in Europe: Modeling and policy applications. *Environmental Modelling & Software, 26*(12), 1489–1501.
54. Stevens, B., & Rose, A. (2002). A dynamic analysis of the marketable permits approach to global warming policy: A comparison of spatial and temporal flexibility. *Journal of Environmental Economics and Management, 44*(1), 45–69.
55. Morrow, W. R., Gallagher, K. S., Collantes, G., & Lee, H. (2010). Analysis of policies to reduce oil consumption and greenhouse-gas emissions from the US transportation sector. *Energy Policy, 38*(3), 1305–1320.
56. Vermont, B., & De Cara, S. (2010). How costly is mitigation of non-CO 2 greenhouse gas emissions from agriculture?: A meta-analysis. *Ecological Economics, 69*(7), 1373–1386.
57. Agrawal, B., & Tiwari, G. N. (2010). Life cycle cost assessment of building integrated photovoltaic thermal (BIPVT) systems. *Energy and Buildings, 42*(9), 1472–1481.
58. Chel, A., Tiwari, G. N., & Chandra, A. (2009). Simplified method of sizing and life cycle cost assessment of building integrated photovoltaic system. *Energy and Buildings, 41*(11), 1172.
59. Marszal, A. J., & Heiselberg, P. (2011). Life cycle cost analysis of a multi-storey residential net zero energy building in Denmark. *Energy, 36*(9), 5600–5609.
60. Basbagill, J., Flager, F., Lepech, M., & Fischer, M. (2013). Application of life-cycle assessment to early stage building design for reduced embodied environmental impacts. *Building and Environment, 60*, 81–92.
61. Erlandsson, M., & Borg, M. (2003). Generic LCA-methodology applicable for buildings, constructions and operation services—today practice and development needs. *Building and Environment, 38*(7), 919–938.
62. Hu, Z., Fang, F., Ben, D., Pu, G., & Wang, C. (2004). Net energy, CO 2 emission, and life-cycle cost assessment of cassava-based ethanol as an alternative automotive fuel in China. *Applied Energy, 78*(3), 247–256.
63. Papong, S., & Malakul, P. (2010). Life-cycle energy and environmental analysis of bioethanol production from cassava in Thailand. *Bioresource Technology, 101*(1), S112–S118.
64. Gluch, P., & Baumann, H. (2004). The life cycle costing (LCC) approach: a conceptual discussion of its usefulness for environmental decision-making. *Building and Environment, 39*(5), 571–580.
65. Utne, I. B. (2009). Improving the environmental performance of the fishing fleet by use of Quality Function Deployment (QFD). *Journal of Cleaner Production, 17*(8), 724–731.
66. Ness, B., Urbel-Piirsalu, E., Anderberg, S., & Olsson, L. (2007). Categorising tools for sustainability assessment. *Ecological Economics, 60*(3), 498–508.
67. Luo, L., Van Der Voet, E., & Huppes, G. (2009). Life cycle assessment and life cycle costing of bioethanol from sugarcane in Brazil. *Renewable and Sustainable Energy Reviews, 13*(6), 1613–1619.
68. Utne, I. B. (2009). Life cycle cost (LCC) as a tool for improving sustainability in the Norwegian fishing fleet. *Journal of Cleaner Production, 17*(3), 335–344.
69. Nguyen, T. L. T., Gheewala, S. H., & Garivait, S. (2007). Energy balance and GHG-abatement cost of cassava utilization for fuel ethanol in Thailand. *Energy Policy, 35*(9), 4585–4596.
70. Reijnders, L., & Huijbregts, M. A. (2007). Life cycle greenhouse gas emissions, fossil fuel demand and solar energy conversion efficiency in European bioethanol production for automotive purposes. *Journal of Cleaner Production, 15*(18), 1806–1812.
71. Yan, X., & Crookes, R. J. (2009). Life cycle analysis of energy use and greenhouse gas emissions for road transportation fuels in China. *Renewable and Sustainable Energy Reviews, 13*(9), 2505–2514.

72. Ugwu, O. O., Kumaraswamy, M. M., Kung, F., & Ng, S. T. (2005). Object-oriented framework for durability assessment and life cycle costing of highway bridges. *Automation in Construction, 14*(5), 611–632.
73. González-García, S., Iribarren, D., Susmozas, A., Dufour, J., & Murphy, R. J. (2012). Life cycle assessment of two alternative bioenergy systems involving Salix spp. biomass: Bioethanol production and power generation. *Applied Energy, 95*, 111–122.
74. Knapp, K., & Jester, T. (2001). Empirical investigation of the energy payback time for photovoltaic modules. *Solar Energy, 71*(3), 165–172.
75. Peng, J., Lu, L., & Yang, H. (2013). Review on life cycle assessment of energy payback and greenhouse gas emission of solar photovoltaic systems. *Renewable and Sustainable Energy Reviews, 19*, 255–274.
76. de Wild-Scholten, M. J. (2013). Energy payback time and carbon footprint of commercial photovoltaic systems. *Solar Energy Materials and Solar Cells, 119*, 296–305.
77. Wilson, R., & Young, A. (1996). The embodied energy payback period of photovoltaic installations applied to buildings in the UK. *Building and Environment, 31*(4), 299–305.
78. Goe, M., & Gaustad, G. (2014). Strengthening the case for recycling photovoltaics: An energy payback analysis. *Applied Energy, 120*, 41–48.
79. Weißbach, D., Ruprecht, G., Huke, A., Czerski, K., Gottlieb, S., & Hussein, A. (2013). Energy intensities, EROIs (energy returned on invested), and energy payback times of electricity generating power plants. *Energy, 52*, 210–221.
80. Gagnon, L., Belanger, C., & Uchiyama, Y. (2002). Life-cycle assessment of electricity generation options: the status of research in year 2001. *Energy Policy, 30*(14), 1267–1278.
81. White, S. W., & Kulcinski, G. L. (2000). Birth to death analysis of the energy payback ratio and CO 2 gas emission rates from coal, fission, wind, and DT-fusion electrical power plants. *Fusion Engineering and Design, 48*(3), 473–481.
82. Schleisner, L. (2000). Life cycle assessment of a wind farm and related externalities. *Renewable Energy, 20*(3), 279–288.
83. Lu, L., & Yang, H. X. (2010). Environmental payback time analysis of a roof-mounted building-integrated photovoltaic (BIPV) system in Hong Kong. *Applied Energy, 87*(12), 3625–3631.
84. Ardente, F., Beccali, G., Cellura, M., & Brano, V. L. (2005). Life cycle assessment of a solar thermal collector: sensitivity analysis, energy and environmental balances. *Renewable Energy, 30*(2), 109–130.
85. Hang, Y., Qu, M., & Zhao, F. (2012). Economic and environmental life cycle analysis of solar hot water systems in the United States. *Energy and Buildings, 45*, 181–188.
86. Wong, I. L., Eames, P. C., & Perera, R. S. (2007). A review of transparent insulation systems and the evaluation of payback period for building applications. *Solar Energy, 81*(9), 1058–1071.
87. Chilton, J. C., Maidment, G. G., Marriott, D., Francis, A., & Tobias, G. (2000). Case study of a rainwater recovery system in a commercial building with a large roof. *Urban water, 1*(4), 345–354.
88. Daouas, N., Hassen, Z., & Aissia, H. B. (2010). Analytical periodic solution for the study of thermal performance and optimum insulation thickness of building walls in Tunisia. *Applied Thermal Engineering, 30*(4), 319.
89. Hacker, J. N., De Saulles, T. P., Minson, A. J., & Holmes, M. J. (2008). Embodied and operational carbon dioxide emissions from housing: a case study on the effects of thermal mass and climate change. *Energy and Buildings, 40*(3), 375–384.
90. Staffell, I., Ingram, A., & Kendall, K. (2012). Energy and carbon payback times for solid oxide fuel cell based domestic CHP. *International Journal of Hydrogen Energy, 37*(3), 2509–2523.
91. Kim, Y. J., & Sanders, G. L. (2002). Strategic actions in information technology investment based on real option theory. *Decision Support Systems, 33*(1), 1–11.

92. McLellan, B. C., Corder, G. D., Giurco, D., & Green, S. (2009). Incorporating sustainable development in the design of mineral processing operations–Review and analysis of current approaches. *Journal of Cleaner Production, 17*(16), 1414–1425.
93. Kjaerland, F. (2007). A real option analysis of investments in hydropower—The case of Norway. *Energy Policy, 35*(11), 5901–5908.
94. Lee, S. C. (2011). Using real option analysis for highly uncertain technology investments: The case of wind energy technology. *Renewable and Sustainable Energy Reviews, 15*(9), 4443–4450.
95. Yeo, K. T., & Qiu, F. (2003). The value of management flexibility—a real option approach to investment evaluation. *International Journal of Project Management, 21*(4), 243–250.
96. Davis, G. A., & Owens, B. (2003). Optimizing the level of renewable electric R&D expenditures using real options analysis. *Energy Policy, 31*(15), 1589–1608.
97. Kumbaroğlu, G., Madlener, R., & Demirel, M. (2008). A real options evaluation model for the diffusion prospects of new renewable power generation technologies. *Energy Economics, 30*(4), 1882–1908.
98. Szolgayova, J., Fuss, S., & Obersteiner, M. (2008). Assessing the effects of CO 2 price caps on electricity investments—a real options analysis. *Energy Policy, 36*(10), 3974–3981.
99. Jalil, A., & Mahmud, S. F. (2009). Environment Kuznets curve for CO 2 emissions: a cointegration analysis for China. *Energy Policy, 37*(12), 5167–5172.
100. Miller, K. D., & Waller, H. G. (2003). Scenarios, real options and integrated risk management. *Long Range Planning, 36*(1), 93–107.
101. Lander, D. M., & Pinches, G. E. (1998). Challenges to the practical implementation of modeling and valuing real options. *The Quarterly Review of Economics and Finance, 38*(3), 537–567.
102. Kim, J., Hwang, M., Jeong, D. H., & Jung, H. (2012). Technology trends analysis and forecasting application based on decision tree and statistical feature analysis. *Expert Systems with Applications, 39*(16), 12618–12625.
103. Hawkes, A. D., & Leach, M. A. (2007). Cost-effective operating strategy for residential micro-combined heat and power. *Energy, 32*(5), 711–723.
104. Tso, G. K., & Yau, K. K. (2007). Predicting electricity energy consumption: A comparison of regression analysis, decision tree and neural networks. *Energy, 32*(9), 1761–1768.
105. Weiner, D., Fisher, D., Moses, E. J., Katz, B., & Meron, G. (2001). Operation experience of a solar-and wind-powered desalination demonstration plant. *Desalination, 137*(1), 7–13.
106. Lee, S. C., & Shih, L. H. (2010). Renewable energy policy evaluation using real option model—The case of Taiwan. *Energy Economics, 32*, S67–S78.
107. Biswal, M., & Dash, P. K. (2013). Detection and characterization of multiple power quality disturbances with a fast S-transform and decision tree based classifier. *Digital Signal Processing, 23*(4), 1071–1083.
108. Cramer, G. M., Ford, R. A., & Hall, R. L. (1976). Estimation of toxic hazard—a decision tree approach. *Food and Cosmetics Toxicology, 16*(3), 255–276.
109. Duncan, R. (1980). What is the right organization structure? Decision tree analysis provides the answer. *Organizational Dynamics, 7*(3), 59–80.
110. Yu, Z., Haghighat, F., Fung, B. C., & Yoshino, H. (2010). A decision tree method for building energy demand modeling. *Energy and Buildings, 42*(10), 1637–1646.
111. Olaru, C., & Wehenkel, L. (2003). A complete fuzzy decision tree technique. *Fuzzy Sets and Systems, 138*(2), 221–254.
112. Varma, V. A., Reklaitis, G. V., Blau, G. E., & Pekny, J. F. (2007). Enterprise-wide modeling & optimization—An overview of emerging research challenges and opportunities. *Computers & Chemical Engineering, 31*(5), 692–711.
113. Wallace, S. W., & Fleten, S. E. (2003). Stochastic programming models in energy. In*Handbooks in operations research and management science* (Vol. 10, pp. 637–677). Amsterdam: Elsevier.
114. Pehnt, M. (2006). Dynamic life cycle assessment (LCA) of renewable energy technologies. *Renewable Energy, 31*(1), 55–71.

115. Liu, B. T., Chien, K. H., & Wang, C. C. (2004). Effect of working fluids on organic Rankine cycle for waste heat recovery. *Energy, 29*(8), 1207–1217.
116. Reiche, D., & Bechberger, M. (2004). Policy differences in the promotion of renewable energies in the EU member states. *Energy Policy, 32*(7), 843–849.
117. Walker, G., & Devine-Wright, P. (2008). Community renewable energy: What should it mean? *Energy Policy, 36*(2), 497–500.
118. Yu, Z., Fung, B. C., Haghighat, F., Yoshino, H., & Morofsky, E. (2011). A systematic procedure to study the influence of occupant behavior on building energy consumption. *Energy and Buildings, 43*(6), 1409–1417.
119. Richardson, B. C. (2005). Sustainable transport: analysis frameworks. *Journal of Transport Geography, 13*(1), 29–39.
120. Lund, H., & Salgi, G. (2009). The role of compressed air energy storage (CAES) in future sustainable energy systems. *Energy Conversion and Management, 50*(5), 1172–1179.
121. Lund, H. (2005). Large-scale integration of wind power into different energy systems. *Energy, 30*(13), 2402–2412.
122. Keeney, R., & Raiffa, H. (1976). *Decisions with Multiple Objectives: Preferences and Value Tradeoffs*. New York: Willey.
123. Sanayei, A., Mousavi, S. F., Abdi, M. R., & Mohaghar, A. (2008). An integrated group decision-making process for supplier selection and order allocation using multi-attribute utility theory and linear programming. *Journal of the Franklin Institute, 345*(7), 731–747.
124. Bose, U., Davey, A. M., & Olson, D. L. (1997). Multi-attribute utility methods in group decision making: past applications and potential for inclusion in GDSS. *Omega, 25*(6), 691–706.
125. Keeney, R. L. (1977). The art of assessing multiattribute utility functions. *Organizational Behavior and Human Performance, 19*(2), 267–310.
126. Ananda, J., & Herath, G. (2005). Evaluating public risk preferences in forest land-use choices using multi-attribute utility theory. *Ecological Economics, 55*(3), 408–419.
127. Zanakis, S. H., Solomon, A., Wishart, N., & Dublish, S. (1998). Multi-attribute decision making: A simulation comparison of select methods. *European Journal of Operational Research, 107*(3), 507–529.
128. Konidari, P., & Mavrakis, D. (2007). A multi-criteria evaluation method for climate change mitigation policy instruments. *Energy Policy, 35*(12), 6235–6257.
129. Holt, G. D. (1998). Which contractor selection methodology? *International Journal of Project Management, 16*(3), 153–164.
130. Pawlak, Z., & Sowinski, R. (1994). Rough set approach to multi-attribute decision analysis. *European Journal of Operational Research, 72*(3), 443–459.
131. Kainuma, Y., & Tawara, N. (2006). A multiple attribute utility theory approach to lean and green supply chain management. *International Journal of Production Economics, 101*(1), 99–108.
132. Kowalski, K., Stagl, S., Madlener, R., & Omann, I. (2009). Sustainable energy futures: Methodological challenges in combining scenarios and participatory multi-criteria analysis. *European Journal of Operational Research, 197*(3), 1063–1074.
133. Anandalingam, G., & Olsson, C. E. (1989). A multi-stage multi-attribute decision model for project selection. *European Journal of Operational Research, 43*(3), 271–283.
134. Velasquez, M., & Hester, P. T. (2013). An analysis of multi-criteria decision making methods. *International Journal of Operations Research, 10*(2), 56–66.
135. Elkarmi, F., & Mustafa, I. (1993). Increasing the utilization of solar energy technologies (SET) in Jordan: Analytic Hierarchy Process. *Energy Policy, 21*(9), 978–984.
136. Forman, E. H., & Gass, S. I. (2001). The analytic hierarchy process-an exposition. *Operations Research, 49*(4), 469–486.
137. Saaty, T. L. (1980). *The analytic hierarchy process: planning, priority setting, resource allocation*. McGrawHill, New York.
138. Kocaoglu, D. F. (1983). A participative approach to program evaluation. *IEEE Transactions on Engineering Management, EM-30*, 112–118.

139. Lee, S. K., Yoon, Y. J., & Kim, J. W. (2007). A study on making a long-term improvement in the national energy efficiency and GHG control plans by the AHP approach. *Energy Policy, 35*(5), 2862–2868.
140. Ramanathan, R., & Ganesh, L. S. (1995). Energy alternatives for lighting in households: an evaluation using an integrated goal programming-AHP model. *Energy, 20*(1), 63–72.
141. Lee, S. K., Mogi, G., & Kim, J. W. (2008). The competitiveness of Korea as a developer of hydrogen energy technology: the AHP approach. *Energy Policy, 36*(4), 1284–1291.
142. Hämäläinen, R. P., & Seppäläinen, T. O. (1986). The analytic network process in energy policy planning. *Socio-Economic Planning Sciences, 20*(6), 399–405.
143. Kaya, T., & Kahraman, C. (2010). Multicriteria renewable energy planning using an integrated fuzzy VIKOR & AHP methodology: The case of Istanbul. *Energy, 35*(6), 2517–2527.
144. Heo, E., Kim, J., & Boo, K. J. (2010). Analysis of the assessment factors for renewable energy dissemination program evaluation using fuzzy AHP. *Renewable and Sustainable Energy Reviews, 14*(8), 2214–2220.
145. Poh, K. L., & Ang, B. W. (1999). Transportation fuels and policy for Singapore: an AHP planning approach. *Computers & Industrial Engineering, 37*(3), 507–525.
146. Ramanathan, R. (2001). A note on the use of the analytic hierarchy process for environmental impact assessment. *Journal of Environmental Management, 63*(1), 27–35.
147. Ulutaş, B. H. (2005). Determination of the appropriate energy policy for Turkey. *Energy, 30*(7), 1146–1161.
148. Köne, A. C., & Büke, T. (2007). An Analytical Network Process (ANP) evaluation of alternative fuels for electricity generation in Turkey. *Energy Policy, 35*(10), 5220–5228.
149. Erdoğmuş, S., Aras, H., & Koç, E. (June 2006). Evaluation of alternative fuels for residential heating in Turkey using analytic network process (ANP) with group decision-making. *Renewable and Sustainable Energy Reviews, 10*(3), 269–279.
150. İ.Yüksel, and M.Dagdeviren. (2007). Using the analytic network process (ANP) in a SWOT analysis–A case study for a textile firm. *Information Sciences, 177*(16), 3364–3382.
151. Aragonés-Beltrán, P., Chaparro-González, F., Pastor-Ferrando, J. P., & Rodríguez-Pozo, F. (2010). An ANP-based approach for the selection of photovoltaic solar power plant investment projects. *Renewable and Sustainable Energy Reviews, 14*(1), 249–264.
152. Xu, P., & Chan, E. H. (2013). ANP model for sustainable Building Energy Efficiency Retrofit (BEER) using Energy Performance Contracting (EPC) for hotel buildings in China. *Habitat International, 37*, 104–112.
153. Hung, S. J. (2011). Activity-based divergent supply chain planning for competitive advantage in the risky global environment: A DEMATEL-ANP fuzzy goal programming approach. *Expert Systems with Applications, 38*(8), 9053–9062.
154. Sarkis, J. (1998). Evaluating environmentally conscious business practices. *European Journal of Operational Research, 107*(1), 159–174.
155. Theißen, S., & Spinler, S. (2014). Strategic analysis of manufacturer-supplier partnerships: An ANP model for collaborative CO 2 reduction management. *European Journal of Operational Research, 233*(2), 383–397.
156. Shiue, Y. C., & Lin, C. Y. (2012). Applying analytic network process to evaluate the optimal recycling strategy in upstream of solar energy industry. *Energy and Buildings, 54*, 266–277.
157. Mazurek, J., & Kiszová, Z. (2012). Modeling dependence and feedback in ANP with fuzzy cognitive maps. In*Proceedings of 30th International Conference Mathematical Methods in Economics* (pp. 558–563).
158. Turcksin, L., Bernardini, A., & Macharis, C. (2011). A combined AHP-PROMETHEE approach for selecting the most appropriate policy scenario to stimulate a clean vehicle fleet. *Procedia-Social and Behavioral Sciences, 20*, 954–965.
159. Tsoutsos, T., Drandaki, M., Frantzeskaki, N., Iosifidis, E., & Kiosses, I. (2009). Sustainable energy planning by using multi-criteria analysis application in the island of Crete. *Energy Policy, 37*(5), 1587–1600.
160. Haralambopoulos, D. A., & Polatidis, H. (2003). Renewable energy projects: structuring a multi-criteria group decision-making framework. *Renewable Energy, 28*(6), 961–973.

161. Madlener, R., Kowalski, K., & Stagl, S. (2007). New ways for the integrated appraisal of national energy scenarios: the case of renewable energy use in Austria. *Energy Policy, 35*(12), 6060–6074.
162. Goumas, M. G., Lygerou, V. A., & Papayannakis, L. E. (1999). Computational methods for planning and evaluating geothermal energy projects. *Energy Policy, 27*(3), 147–154.
163. Cavallaro, F., & Ciraolo, L. (2005). A multicriteria approach to evaluate wind energy plants on an Italian island. *Energy Policy, 33*(2), 235–244.
164. Goumas, M., & Lygerou, V. (2000). An extension of the PROMETHEE method for decision making in fuzzy environment: Ranking of alternative energy exploitation projects. *European Journal of Operational Research, 123*(3), 606–613.
165. Ren, H., Gao, W., Zhou, W., & Nakagami, K. I. (2009). Multi-criteria evaluation for the optimal adoption of distributed residential energy systems in Japan. *Energy Policy, 37*(12), 5484–5493.
166. Cavallaro, F. (2009). Multi-criteria decision aid to assess concentrated solar thermal technologies. *Renewable Energy, 34*(7), 1678–1685.
167. Beynon, M. J., & Wells, P. (2008). The lean improvement of the chemical emissions of motor vehicles based on preference ranking: A PROMETHEE uncertainty analysis. *Omega, 36*(3), 384–394.
168. Papadopoulos, A., & Karagiannidis, A. (2008). Application of the multi-criteria analysis method Electre III for the optimisation of decentralised energy systems. *Omega, 36*(5), 766–776.
169. Cavallaro, F. (2010). A comparative assessment of thin-film photovoltaic production processes using the ELECTRE III method. *Energy Policy, 38*(1), 463–474.
170. Georgopoulou, E., Lalas, D., & Papagiannakis, L. (1997). A multicriteria decision aid approach for energy planning problems: The case of renewable energy option. *European Journal of Operational Research, 103*(1), 38–54.
171. Huang, J. P., Poh, K. L., & Ang, B. W. (1995). Decision analysis in energy and environmental modeling. *Energy, 20*(9), 843–855.
172. Kahraman, C., & Kaya, İ. (2010). A fuzzy multicriteria methodology for selection among energy alternatives. *Expert Systems with Applications, 37*(9), 6270–6281.
173. Neves, L. P., Martins, A. G., Antunes, C. H., & Dias, L. C. (2008). A multi-criteria decision approach to sorting actions for promoting energy efficiency. *Energy Policy, 36*(7), 2351–2363.
174. Topcu, Y. I., & Ulengin, F. (2004). Energy for the future: An integrated decision aid for the case of Turkey. *Energy, 29*(1), 137–154.
175. Shen, Y. C., Lin, G. T., Li, K. P., & Yuan, B. J. (2010). An assessment of exploiting renewable energy sources with concerns of policy and technology. *Energy Policy, 38*(8), 4604–4616.
176. Milani, A. S., Shanian, A., & El-Lahham, C. (2006). Using different ELECTRE methods in strategic planning in the presence of human behavioral resistance. *Journal of Applied Mathematics and Decision Sciences, 2006*, 1–19.
177. Crawley, D. B., Hand, J. W., Kummert, M., & Griffith, B. T. (2008). Contrasting the capabilities of building energy performance simulation programs. *Building and Environment, 43*(4), 661–673.
178. Yerramalla, S., Davari, A., Feliachi, A., & Biswas, T. (2003). Modeling and simulation of the dynamic behavior of a polymer electrolyte membrane fuel cell. *Journal of Power Sources, 124*(1), 104–113.
179. Markel, T., Brooker, A., Hendricks, T., Johnson, V., Kelly, K., Kramer, B., O'Keefe, M., Sprik, S., & Wipke, K. (2002). ADVISOR: a systems analysis tool for advanced vehicle modeling. *Journal of Power Sources, 110*(2), 255–266.
180. Daim, T. U., Rueda, G., Martin, H., & Gerdsri, P. (2006). Forecasting emerging technologies: Use of bibliometrics and patent analysis. *Technological Forecasting and Social Change, 73*(8), 981–1012.

181. Shah, R. C., Roy, S., Jain, S., & Brunette, W. (2003). Data mules: Modeling and analysis of a three-tier architecture for sparse sensor networks. *Ad Hoc Networks, 1*(2), 215–233.
182. Swan, L. G., & Ugursal, V. I. (2009). Modeling of end-use energy consumption in the residential sector: A review of modeling techniques. *Renewable and Sustainable Energy Reviews, 13*(8), 1819–1835.
183. Kellner, M. I., Madachy, R. J., & Raffo, D. M. (1999). Software process simulation modeling: why? what? how? *Journal of Systems and Software, 46*(2), 91–105.
184. Perez, R., Ineichen, P., Seals, R., Michalsky, J., & Stewart, R. (1990). Modeling daylight availability and irradiance components from direct and global irradiance. *Solar Energy, 44*(5), 271–289.
185. Fong, K. F., Hanby, V. I., & Chow, T. T. (2006). HVAC system optimization for energy management by evolutionary programming. *Energy and Buildings, 38*(3), 220–231.
186. Cai, Y. P., Huang, G. H., Lin, Q. G., Nie, X. H., & Tan, Q. (2009). An optimization-model-based interactive decision support system for regional energy management systems planning under uncertainty. *Expert Systems with Applications, 36*(2), 3470–3482.
187. Yang, H., Zhou, W., Lu, L., & Fang, Z. (2008). Optimal sizing method for stand-alone hybrid solar–wind system with LPSP technology by using genetic algorithm. *Solar Energy, 82*(4), 354–367.
188. Li, C. H., Zhu, X. J., Cao, G. Y., Sui, S., & Hu, M. R. (2009). Dynamic modeling and sizing optimization of stand-alone photovoltaic power systems using hybrid energy storage technology. *Renewable Energy, 34*(3), 815–826.
189. Ulleberg, Ø. (2003). Modeling of advanced alkaline electrolyzers: a system simulation approach. *International Journal of Hydrogen Energy, 28*(1), 21–33.
190. Banos, R., Manzano-Agugliaro, F., Montoya, F. G., Gil, C., Alcayde, A., & Gómez, J. (2011). Optimization methods applied to renewable and sustainable energy: A review. *Renewable and Sustainable Energy Reviews, 15*(4), 1753–1766.
191. Ren, H., Gao, W., & Ruan, Y. (2009). Economic optimization and sensitivity analysis of photovoltaic system in residential buildings. *Renewable Energy, 34*(3), 883–889.
192. Benonysson, A., Bøhm, B., & Ravn, H. F. (1995). Operational optimization in a district heating system. *Energy Conversion and Management, 36*(5), 297–314.
193. Münster, M., & Meibom, P. (2011). Optimization of use of waste in the future energy syste. *Energy, 36*(3), 1612–1622.
194. Cavallaro, F. (2010). Fuzzy TOPSIS approach for assessing thermal-energy storage in concentrated solar power (CSP) systems. *Applied Energy, 87*(2), 496–503.
195. Behzadian, M., Otaghsara, S. K., Yazdani, M., & Ignatius, J. (2012). A state-of the-art survey of TOPSIS applications. *Expert Systems with Applications, 39*(17), 13051–13069.
196. Chamodrakas, I., & Martakos, D. (2012). A utility-based fuzzy TOPSIS method for energy efficient network selection in heterogeneous wireless networks. *Applied Soft Computing, 12*(7), 1929–1938.
197. Sadeghzadeh, K., & Salehi, M. B. (2011). Mathematical analysis of fuel cell strategic technologies development solutions in the automotive industry by the TOPSIS multi-criteria decision making method. *International Journal of Hydrogen Energy, 36*(20), 13272–13280.
198. Yan, G., Ling, Z., & Dequn, Z. (2011). Performance evaluation of coal enterprises energy conservation and reduction of pollutant emissions base on GRD-TOPSIS. *Energy Procedia, 5*, 535–539.
199. Choudhary, D., & Shankar, R. (2012). An STEEP-fuzzy AHP-TOPSIS framework for evaluation and selection of thermal power plant location: A case study from India. *Energy, 42*(1), 510–521.
200. Wang, E. (2015). Benchmarking whole-building energy performance with multi-criteria technique for order preference by similarity to ideal solution using a selective objective-weighting approach. *Applied Energy, 146*, 92–103.

201. Bas, E. (2013). The integrated framework for analysis of electricity supply chain using an integrated SWOT-fuzzy TOPSIS methodology combined with AHP: The case of Turkey. *International Journal of Electrical Power & Energy Systems, 44*(1), 897–907.
202. Haehnlein, S., Bayer, P., & Blum, P. (2010). International legal status of the use of shallow geothermal energy. *Renewable and Sustainable Energy Reviews, 14*(9), 2611–2625.
203. Daim, T. U., Kayakutlu, G., & Cowan, K. (2010). Developing Oregon's renewable energy portfolio using fuzzy goal programming model. *Computers & Industrial Engineering, 59*(4), 786–793.
204. Energyhomes.Org. (2008). *Leadership in energy and environmental design*. Centennial.
205. Kraan, C. M. (2013). Drivers and barriers to deep geothermal energy in the Netherlands: What are the implications of government policy?, M.Sc, University of Edinburgh, School of Geosciences.
206. Geothermal Basics – Power Plant Costs, Geo-energy.org. (2016). [Online]. Available: http://geo-energy.org/geo_basics_plant_cost.aspx. Accessed: 29 May 2016.
207. Rybach, L. (2003). Geothermal energy: sustainability and the environment. *Geothermics, 32*(4), 463–470.
208. Northwest Energy Efficiency Task Force, Nwcouncil.org. (2016). [Online]. Available: http://www.nwcouncil.org/energy/neet/home/. Accessed 29 May 2016.
209. State of Oregon, Employment Department, Population growth rate increases in Oregon for third straight year, W. Burchard, August 2015.
210. Shah, V. P., Debella, D. C., & Ries, R. J. (2008). Life cycle assessment of residential heating and cooling systems in four regions in the United States. *Energy and Buildings, 40*(4), 503–513.
211. Newsham, G. R., & Bowker, B. G. (2010). The effect of utility time-varying pricing and load control strategies on residential summer peak electricity use: a review. *Energy Policy, 38*(7), 3289–3296.
212. Saidur, R. (2010). A review on electrical motors energy use and energy savings. *Renewable and Sustainable Energy Reviews, 14*(3), 877–898.
213. Regnier, E. (2007). Oil and energy price volatility. *Energy Economics, 29*(3), 405–427.
214. Kaygusuz, K., & Kaygusuz, A. (2004). Geothermal energy in Turkey: the sustainable future. *Renewable and Sustainable Energy Reviews, 8*(6), 545–563.
215. Geothermal Energy Association. (2015). Annual U.S. & Global Geothermal Power Production Report, Geo-Energy.Org.
216. Daim, T., Yates, D., Peng, Y., & Jimenez, B. (August 2009). Technology assessment for clean energy technologies: the case of the Pacific Northwest. *Technology in Society, 31*(3), 232–243.
217. Gerdsri, P., & Kocaoglu, D. (2009). A systematic approach to developing national technology policy and strategy for emerging technologies: A case study of nanotechnology for Thailand's agriculture industry. In*In Management of Engineering & Technology, 2009. PICMET 2009. Portland International Conference* (pp. 447–461).
218. Hämäläinen, R. P., & Karjalainen, R. (1992). Decision support for risk analysis in energy policy. *European Journal of Operational Research, 56*(2), 172–183.
219. Gerdsri, P., & Kocaoglu, D. F. (2008). HDM for developing national emerging technology strategy and policy supporting sustainable economy: a case study of nanotechnology for Thailand's agriculture. In*Management of Engineering & Technology, 2008. PICMET 2008. Portland International Conference* (pp. 344–350).
220. Geothermal Technologies Program, D. K. Garman, U.S. Department of Energy, Energy Efficiency and Renewable Energy.
221. Fridleifsson, I. B. (2001). Geothermal energy for the benefit of the people. *Renewable and Sustainable Energy Reviews, 5*(3), 299–312.
222. Tourkolias, C., & Mirasgedis, S. (2011). Quantification and monetization of employment benefits associated with renewable energy technologies in Greece. *Renewable and Sustainable Energy Reviews, 15*(6), 2876–2886.

223. Agioutantis, Z., & Bekas, A. (2000). The potential of district heating using geothermal energy. A case study, Greece. *Geothermics, 29*(1), 51–64.
224. Chatzimouratidis, A. I., & Pilavachi, P. A. (2008). Multicriteria evaluation of power plants impact on the living standard using the analytic hierarchy process. *Energy Policy, 36*(3), 1074–1089.
225. Lehr, U., Nitsch, J., Kratzat, M., Lutz, C., & Edler, D. (2008). Renewable energy and employment in Germany. *Energy Policy, 36*(1), 108–117.
226. Geothermal Rules Encourage AlternativeEnergy Development on Federal Lands, Doi.gov. (2016). [Online]. Available: https://www.doi.gov/sites/doi.gov/files/archive/news/archive/06_News_Releases/060721a.htm. Accessed 01 Jun 2016.
227. Geothermal Energy, US Department of interior, Bureau of land management.
228. Geothermal Energy Why it matters to Oregon, Oregon Department of Energy, Salem, December 2014.
229. Evans, A., Strezov, V., & Evans, T. J. (2009). Assessment of sustainability indicators for renewable energy technologies. *Renewable and Sustainable Energy Reviews, 13*(5), 1082–1088.
230. Hondo, H. (2005). Life cycle GHG emission analysis of power generation systems: Japanese case. *Energy, 30*(11), 2042–2056.
231. Panwar, N. L., Kaushik, S. C., & Kothari, S. (2011). Role of renewable energy sources in environmental protection: a review. *Renewable and Sustainable Energy Reviews, 15*(3), 1513–1524.
232. Kaygusuz, K. (2009). Energy and environmental issues relating to greenhouse gas emissions for sustainable development in Turkey. *Renewable and Sustainable Energy Reviews, 13*(1), 253–270.
233. Bayer, P., Saner, D., Bolay, S., Rybach, L., & Blum, P. (2012). Greenhouse gas emission savings of ground source heat pump systems in Europe: A review. *Renewable and Sustainable Energy Reviews, 16*(2), 1256–1267.
234. Jacobson, M. Z., & Delucchi, M. A. (2011). Providing all global energy with wind, water, and solar power, Part I: Technologies, energy resources, quantities and areas of infrastructure, and materials. *Energy Policy, 39*(3), 1154–1169.
235. Abbasi, S. A., & Abbasi, N. (2000). The likely adverse environmental impacts of renewable energy sources. *Applied Energy, 65*(1), 121–144.
236. De Vries, B. J., Van Vuuren, D. P., & Hoogwijk, M. M. (2007). Renewable energy sources: Their global potential for the first-half of the 21st century at a global level: An integrated approach. *Energy Policy, 35*(4), 2590–2610.
237. Mahmoudi, H., Spahis, N., Goosen, M. F., Ghaffour, N., Drouiche, N., & Ouagued, A. (2010). Application of geothermal energy for heating and fresh water production in a brackish water greenhouse desalination unit: A case study from Algeria. *Renewable and Sustainable Energy Reviews, 14*(1), 512–517.
238. Fehler, M. C. (1989). Stress control of seismicity patterns observed during hydraulic fracturing experiments at the Fenton Hill Hot Dry Rock geothermal energy site, New Mexico. *International Journal of Rock Mechanics and Mining Sciences & Geomechanics Abstracts, 26*(3), 211–219.
239. Pine, R. J., & Batchelor, A. S. (1984). Downward migration of shearing in jointed rock during hydraulic injections. *International Journal of Rock Mechanics and Mining Sciences & Geomechanics Abstracts, 21*(5), 249–263.
240. Evans, K. F., Zappone, A., Kraft, T., Deichmann, N., & Moia, F. (2012). A survey of the induced seismic responses to fluid injection in geothermal and CO 2 reservoirs in Europe. *Geothermics, 41*, 30–54.
241. Majer, E. L., & Peterson, J. E. (2007). The impact of injection on seismicity at The Geysers, California Geothermal Field. *International Journal of Rock Mechanics and Mining Sciences, 44*(8), 1079–1090.

242. Charléty, J., Cuenot, N., Dorbath, L., Dorbath, C., Haessler, H., & Frogneux, M. (2007). Large earthquakes during hydraulic stimulations at the geothermal site of Soultz-sous-Forêts. *International Journal of Rock Mechanics and Mining Sciences, 44*(8), 1091–1105.
243. Chang, J., Leung, D. Y., Wu, C. Z., & Yuan, Z. H. (2003). A review on the energy production, consumption, and prospect of renewable energy in China. *Renewable and Sustainable Energy Reviews, 7*(5), 453–468.
244. Asif, M., & Muneer, T. (2007). Energy supply, its demand and security issues for developed and emerging economies. *Renewable and Sustainable Energy Reviews, 11*(7), 1388–1413.
245. Akella, A. K., Saini, R. P., & Sharma, M. P. (2009). Social, economical and environmental impacts of renewable energy systems. *Renewable Energy, 34*(2), 390–396.
246. Omer, A. M. (2008). Energy, environment and sustainable development. *Renewable and Sustainable Energy Reviews, 12*(9), 2265–2300.
247. Shuit, S. H., Tan, K. T., Lee, K. T., & Kamaruddin, A. H. (2009). Oil palm biomass as a sustainable energy source: a Malaysian case study. *Energy, 34*(9), 1225–1235.
248. Bilgen, S., Keleş, S., Kaygusuz, A., Sarı, A., & Kaygusuz, K. (2008). Global warming and renewable energy sources for sustainable development: a case study in Turkey. *Renewable and Sustainable Energy Reviews, 12*(2), 372–396.
249. Fridleifsson, I. B. (2003). Status of geothermal energy amongst the world's energy sources. *Geothermics, 32*(4), 379–388.
250. Evrendilek, F., & Ertekin, C. (2003). Assessing the potential of renewable energy sources in Turkey. *Renewable Energy, 28*(15), 2303–2315.
251. Kumar, A., Kumar, K., Kaushik, N., Sharma, S., & Mishra, S. (2010). Renewable energy in India: current status and future potentials. *Renewable and Sustainable Energy Reviews, 14*(8), 2434–2442.
252. Østergaard, P. A., & Lund, H. (2011). A renewable energy system in Frederikshavn using low-temperature geothermal energy for district heating. *Applied Energy, 88*(2), 479–487.
253. Rezaie, B., & Rosen, M. A. (2012). District heating and cooling: Review of technology and potential enhancements. *Applied Energy, 93*, 2–10.
254. Chamorro, C. R., Mondéjar, M. E., Ramos, R., Segovia, J. J., Martín, M. C., & Villamañán, M. A. (2012). World geothermal power production status: Energy, environmental and economic study of high enthalpy technologies. *Energy, 42*(1), 10–18.
255. Lund, J. W., Freeston, D. H., & Boyd, T. L. (2011). Direct utilization of geothermal energy 2010 worldwide review. *Geothermics, 40*(3), 159–180.
256. Ball, M., & Wietschel, M. (2009). The future of hydrogen–opportunities and challenges. *International Journal of Hydrogen Energy, 34*(2), 615–627.
257. Crompton, P., & Wu, Y. (2005). Energy consumption in China: past trends and future directions. *Energy Economics, 27*(1), 195–208.
258. Dorian, J. P., Franssen, H. T., & Simbeck, D. R. (2006). Global challenges in energy. *Energy Policy, 34*(15), 1984–1991.
259. Franco, A., & Diaz, A. R. (2009). The future challenges for "clean coal technologies": joining efficiency increase and pollutant emission control. *Energy, 34*(3), 348–354.
260. Oh, T. H., Pang, S. Y., & Chua, S. C. (2010). Energy policy and alternative energy in Malaysia: issues and challenges for sustainable growth. *Renewable and Sustainable Energy Reviews, 14*(4), 1241–1252.
261. Stiegel, G. J., & Ramezan, M. (2006). Hydrogen from coal gasification: an economical pathway to a sustainable energy future. *International Journal of Coal Geology, 65*(3), 173–190.
262. Dincer, I. (2000). Renewable energy and sustainable development: a crucial review. *Renewable and Sustainable Energy Reviews, 4*(2), 157–175.
263. Momirlan, M., & Veziroglu, T. N. (2005). The properties of hydrogen as fuel tomorrow in sustainable energy system for a cleaner planet. *International Journal of Hydrogen Energy, 30*(7), 795–802.
264. Lund, J. W., Freeston, D. H., & Boyd, T. L. (2005). Direct application of geothermal energy: 2005 worldwide review. *Geothermics, 34*(6), 691–727.

265. Chiodini, G., & Cioni, R. (1989). Gas geobarometry for hydrothermal systems and its application to some Italian geothermal areas. *Applied Geochemistry, 4*(5), 465–472.
266. Hepbasli, A., & Akdemir, O. (2004). Energy and exergy analysis of a ground source (geothermal) heat pump system. *Energy Conversion and Management, 45*(5), 737–753.
267. Casas, W., & Schmitz, G. (2005). Experiences with a gas driven, desiccant assisted air conditioning system with geothermal energy for an office building. *Energy and Buildings, 37*(5), 493–501.
268. Sanner, B., Karytsas, C., Mendrinos, D., & Rybach, L. (2003). Current status of ground source heat pumps and underground thermal energy storage in Europe. *Geothermics, 32*(4), 579–588.
269. Cai, W. G., Wu, Y., Zhong, Y., & Ren, H. (2009). China building energy consumption: situation, challenges and corresponding measures. *Energy Policy, 37*(6), 2054–2059.
270. Hähnlein, S., Bayer, P., Ferguson, G., & Blum, P. (2013). Sustainability and policy for the thermal use of shallow geothermal energy. *Energy Policy, 59*, 914–925.
271. Allen, A., Milenic, D., & Sikora, P. (2003). Shallow gravel aquifers and the urban 'heat island'effect: a source of low enthalpy geothermal energy. *Geothermics, 32*(4), 569–578.
272. Stambouli, A. B., Khiat, Z., Flazi, S., & Kitamura, Y. (2012). A review on the renewable energy development in Algeria: current perspective, energy scenario and sustainability issues. *Renewable and Sustainable Energy Reviews, 16*(7), 4445–4460.
273. Akorede, M. F., Hizam, H., & Pouresmaeil, E. (2010). Distributed energy resources and benefits to the environment. *Renewable and Sustainable Energy Reviews, 14*(2), 724–734.
274. Bloomquist, R. G. (2003). Geothermal space heating. *Geothermics, 32*(4), 513–526.
275. Shen, L. Y., & Tam, V. W. (2002). Implementation of environmental management in the Hong Kong construction industry. *International Journal of Project Management, 20*(7), 535–543.
276. Tsoutsos, T., Frantzeskaki, N., & Gekas, V. (2005). Environmental impacts from the solar energy technologies. *Energy Policy, 33*(3), 289–296.
277. Payraudeau, S., & van der Werf, H. M. (2005). Environmental impact assessment for a farming region: a review of methods. *Agriculture, Ecosystems & Environment, 107*(1), 1–19.
278. Krajnc, D., & Glavič, P. (2005). A model for integrated assessment of sustainable development. *Resources, Conservation and Recycling, 43*(2), 189–208.
279. Menegaki, A. (2008). Valuation for renewable energy: a comparative review. *Renewable and Sustainable Energy Reviews, 12*(9), 2422–2437.
280. Tam, C. M., Tam, V. W., & Tsui, W. S. (2004). Green construction assessment for environmental management in the construction industry of Hong Kong. *International Journal of Project Management, 22*(7), 563–571.
281. Berardi, U. (2013). Stakeholders' influence on the adoption of energy-saving technologies in Italian homes. *Energy Policy, 60*, 520–530.
282. Gilchrist, A., & Allouche, E. N. (2005). Quantification of social costs associated with construction projects: state-of-the-art review. *Tunnelling and Underground Space Technology, 20*(1), 89–104.
283. Christie, N., Smyth, K., Barnes, R., & Elliott, M. (2014). Co-location of activities and designations: A means of solving or creating problems in marine spatial planning? *Marine Policy, 43*, 254–261.
284. Geo-energy.org, Geothermal Basics – Basics. (2015). [Online]. Available: http://geo-energy.org/Basics.aspx. Accessed 25 June 2015.
285. Huang, B., Ouyang, Z., Zheng, H., Zhang, H., & Wang, X. (2008). Construction of an eco-island: a case study of Chongming Island, China. *Ocean and Coastal Management, 51*(8), 575–588.
286. Energyalmanac.ca.gov, Types of Geothermal Power Plants. (2015). [Online]. Available: http://energyalmanac.ca.gov/renewables/geothermal/types.html. Accessed 25 June 2015.
287. Yari, M. (2010). Exergetic analysis of various types of geothermal power plants. *Renewable Energy, 35*(1), 112–121.
288. Shanben, Q., Fangxun, L. I., & Nianru, L. I. (1989). Turbogenerator units operating on duo-flash cycle in the Yangbajain geothermal power plant, Tibet, China. In*Energy Conversion Engineering Conference, 1989. IECEC-89., Proceedings of the 24th Intersociety* (pp. 2151–2154).

289. Gallup, D. L. (1996). Combination flash-bottoming cycle geothermal power generation: a case history. In*Energy conversion engineering conference, 1996. IECEC 96., proceedings of the 31st intersociety* (Vol. 3, pp. 1622–1627).
290. Jalilinasrabady, S., Itoi, R., Valdimarsson, P., Saevarsdottir, G., & Fujii, H. (2012). Flash cycle optimization of Sabalan geothermal power plant employing exergy concept. *Geothermics, 43*, 75–82.
291. Luo, C., Huang, L., Gong, Y., & Ma, W. (2012). Thermodynamic comparison of different types of geothermal power plant systems and case studies in China. *Renewable Energy, 48*, 155–160.
292. Geothermal.marin.org, Introduction to Geothermal Energy – Power Plant Geysers 2. (2015). [Online]. Available: http://geothermal.marin.org/geopresentation/sld053.htm. Accessed 25 June 2015.
293. Onlinenevada.org, Steamboat Springs Geothermal Field | ONE. (2015). [Online]. Available: http://www.onlinenevada.org/articles/steamboat-springs-geothermal-field. Accessed 25 June 2015.
294. Bliem, C. J., & Mines, G. L. (1991). *Advanced binary geothermal power plants: Limits of performance*. Idaho Falls: EG and G Idaho.
295. Lund, J. W., & Klein, R. (1995). Prawn Park-Taupo, New Zealand. *Geo-Heat Center Quarterly Bulletin, 16*(4), 27–29.
296. Truesdell, A. H., & White, D. E. (1973). Production of superheated steam from vapor-dominated geothermal reservoirs. *Geothermics, 2*(3), 154–173.
297. Kanoglu, M. (2002). Exergy analysis of a dual-level binary geothermal power plant. *Geothermics, 31*(6), 709–724.
298. Kanoğlu, M., & Çengel, Y. A. (1999). Economic evaluation of geothermal power generation, heating, and cooling. *Energy, 24*(6), 501–509.
299. Toni, B. (2011). Geothermal demonstration project.
300. Oit.edu, Geo-Heat Center. (2015). [Online]. Available: http://www.oit.edu/orec/geo-heat-center. Accessed 25 June 2015.
301. Renewable Energy in Oregon, American Council On Renewable Energy (ACORE), September 2014.
302. Geothermal Exchange Organization, Geothermal Exchange Organization – Geothermal Heat Pumps. (2015). [Online]. Available: https://www.geoexchange.org/. Accessed 25 June 2015.
303. Energy.gov, Direct Use of Geothermal Energy | Department of Energy. (2015). [Online]. Available: http://energy.gov/eere/geothermal/direct-use-geothermal-energy. Accessed 25 June 2015.
304. Huttrer, G. W. (2001). The status of world geothermal power generation 1995–2000. *Geothermics, 30*(1), 1–27.
305. Hurter, S., & Schellschmidt, R. (2003). Atlas of geothermal resources in Europe. *Geothermics, 32*(4), 779–787.
306. Cataldi, R., Mongelli, F., Squarci, P., Taffi, L., Zito, G., & Calore, C. (1995). Geothermal ranking of Italian territory. *Geothermics, 24*(1), 115–129.
307. Lund, J. W. (2003). The USA geothermal country update. *Geothermics, 32*(4), 409–418.
308. Energy.gov, Geothermal Heat Pumps. (2015). [Online]. Available: http://energy.gov/energysaver/articles/geothermal-heat-pumps. Accessed 25 June 2015.
309. Oregon.gov, Geothermal Energy Ground-Source Heat Pumps. (2015). [Online]. Available: http://www.oregon.gov/energy/renew/geothermal/pages/gshp.aspx. Accessed 25 June 2015.
310. Current, J., Ratick, S., & ReVelle, C. (1998). Dynamic facility location when the total number of facilities is uncertain: A decision analysis approach. *European Journal of Operational Research, 110*(3), 597–609.
311. Okoli, C., & Pawlowski, S. D. (2004). The Delphi method as a research tool: an example, design considerations and applications. *Information Management, 42*(1), 15–29.
312. Sheikh, N., Daim, T., & Kocaoglu, D. F. (2011). Use of multiple perspectives and decision modeling for PV technology assessment. In*Technology Management in the Energy Smart World (PICMET 2011)* (pp. 1–21).

313. Nutt, D. J., King, L. A., & Phillips, L. D. (2010). Drug harms in the UK: a multicriteria decision analysis. *The Lancet, 376*(9752), 1558–1565.
314. Kim, S. Y., Karlawish, J. H., & Caine, E. D. (2002). Current state of research on decision-making competence of cognitively impaired elderly persons. *The American Journal of Geriatric Psychiatry, 10*(2), 151–165.
315. Liberatore, M. J., & Nydick, R. L. (2008). The analytic hierarchy process in medical and health care decision making: A literature review. *European Journal of Operational Research, 189*(1), 194–207.
316. Shanteau, J. (1988). Psychological characteristics and strategies of expert decision makers. *Acta Psychologica, 68*(1–3), 203–215.
317. Daim, T. U. (1998). Technology evaluation and acquisition strategies and their implications in the US electronics manufacturing industry, Portland State University.
318. Fink, A. J. M. R. H. (1984). *American Journal of Public Health, 74*, 979–983.
319. Weiss, D. J., & Shanteau, J. (2003). Empirical assessment of expertise. *Human Factors: The Journal of the Human Factors and Ergonomics Society, 45*(1), 104–116.
320. Ra, J. W. (1988). *Analysis of expert judgments in hierarchical decision process*. University of Pittsburgh.
321. G. Council, What is Geothermal? – Geothermal Resources Council, Geothermal.org. (2017). [Online]. Available: https://geothermal.org/what.html. Accessed 19 Jan 2017.
322. Geothermal heat pump, En.wikipedia.org. (2017). [Online]. Available: https://en.wikipedia.org/wiki/Geothermal_heat_pump. Accessed: 19 Jan 2017.
323. Geothermal Today. (2003). 1st ed. U.S Department of Energy.
324. (2017). [Online]. Available: https://www.nrel.gov/workingwithus/re-geo-elec-production.html. Accessed 19 Jan 2017.
325. Paired Comparison Analysis: Working Out Relative Importances, Mindtools.com. (2017). [Online]. Available: https://www.mindtools.com/pages/article/newTED_02.htm. Accessed 19 Jan 2017.

Chapter 5
Technology Assessment: Demand Response Technologies in the Pacific Northwest

Judith Estep and Tugrul U. Daim

5.1 Introduction

The goal of this research is to develop a decision model that can be used to identify the technology transfer potential of a research proposal. An organization can use the model to select the proposals whose research outcomes are more likely to move into application. The model begins to close the chasm between research and application – otherwise known as the "valley of death." A hierarchical decision model, along with desirability curves, was used to understand the complexities of the researcher and recipient relationship, specific to technology transfer. In this research, the evaluation criteria of several research organizations were assessed to understand the extent to which the success attributes that were identified in literature were considered when reviewing research proposals. The quantified model was validated using a case study involving demand response (DR) technology proposals in the Pacific Northwest.

While there are voluminous amounts of information about technology transfer and attributes of successful technology transfer, there is a lack of information about how to assimilate these success attributes – in other words, a framework for *how* successful technology transfer occurs. It is not enough to just *develop* a technology that solves an energy-related problem. Utilities are also faced with a challenge of integrating the technology into an existing infrastructure and doing so, reliably and seamlessly. In order for a solution to be effective and have an impact, the technology needs to be *applied* – without the technology transfer component, energy strategies

J. Estep
Bonneville Power Administration, Portland, OR, USA
e-mail: jaestep@bpa.gov

T.U. Daim (✉)
Portland State University, Portland, OR, USA
e-mail: tugrul.u.daim@pdx.edu

T.U. Daim et al. (eds.), *Infrastructure and Technology Management*,
Innovation, Technology, and Knowledge Management,
https://doi.org/10.1007/978-3-319-68987-6_5

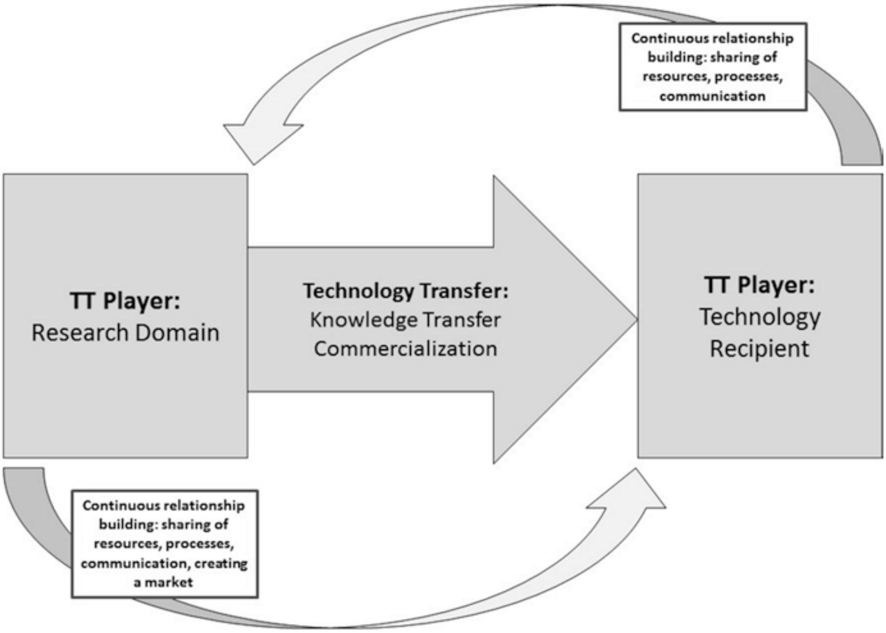


Fig. 5.1 How technology transfer is understood for this research

cannot be realized. Therefore, there is a need to understand the difficulties associated with technology transfer.

Figure 5.1 represents how technology transfer will be understood for the purposes of this research. The players are the research organizations (national labs, universities, nonprofit collaborators, and private industry) and the technology recipient.

5.2 Literature Review

5.2.1 Attributes of Successful TT

A comprehensive literature review was conducted to understand what is necessary for successful technology transfer. Is there a special "recipe" that will guarantee a successful technology transfer? What should the research organization focus on to be successful? Should the technology recipient focus on similar attributes? Or do something different instead? How should the researcher and the technology recipient interact to emphasize the relationship element of technology transfer? The goal of this literature review section is to identify and define the success attributes. Initially, the technology transfer literature was organized using Reisman's taxonomy. Organizing the literature this way was helpful to identify ways of conceptualizing the voluminous amount of technology transfer literature. Reisman's taxonomy categorizes technology transfer into four main factors: the actors, transaction types, motivations, and disciplines involved in the technology transfer [1]. The first factor describes the *actors* – who is involved in the transfer process? Subgroups include scientific discipline, geographic locations, etc. Next are the *transaction types* that are important to frame the transfer process – does the process include internal or external elements, joint venture opportunities, or intellectual property, etc. As implied, *motivations* describe the reasons for executing the technology transfer. The *discipline* factor helps to understand if the technology transfer discussion is related to economics, management, etc.

5.2.1.1 Organizational

Organizational elements emphasize actions or processes within an organization that are necessary for successful technology transfer. Resounding themes in literature are developed in subsequent paragraphs. Researchers agree that less bureaucracy, close proximity between the researcher and the technology recipient, and the benefits of the two organizations having a similar makeup in terms of size and mission objectives and overall having organizational homogeneity, are beneficial for technology transfer. Literature also discusses the need to have a flexible budget as beneficial for technology transfer. Understanding the technical and stakeholder organizational complexities is also important to consider for technology transfer success.

Agreements or contracts are necessary for research and subsequent technology transfer. However, the degree of process or bureaucracy related to these agreements has an impact on successful technology transfer. Big or small, all organizations have a certain amount of agreements or contracts that are a necessary part of technology transfer. Bureaucracy is associated with any organization. Franza and Greiner suggest that organizations that have long times to contract or are otherwise bureaucratic in their processes is not good for technology transfer [2]. The impact of too much process is also described by Bozeman when he discusses Cooperative Research and Development Agreements (CRADAs). A CRADA agreement provides a quick and unique access to extensive government-funded R&D resources that can be pooled with your own money to yield powerful research results, while providing intellectual property protection as you move swiftly to commercialization [3]. Franza, Rogers, and Bozeman agree that the length of time to execute agreements and extensive bureaucracy is not desirable for technology transfer.

Ham and Mowrey say that flexible budgets are necessary for successful technology transfer. Working with the government labs, flexible budgets allow for a gradual ramp-up of a project. However, too much time to negotiate the contracting mechanism can stall the research and potentially change the project goals [4]. Bozeman states the inflexible budgets and managerial processes make the CRADA ineffective with requirements of technology development projects that must meet a tight schedule for success [3]. Another way of defining budget flexibility is with requiring cost share as part of the project funding. The Bonneville Power Administration, along with other Department of Energy research organizations, requires research partners to share in the financial responsibility of funding a project. There are varying degrees of cost share required, but the purpose is to create a collaborative work environment between the researcher and technology recipient. This is done through a shared investment.

The proximity between the researcher and the technology recipient is an important characteristic for successful technology transfer. Mora-Valentin et al. hypothesized that the closer the two entities are the better for technology transfer. Closer geographic locations facilitate face-to-face communications among team members and encourage relationship building. However, their research results were not conclusive [5]. In contrast, Franza et al. identify geographic proximity as a "difference maker." As defined, a difference maker is a set of attributes that were present in the successful transfers they researched and tend to be absent in the failed transfer attempts [6].

Boulter and Bendell look at the contributions of firm size, high degree of institutionalization, similar experiences for success, the mission of the organization, and similar agendas to successful technology transfers [7]. They describe these similarities as homophily or organizational homogeneity – they allow people to communicate better based on the degree of similarity. When there are disparities, especially with the expectations for success, there could be difficulties in successfully transferring the technology. One example of different expectations would be with national labs. Typically, the national lab culture is described as slow to change, with a basic research focus. This is in sharp contrast to private firms, which are characterized by speed, a quick decision-making, and fast returns on investments [8, 9]. Establishing common goals is a foundation for building collaborative relationships, which are fundamental to successful technology transfer. Grant and Franza researched 19 technology transfer actions from the US Air Force lab. The 19 actions or projects included failed and successful technology transfer. Of these, 92.9% of the successes had technology transfer between similar industries and 100% had similar composition [6]. Research results from Ham and Mowrey, Balachandra, Bozeman, Wen-Hsiang, and Greiner and Franza support the concept of similarities between the research organization and the technology recipient as contributing to successful technology transfer. The concept of organizational homogeneity can be extended to include risk propensity. Risk propensity is defined as the level of research risk the researcher and technology recipient are willing to manage. Perry states that national labs are risk averse – their target is to by 80–90% successful. Compare this risk inclination to a start-up where the expectation is an 80–90% failure rate; these mind-sets are in stark contrast. The expectations for success are very different so the likelihood of successful technology transfer is diminished [10]. Greiner and Franza specify technical risk adversity as a barrier to technology transfer. In their research, operators are comfortable with the status quo, which creates an unwillingness to test or accept the new technology [2].

Finally, complexities related to technologies and stakeholders are considered relative to successful technology transfer. In order to ensure a sense of ownership is created with the research, stakeholders need to be considered during the R&D phase. Their contributions during the R&D phase will facilitate a successful technology transfer. A common theme related to organizational cultures is the need for stakeholder engagement. Balachandra states, "…a climate for stimulating innovation and facilitating meaningful technology diffusion is created by…stakeholders" [8]. Painuly identifies critical elements necessary for a successful technology transfer to include mechanisms to realize and encourage stakeholder involvement. Stakeholders are also pivotal to the identification and navigating barriers to successful outcomes [11]. Related to technical complexities, the more complex technology requires higher cooperation between transferor and transferee in order to make the best utility in the technology. Technologies that are more complex will incite more interest and interest in obtaining the technology from the researcher [12].

Table 5.1 summarizes the organizational strategies that are necessary for successful technology transfer.

Table 5.1 Organizational success attributes

Attribute: literature defined	Description	Source
Bureaucracy	This attribute considers the level of detail and duration of setting up agreements/contracts between the researchers and technology recipients	Bozeman [13], Franza et al. [14], and Lutzenhiser [15]
Budget flexibility	The ability to have budget flexibility is preferred for successful technology transfer. In this context, budget flexibility is defined as allowing budget to move between fiscal years, amount of discretionary funding or cost share required to fund a project, and the personnel level that is authorized to release funding	Franza and Grant [6], Ham and Mowery [4], Balachandra et al. [8], and Bozeman [13]
Geographic proximity	Refers to the geographic proximity between the researcher and technology recipient	Franza and Grant [6], Bozeman [13], Greiner and Franza [2], Mora-Valentin et al. [5], and Boutler and Bendell [7]
Technical and stakeholder complexities	This attribute refers to the number of impacted stakeholders/project team and the number of research areas (road map topics) addressed by the proposal	Wen-Hsiang and Tsai [12], Mueller and Wallace [16], and Greiner and Franza [2]
Organizational homogeneity	Similar strategic alignment, high degree of institutionalization, similar industries and composition of personnel, size of firms, motivations for doing research, and similar expectations for success	Franza and Grant [6], Ham and Mowery [4], Balachandra et al. [8], Bozeman [13], Wen-Hsiang and Tsai [12], Lutzenhiser [15], and Greiner and Franza [2]

5.2.1.2 Technological

This perspective considers actions related to the technology as important for successful technology transfer. Actions include the researcher's previous cooperative experience and ability to demonstrate the technology, understanding of the recipient's technology needs, and the existence of and ability of the Technology Transfer Office to be effective at marketing the technology. The literature review summary that follows supports this perspective definition.

Some technology transfer barriers are related to the maturity of the technology. Technologies that are immature, or lower on the technology readiness level (TRL) scales, are associated with basic research and not yet likely to be considered for application. However, technologies that have higher TRLs (levels 8–9) are ready for demonstration; the concept of technology readiness levels was introduced in Chap. 1. Mueller, M, et al., Shove, E, and Luiten, E. et al. state that the interest in a technology is elevated when there have been successful demonstration projects [16]. Successful demonstrations minimize the risk of investing in an otherwise unknown technology, communicate the benefits of using the technology, help to develop interoperability standards [17], and provide an opportunity for user feedback that could be included in future revisions. In fact, these demonstrations help to create a market, or demand, for the technology. These demonstrations set the stage for a "market-pull" environment, where technology transfer is more likely to occur. The researchers suggest that successful demonstration projects help to establish the market, and this market is made up of individuals who will be technology recipients. Demonstration projects are helpful to minimize the public's perception of the "invisibility of energy measures" [2]. In other words, the public is less likely to adopt a technology if they cannot appreciate the net benefit. The technology must address the question, "What's in it for me?" Specific to energy efficiency innovations, communication is vital to increase user acceptance or encourage people to use the technology. One way of communicating is through demonstrations or technology publications.

It is important to understand the needs of the technology recipient. This knowledge helps to proactively address the question of "what's in it for me." The public's willingness to change has the potential of stifling technology transfer. They don't want to change their lifestyle (e.g., turning back their hot water heater or turning up their air conditions in demand response scenarios), they are skeptical of new innovations, and there is a feeling that the public opinion was not considered when designing products. In these cases, a market was not created [11, 13].

The existence of a dedicated technology transfer office is identified as a "difference maker," when considering successful attributes. Franza et al. research [6] was to identify attributes most strongly associated with successful technology transfer. Franza identified "difference makers" as essential elements that were included in the majority of successful transfers. The existence of a dedicated TT Office was foremost. It is a necessary conduit moving from research into application. Given the existence of a TTO, it should be staffed with marketing experience, and dedicating a portion of the budget to marketing and technology transfer activities is seen as essential to create a market that is willing to accept the technology [18]. Franza states that emphasis should be placed on advertising to the relevant industry [6]. In fact, Siegel suggests that the TT Office should be staffed with marketing personnel [18]. A market pull is more easily created if the needs of the adopters are understood.

Technology elements do not refer to the technology itself, in terms of its ability to meet technology specifications (e.g., durability, etc.). Rather the focus is on setting up an environment for technology transfer to occur. In addition, an emphasis is placed on activities that create a market that is ready to accept the technology. Therefore, technological elements are defined as creating these opportunities. Table 5.2 summarizes the technological success attributes.

5.2.1.3 Social

The social perspective is the view of the situation from the eyes of the individual(s) and involves actions related to people. A common theme among the researchers is creating an atmosphere of trust – having transparent, effective communication is pivotal for success. This involves a heightened cultural awareness as necessitated by

Table 5.2 Technological success attributes

Attribute: literature defined	Description	Source
Cooperative experience	How much experience does the researcher have working with others? Are they new (no cooperative experience) or are they very familiar working with other organizations on R&D. More cooperative experience implies higher likelihood of technology transfer because they are familiar with potential barriers based on their previous experience	Wen-Hsiang and Tsai [12], and Mora-Valentin et al. [5]
Understanding the recipient	Understand perceptions of adopters; how familiar is the research organization with the customer requirements and/or market needs	Sharma [19], Balachandra et al. [8], and Isaacs et al. [20]
Educate/demonstrate technology	How many successful technology demonstrations does the organization have (for the case study)? As an example, assuming the case study is for demand response technologies, how many demonstrations of heat pump water heaters has the researcher been involved with – more technology demonstrations are better for successful technology transfer. Demonstrations are one way to educate others about the technology	Balachandra et al. [8], Wen-Hsiang and Tsai [12], Greiner and Franza [2], and Spann et al. [21]
Dedicated TTO	Does the research organization have a dedicated TTO that can coordinate activities between the researcher and the technology recipient	Franza and Grant [6]
TTO marketing experience	Literature suggests that the TTO should be staffed with personnel who have marketing experience	Siegel et al. [18]

an ever-developing global economy. The policies around how many people are dedicated to the technology transfer effort and the willingness of the researcher to "loan" personnel are desirable for successful technology transfer. Finally, recognizing success with a reward system is cited as beneficial for technology transfer. These themes will be developed and substantiated with literature citations.

An atmosphere of trust is created by effective and frequent communication throughout the R&D process. Communication within or to an organization is also significant as technology moves from research and development to the early stages of technology transfer. Consistent throughout the literature was the significant influence communication had on the technology transfer process, especially when discussing energy innovation. L.M. Murphy et al. state that "…reducing information gaps between public and private sectors…" and "…ensuring access to data knowledge…" are essential [22]. Other authors discuss the higher the trust, the more willing an organization is to share information – the trust is established via effective and active communication [4]. "Trust is crucial in aiding the process involved with the transfer of all types of knowledge" [23]. Lai and Tsai state that the technology transfer process faces many skills related to the interaction of the stakeholders [12]. Therefore, a clear, positive, and understandable message facilitates technology transfer. Mora-Valentin verified that there was a correlation between higher levels of trust and a positive influence on technology transfer [5].

The idea of developing a relationship by creating an atmosphere of trust between the researcher and the recipient is complementary to the success attribute of cultural awareness. The global world economy provides opportunities to interface with other cultures. Being sensitive to communication styles and different heritages and being cognizant of the diversity of technology recipients are necessary for successful technology transfer. Lai and Tsai state "…cultural awareness is seen by researchers as necessary for successful technology transfer. Cultural differences have a significant impact on the success or failure of TT. Also, it is obvious that the higher similarity of cultures for two parties, the greater facilitation to the TT's performance…" [12]. Boulter and Bendell agree by stating "…attitude towards outsiders…find a common ground to be able to communicate effectively about multiple interests to seek a shared sense of purpose, goals, and rewards…" [7]. Regarding university technology transfer, Siegal says that work to eliminate cultural and informational barriers which are an impediment to technology transfer process [18].

Personnel involved in the technology transfer process, whether they be dedicated to integrate the technology or whether the research organization has a favorable leave policy, is beneficial for technology transfer. Related to university technology transfer, Siegal suggests devoting extra resources to the process [18]. Franza et al. suggest that the technology recipient should dedicate personnel over the life of the transfer project. This is one of the seven "difference makers" Franza identifies for successful technology transfer [6]. The research done by Mora-Valentin et al. says that more commitment has a positive influence on technology transfer [5]. Finally, E.M. Rogers suggests that the favorable entrepreneurial leave policies of the federal labs encourage technology transfer. By allowing researchers to be loaned to the technology recipient they are being used as a technology transfer mechanism, in essence, the movement of technology through people. This is a common practice in Japan. E.M. Rogers et al. use a case study to illustrate the effectiveness of "shuko" – a Japanese term that describes the temporary transfer of personnel knowledgeable about the technology to work with the technology recipient. This process encourages tacit knowledge transfer which is seen as having the potential for greater payoffs than tangible products [24].

Acknowledging successful transfers by having an established reward system encourages more innovative thinking as well as suggests the researchers have knowledge and experience with those attributes necessary for successful technology transfer. Siegal states that if universities want to foster an atmosphere of commercialization, one area of focus should be on developing a rewards system [18]. This practice is also in place at national labs and industry with the appointment of "fellows." This is a way of recognizing technical excellence in support of the organization's mission statement. To encourage research not being done in their "spare time," the CHI panel discussion encourages a reward system [25].

The balance between the public's disdain for new technology and realizing the benefits of the technology is precarious. The relationships between national labs and private firms are on similar footing. The consensus among the researchers is that sharing of information, personnel, and using opportunities for transparency are fundamental for successful technology transfer. Table 5.3 summarizes the social success attributes for technology transfer.

Table 5.3 Social success attributes

Attribute: literature defined	Description	Source
Atmosphere of trust	Fundamental to successful technology transfer is establishing a trusting relationship between the research and technology recipient. This can be accomplished by frequent communication, structured project management, cooperative risk assessments, etc.	Franza and Grant [6], Wen-Hsiang and Tsai [12], Greiner and Franza [2], Rogers et al. [24], Mora-Valentin et al. [5], and Boulter and Bendell [7]
Cultural awareness	Personnel that are more aware of and have more experience interacting with different cultures are more successful at technology transfer	Wen-Hsiang and Tsai [12], Greiner and Franza [2], Mora-Valentin et al. [5], and Boulter and Bendell [7]
Personnel involvement	This attribute refers to the degree that researchers are involved in the hand-off process. When do the researchers start to consider technology transfer and start to involve end users/technology recipients	Ham and Mowrey [4] and Rogers et al. [26]
Manpower flexibility	The willingness to "loan" researchers to help with technology transfer was cited as necessary for technology transfer; favorable leave policies	Balachandra et al. [8] and Perry [10]
Rewards system	Does the research or technology recipient organization have systems in place to recognize innovative thinking? Literature suggests that having a reward system in place facilitates technology transfer	Franza and Grant [6], Wen-Hsiang and Tsai [12], Greiner and Franza [2], Rogers et al. [24], and Mora-Valentin et al. [5]

5.2.1.4 Market

The last perspective to consider when identifying technology transfer success attributes is market. As the name implies, these success elements emphasize those attributes that are necessary to create a market that is willing and ready to accept the technology. These attributes include creating a business plan, having common standards and government incentives to encourage transfer, and establishing that the technology is financially feasible – think making a business case for solar panels. Related to people within the technology recipient organization, a supportive champion and the level of interest from top management can have an impact on technology transfer success. Each of these assertions is developed to include references from literature.

The adoption of solar panels is a good example of how financial feasibility, using government incentives, works to create a viable market for the technology. Initially, solar was too expensive for widespread adoption by the consumer. However, as the technology matured and incentives were implemented, the business case improves and adoption increases. Examples of government incentives include the 2009 Recovery Act, which invested billions into energy research. At the consumer level, the Ashland, OR, "Bright Way to Heat Loan" encourages solar-based water heating. The latter incentive is targeted to residential customers in the form of rebates or access to interest-free loans. In a market dominated by incumbent technologies, the researchers agree that, in order to realize widespread diffusion of a new technology, policies that encourage adoption are necessary. L.M. Murphy et al. state "…government activities to promote sustainable energy technologies must include both a supply push and a demand pull…" [22]. This environment is created by effective government policies. Fred Gordon, Energy Trust Oregon, suggested that in order to transform the market, the government agencies need to inject supply chain features when developing a technology as well as to provide training skills to help market adoption. Related to green buildings, Kok et al. provides evidence that the "…diffusion of energy efficient technologies is more responsive to energy prices…" [27]. Incentives to help create financial feasibility are also supported by Balachandra, "…government activities to support…adoption include both supply-push and demand-pull policies during the period spanning pre-commercialization…" [8]. Lai and Tsai state that, "…government policy is always a crucial factor in influencing technology transfer. The integrity of law…will stimulate or facilitate technology transfer activities" [12]. Franza identifies having a business plan for commercialization as one of his "difference makers" and serves as the basis for determining financial feasibility [6]. Grant and Franza's research, which examined 19 technology transfer activities, shows that an adequately funded project was present in 71% of successful transfers and having a business plan in place was identified in 80% of successful transfers [6].

Related to the need for support within the technology recipient organization, the CHI panel discussion stated, "…people, not papers, transfer technology. Technology transfer is a grass roots effort and requires buy-in and active participation.

It requires support from the top" [25]. Lai and Tsai state that the technology recipient's support is an important factor for successful technology transfer [12]. Carayannis et al. examined five successful technology transfer cases, and the presence of an internal champion and their commitment through the transfer process was vital; a strong champion was identified as a bridge between the research and technology application [28]. In Balachandra's research, top management support was a component in 100% of all successful technology transfers [8]. Bozeman supports the need for active support from management, "…Projects were more likely to transfer if they were initiated by either the R&D managers or top managers in the company…" [13].

The Table 5.4 summarizes the market related success attributes.

Table 5.4 Market success attributes

Attribute: literature defined	Description	Source
Business plan	Clearly defined need is created; technology recipient has a business plan for commercialization; diffusion process needs to be induced; does a comprehensive business plan exist that supports the technology in the recipient organization?	Franza and Grant [6] and Balachandra et al. [8]
Government incentives	Incentives are seen as a way to entice a market to invest in technology. Examples include rebates for purchasing LED lightbulbs or tax credits for wind farms	Balachandra et al. [8]
Financial feasibility	Has financial feasibility been determined? Examples include price point of solar panels for the residential market have not been completely realized and is seen as one of the barriers to their widespread adoption in the USA	Sharma [19] and Franza and Grant [6]
Organizational technology champion	A dedicated champion in the recipient organization is fundamental to successful technology transfer. The champion can shepherd the technology through organizational barriers; a sense of ownership is created	Balachandra et al. [8], Bozeman [13], and Painuly [11]
Level of top management interest	Technology transfer initiated and having top management involvement is necessary for technology transfer The top management in the organization needs to see the value of the technology. Their support is required for successful technology transfer	Bozeman [13]
Common standards	Common standards help to facilitate the introduction of multiple but similar technologies into the market. Common communication protocols are examples of standards that help to facilitate demand response technologies	Neshati [29] and Balachandra et al. [8]

5.3 Development of the Research Model

This research relies heavily on expert opinion of perspectives, success attributes, and methodologies related to technology transfer. Model weights are determined and desirability curves are developed by quantified expert judgments.

Each panel participant was contacted via email or personally to determine his or her ability and willingness to participate. The face-to-face or voice communications were helpful to describe the objective of the research and to discuss the level of the model they were asked to assess. The inconsistency and disagreements in the model results suggest that this was an effective means to clarify expectations.

Those who agreed to participate returned the necessary signed consent forms. Once these were received, the researcher sent a link to a Survey Monkey assessment tool to obtain their quantified judgment. Table 5.5 shows how the breakdown of each panel, their job titles, and the organizations they represent.

Table 5.5 Expert panels

Expert	Background	P_0	P_1	P_2	P_3	P_4	P_5	P_6
E1	Program Director, DOE	x	x					
E2	R&D Chief Officer, Utility	x	x				x	
E3	Vice President, Utility R&D Cooperative	x	x					
E4	Vice President, Utility R&D Cooperative		x					
E5	Sr. Vice President, Utility		x					
E6	Executive VP, Utility		x					
E7	Sr. Research Scientist, National Lab	x	x					
E8	R&D Executive, CAISO		x					
E9	Sr. Technology Transfer Manager, National Lab		x					
E10	Technology to Market Advisor, DOE	x	x					
E11	Vice President Technology Management, Utility R&D Cooperative	x	x					
E12	Sr. Analyst, NW Power Council						x	
E13	Sr. Analyst, Utility						x	
E14	Executive VP, Utility						x	x
E15	Policy Strategist, Utility						x	x
E17	Manager, Power Resources, Utility						x	
E18	Public Utilities Specialist, Utility						x	
E19	Director of Retail Programs, Utility						x	
E20	Sr. Public Utilities Specialist, Utility						x	x
E21	Project Manager, Industry			x		x		
E22	Project Manager, Utility			x		x		
E23	Project Manager, Consulting Services			x		x		x,x
E24	Project Manager, Industry			x		x		
E25	Professor, University			x		x		

(continued)

Table 5.5 (continued)

Expert	Background	P_0	P_1	P_2	P_3	P_4	P_5	P_6
E26	Sr. Instructor, University			x		x		
E27	Project Manager, Industry			x		x		
E28	Project Manager, Industry			x		x		
E29	Project Manager, Industry			x		x		x,x
E30	Project Manager, Utility			x		x		
E31	Project Manager, Consulting Services			x		x		
E32	Project Manager, Industry			x		x		
E33	Project Manager, Utility	x		x		x		x,x
E34	Demand Response Program Manager, Utility				x			
E35	Principal Investigator, Utility				x			
E36	Technical Executive, Utility R&D Cooperative				x			x
E37	Assistant Prof, University				x			
E38	Principal Investigator, Utility				x			
E39	Assistant Prof, University				x			x
E40	Principal Investigator, Utility				x			
E41	Principal Investigator, Utility				x			x
E42	Principal Investigator, National Lab				x			
E43	Principal Investigator, Utility R&D Cooperative				x			
E44	R&D Manager, Utility	x						
E45	Technology Transfer Manager, Utility R&D Cooperative	x						
E46	R&D Executive Consultant	x						
E47	Sr. R&D Technical Advisor, Utility R&D Cooperative	x						
E48	Professor, University	x						
E49	R&D Manager, Utility	x						
E50	R&D Manager, Utility	x						
E51	R&D Manager, Utility	x						
E52	R&D Manager, Utility	x						
E53	R&D Manager, Utility	x						
E54	Sr. R&D Technical Advisor, Utility R&D Cooperative	x			x			
Total		*18*	*11*	*13*	*11*	*13*	*9*	*9*

The output is a quantified model with the associated weights for perspectives and success attributes. The model is presented at the end of the chapter. Inconsistency and disagreements are discussed as appropriate. Figure 5.2 summarizes the output of expert judgment quantification. The most important perspective is market with a value of 0.39, and the corresponding most important success attribute is determining financial feasibility by assessing the ROI (0.23). This is followed closely by level of top management interest (0.22). In order of contribution to developing a technology transfer score, technological, social, and organizational are next important. Within each perspective, the associated success attribute with the highest

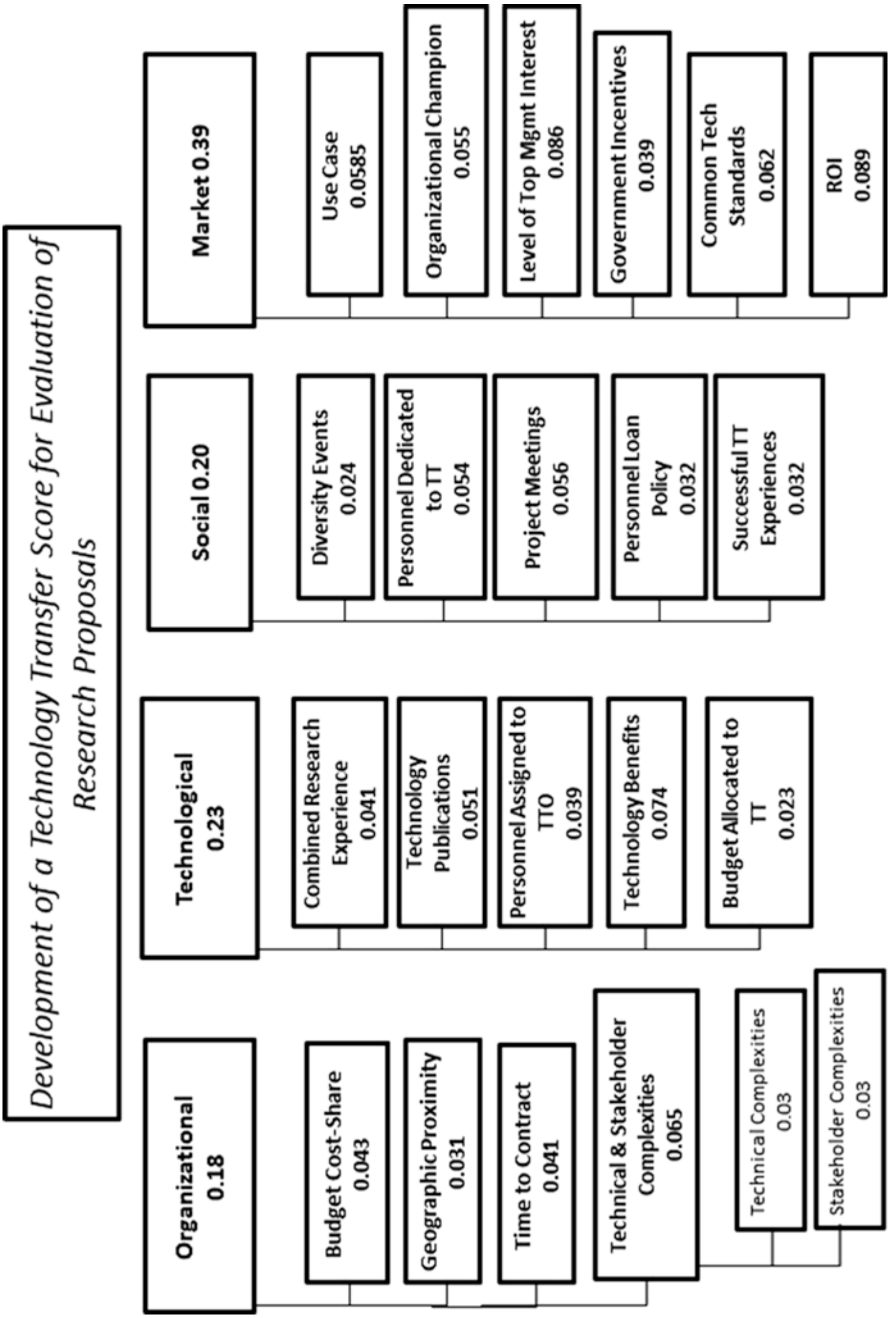


Fig. 5.2 Weighted model

score supports the concept described in literature as important, that is, building a relationship is necessary for successful technology transfer. For example, in organizational perspective, technical and stakeholder complexities are most important. In the technological perspective, describing the technology benefits ranked highest. Finally, in the social perspective, project team meetings to facilitate communication and develop trust is the most important success attribute.

5.4 Analysis Case Development

As previously described, this research focuses on moving (research) from a demonstration stage (TRLs 6–7) to the commercialization stage (TRLs 8–9). The model is validated using a case study of demand response technologies.

Demand response technologies were selected for the case study because they provide solutions for Pacific Northwest Utility needs, which are renewable energy integration, load growth, and alternatives for an aging infrastructure. In addition, they are typically more mature technologies. This criterion (mature technologies) was also mentioned as increasing the technology transfer potential. Specific information about the research organization (e.g., name, technology characteristics) will remain anonymous.

Table 5.6 lists the general technology that is being tested, participating organizations, and the potential energy impact. The TRLs for these projects are 7–9 (e.g., ready for application). A more thorough discussion of each technology, and how it can be used as a resource for demand response, follows the summary table.

Proposal 1 This proposal is testing large battery storage that can be used by a utility. The utility can use the battery system to store energy when the production of renewable energy exceeds energy consumption by the consumer. The battery can

Table 5.6 Research proposals

	Proposal 1	Proposal 2	Proposal 3
DR technology	Utility scale battery storage	Consumer heat pump water heaters (HPWH)	Retail supermarket refrigeration
Participating organizations	Industry Utility partner	University Collaborative partner National lab	National lab Industry
Potential energy impact	1 MWh storage	Not stated – will be measured as part of research	Not stated – will be measured as part of research
Objectives	Develop control strategies to maximize storage potential and demonstration of a 500-kW, 1-MWh storage system at the utility scale	Develop protocols for DR testing of HPWH and fully characterize the energy storage potential	Develop control strategies and evaluate the strategies in supermarket field tests

store renewable energy when it is produced; typically, wind energy production is highest at night, a time when energy demand is low. It acts as a DR technology because it can be used by the participating utility to reduce peak load demand by dispatching the stored energy during the peak demand.

The research proposal has identified a utility in the Pacific Northwest that is willing to partner to test the storage and demand response potential of the battery system.

Proposal 2 The inherent characteristics of heat pump water heaters (HPWH) make them an ideal candidate for DR. They contribute significantly to peak demand because people use hot water for showers in the morning, a peak demand time and because HPWHs have the ability to store and release heat energy over time.

This proposal aims to increase or decrease water heater electric loads in response to a communication signal via the homeowner's WiFi. The HPWH will be allowed to heat to 160°F but there are mechanisms in place to deliver the water no hotter than 130°F. The HPWH will be allowed to charge when the demand is low (typically overnight) in anticipation of usage in the morning. The benefit is that it will reduce peak load in the morning, since it will already be charged during the night.

The proposal will work with end-use customers to understand the ability of HPWHs to respond to DR signals as well as get feedback from the customers regarding how they perceive the technology. For instance, was there any interruption to the quality of your hot water? Or, were there any interface issues with the DR signal equipment?

Proposal 3 The objective of this proposal is to use supermarket refrigeration for DR. Typically, supermarket refrigeration systems are "energy hogs" and represent a substantial load for a utility. As well, energy costs cut into the already slim profit margins for a supermarket. If the system can be used for DR and to control the load, there is a benefit for the utility as well as the operator.

There are many components in a refrigeration system. These include compressors, condensers, lighting, fans, and defrost equipment. If one or many of these can respond to a DR event, then there is the potential to balance system loads for a utility, and for the supermarket, it allows them to operate the system more predictably and at potentially higher temperatures; one test was to ensure food integrity and safety. In this case, a DR event is defined as cooling the refrigeration system or turning off cooling capacity.

The next chapter applies the model to these use cases and conducts four scenario analyses to understand the model's sensitivity to perturbations. Project performance and reasons for including the projects in the portfolio will be considered in combination with the technology transfer score. During the model validation phase, experts would be asked to verify 1. if a technology transfer score was used, would these proposals have been selected and 2. based on the project performance, would technology transfer scores provide an insight into what is actually happening in the project now? As an example, if a weak communication plan was identified as part of assessing the technology transfer score, how is the actual project communication occurring?

Relative to the other proposals, the strengths of Proposal 1 (utility scale energy storage) are that they have the most years of combined research experience, most technology publications, and best awareness of recipient needs – their proposal includes ten technology benefits. The weaknesses of their proposal are they require more cost share, and there is some support from *middle* management but it is not consistent (Table 5.7). The strengths and weaknesses of Proposal 1 and the corresponding desirability curve values are provided:

Proposal 2's (heat pump water heaters for demand response) strengths include the least technical complexity; therefore, the researchers are able to have very directed focus and not worry about the interface of many technology characteristics. The proposal has the best description of project team meetings – weekly meetings and site visits are planned. There is support, but not consistent, from *executives* within the organization. It also is the only proposal that dedicates a portion of the project budget to technology transfer activities. Its weakest area is in their personnel loan policy – one does not exist (Table 5.8). The strengths and weaknesses of Proposal 2 and the corresponding desirability curve values are provided:

Proposal 3 (Supermarket Refrigeration) characteristics are similar to Proposal 2 except that Proposal 3 has a personnel loan policy and recommends diversity events – each of these supports successful technology transfer. However, this proposal has the most amount of stakeholder complexity, which could be a barrier to successful technology transfer. This weakness could be offset by the number of project team meetings they have proposed (Table 5.9). The strengths and weaknesses of Proposal 3 and the corresponding desirability curve values are provided:

Table 5.7 Proposal #1 strengths and weaknesses

Proposal 1	Success attribute	Success attribute score	Desirability value
Strengths	Combined research experience	47 years of combined experience	85
	Technology publications	45 publications	100
	Technology benefits	10 technology benefits	100
Weaknesses	Cost share	62%	40
	Level of management interest	Some support by middle mgmt but it is not consistent	32

Table 5.8 Proposal 2 strengths and weaknesses

Proposal 2	Success attribute	Success attribute score	Desirability value
Strengths	Technical complexity	1 technology characteristic	100
	Project meetings	Weekly meetings and site visits	100
	Level of management interest	Execs are aware but their engagement is not consistent	43
	Budget allocated to TT	5% of R&D budget is allocated to TT	57
Weaknesses	Personnel loan to recipient	Researchers are not loaned to TT recipient	0

Table 5.9 Proposal 3 strengths and weaknesses

Proposal 3	Success attribute	Success attribute score	Desirability value
Strengths	Technical complexity	2 technology characteristics	83
	Project meetings	Weekly meetings	90
	Level of management interest	Execs are aware but their engagement is not consistent	43
	Personnel loan to recipient	Researchers are loaned up to 1 year	77
	Diversity events	Recommended	22
Weakness	Stakeholder complexity	7 stakeholders	3

Table 5.10 Baseline technology transfer scores

Baseline analysis	Proposal 1	Proposal 2	Proposal 3
Technology transfer score	37.6	47.7	45.7
Rank	3	1	2

For all proposals in the case study, an ROI was not available. It's not that one cannot be calculated; rather, it is about one not being determined for each proposal. Therefore, the score of ROI is zero for all three proposals and the corresponding desirability value is also zero.

The desirability values for each of the success attributes were captured for each proposal. These values were multiplied by the relative weights and the perspective weight to determine the technology transfer score. Table 5.10 shows the technology transfer score for each proposal.

The highest possible score for each proposal, based on the perspective priorities and corresponding weights for the success attributes, is 100.00. None of the proposals had a high technology transfer score. One of the analysis scenarios will discuss how a proposal can improve the technology transfer potential.

Proposal 2 had the highest technology transfer score. Looking at the desirability curve values, along with the success attribute and perspective prioritization to understand the resulting technology transfer score, Proposal 2 had executive engagement in the market perspective; market perspective was the most important perspective as determined by the expert panel (0.39). The executive engagement was not consistent, however. Nonetheless, this set the proposal apart for Proposal 1 were there was only middle management support. The next most important perspective was technological (0.23). Within the technological perspective, the most important success attribute was technology benefits (0.32). Proposal 2 had a high number technology benefits identified. Proposal 2 also had personnel assigned to the TTO. The social perspective is where the biggest differences are for Proposal 2. Relative to the other two proposals, Proposal 2 has the best project meetings value. Their proposal identified weekly team meetings and site visits. These attributes are important to facilitate communication and subsequently trust among the project team.

Proposal 1 scored the lowest of all three (proposals). One difference was the level of top management support. This success attribute is associated with the highest ranked perspective (market, 0.39) and it corresponds to the second highest ranked success attribute (level of top management interest, 0.22) – so if a proposal scores low in this area, it is bound to have an impact on its overall technology transfer score. In fact, it does. Of the three proposals, this one only had middle management support and it was inconsistent.

To improve the baseline score, the level of top management support needs to improve. It could improve by more dedicated meetings with the management team to understand their resistance to the technology and to clarify any misgivings or to emphasize the benefits of the technology. The next area of improvement would be to have dedicated people assigned to the TT office. However, because the company sponsoring the proposal is a small private organization, a dedicated TT Office might be a challenge from a resource or financial perspective. Assigning dual roles to the project team members could improve the TT potential but it may also be a distraction for the team trying to allocate time to many project activities.

For each of the individual extreme scenarios previously identified, Proposal 1 could emphasize other success attributes to improve their TT score. For the Technological focus, the proposal scored high in the number of technology benefits, but they would need to have some percentage of the R&D budget dedicated to TT activities; currently there is no budget allocated.

If the extreme scenario is a social focus, Proposal 1 could improve their score by having more frequent project team meetings; of the three proposals, this one had the fewest interactions. Regarding loaning researchers, this is a small company so loaning researchers might detract from other projects or work and would not be feasible. Likewise, if the extreme scenario is an organizational focus, having a more focused proposal (e.g., fewer technology characteristics) and fewer stakeholders would improve their TT score. A similar analysis is done for Proposal 3. Proposal 3 had similar market success attribute scores as Proposal 2 (the highest TT score). However, there is room for improvement in the other perspectives and success attributes. Having more consistent engagement from executives would be beneficial for the TT score; this is the highest weighted perspective (market) and the highest rated success attribute (level of top management interest). In a technological focus extreme scenario, increasing the number of technology publications and the number of technology benefits would improve the TT score; Proposal 3 had the lowest number of technology benefits identified of the three proposals. For a social focus, Proposal 3 could increase the number of team meetings and the number of personnel dedicated to the TTO. Proposal 3 would benefit from decreasing the number of impacted stakeholders in an organizational focus extreme scenario. Proposal 3 had the highest number of impacted stakeholders (7). The effort to maintain effective communication among so many stakeholders would be significant.

A summary of the changes is shown in Table 5.11. The table shows the baseline TT score as well as the impact of making incremental changes to improve desirability value. The incremental impacts are represented by the "better success attribute score," and the corresponding TT score and percent increase over the baseline TT score are shown. Also, the impact of increasing to the best success attribute score is provided. However, it may or may not be possible to increase the values this significantly (e.g., decreasing the number of impacted stakeholders or increasing the number of personnel dedicated to TT), but the outcome is shown for the best

Table 5.11 TT Score increases with changes to desirability values

Success attribute	Proposal 1			Proposal 2			Proposal 3		
	Original success attribute score	*Better success attribute score*	*Best success attribute score*	*Original success attribute score*	*Better success attribute score*	*Best success attribute score*	*Original success attribute score*	*Better success attribute score*	*Best success attribute score*
Stakeholder complexities	3 stakeholders	2 stakeholders	1 stakeholder	3 stakeholders	2 stakeholders	1 stakeholder	7 stakeholders	3 stakeholders	1 stakeholder
Personnel dedicated to TT	frac12, person	1 person	More than 10 people	½ person	1 person	More than 10 people	0 people	½ person	More than 10 people
Level of top management interest	Some interest by middle mgmt	Execs are aware but not consistent	Execs are fully engaged	Execs are aware but not consistent	Execs are somewhat engaged but not fully engaged	Execs are fully engaged	Execs are aware but not consistent	Execs are somewhat engaged but not fully engaged	Execs are fully engaged
	Original TT score	*Revised TT score*	*Revised TT score*	*Original TT score*	*Revised TT score*	*Revised TT score*	*Original TT score*	*Revised TT score*	*Revised TT score*
TT score	37.61	40.03	50.01	47.72	51.51	59.18	45.73	49.84	58.99
Percent increase		*6.4%*	*33%*		*7.9%*	*24%*		*9.0%*	*29%*

potential increase. Note that the changes in desirability values and subsequent TT scores are only considered for the highest success attributes. Increases in other success attributes would also incrementally improve the TT score.

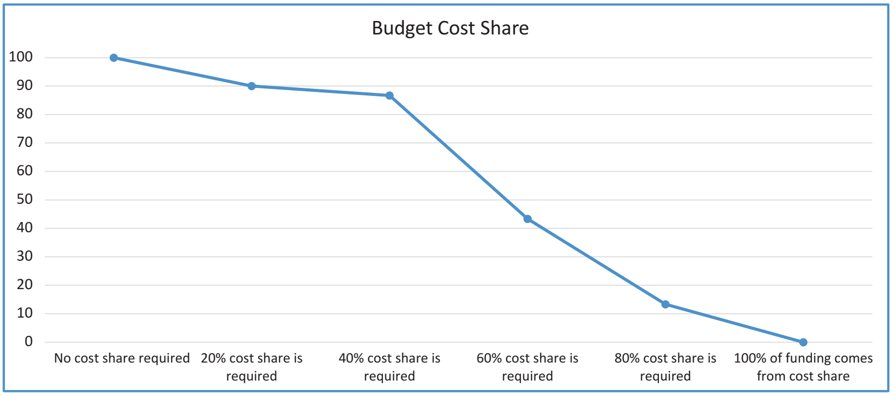
5.5 Conclusions

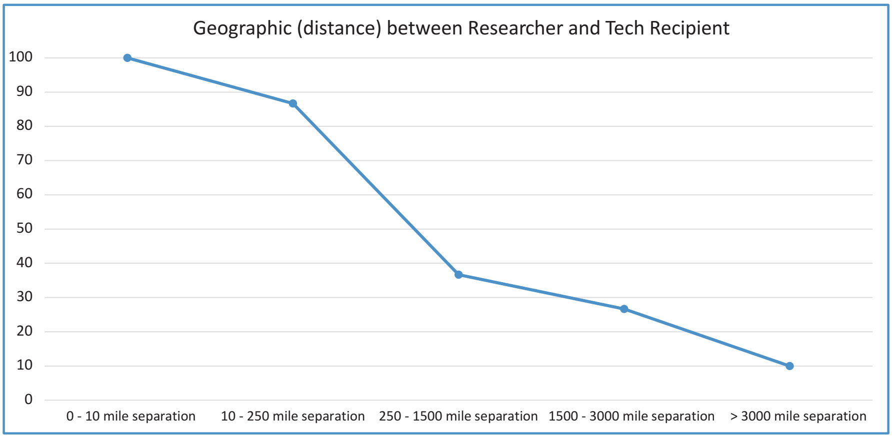
This research focused on identifying what attributes should be the focus to facilitate successful technology transfer and development of a technology transfer score that can be used to inform the selection of the most promising research proposal. The model framework and literature defined success attributes were determined appropriate for assessing the technology transfer potential of a research proposal by an extensive expert panel. The qualitative results of the model are consistent with literature findings. That is, technology transfer is more about building and maintaining an effective relationship between the researcher and technology recipient.

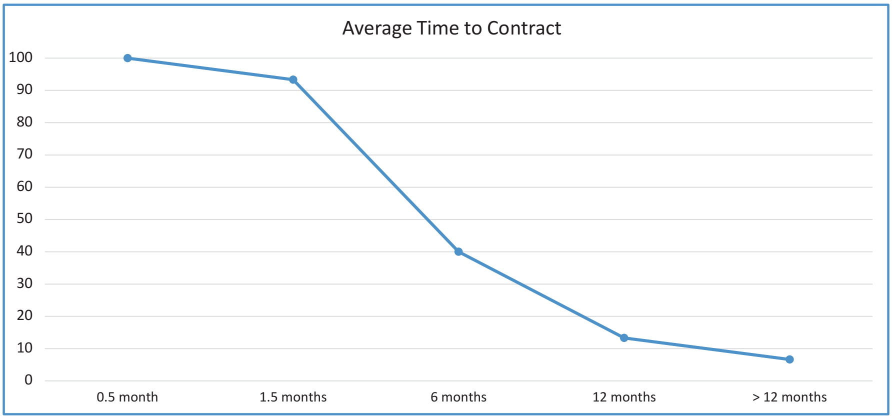
The results of this research will provide valuable information to organizations that sponsor research. Knowledge is power – by identifying those attributes which contribute to successful technology transfers, an organization could take a proactive approach by ensuring that those elements are implemented and effective in their organizations. While the case study focus is on the utility industry, the model can easily be applied to any organization that solicits technology research proposals, and the TT score can be incorporated appropriately in an assessment methodology.

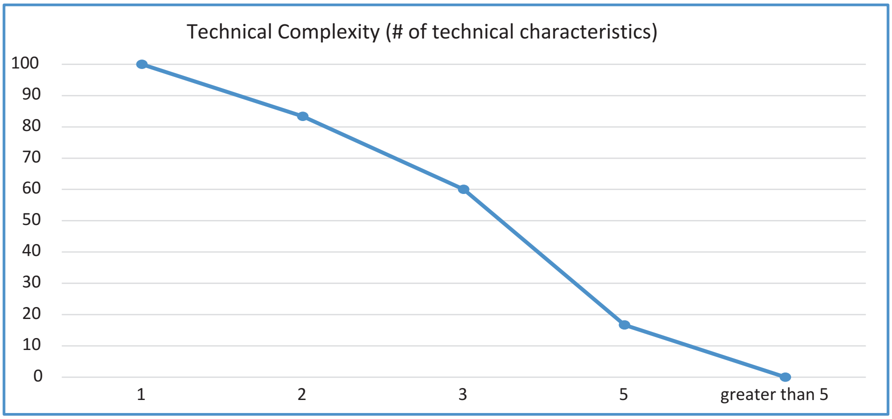
The criterion-related validation confirmed that this model would be useful as an additional input into the proposal evaluation process. If the model had been used, would Proposal 3 have been selected? If so, it would have identified potential issues with management support that could have been addressed, instead of the project being removed from the portfolio.

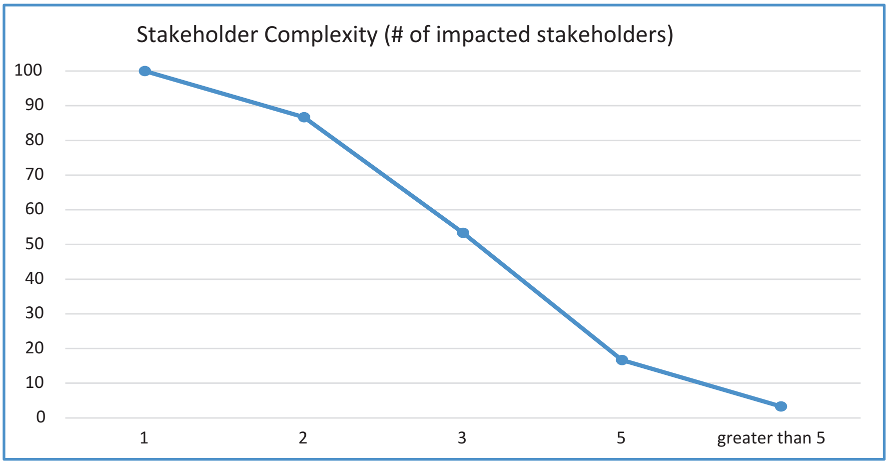
Appendix

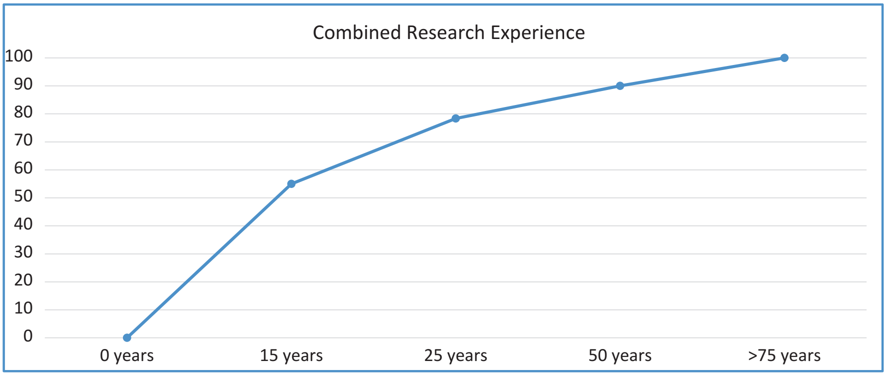


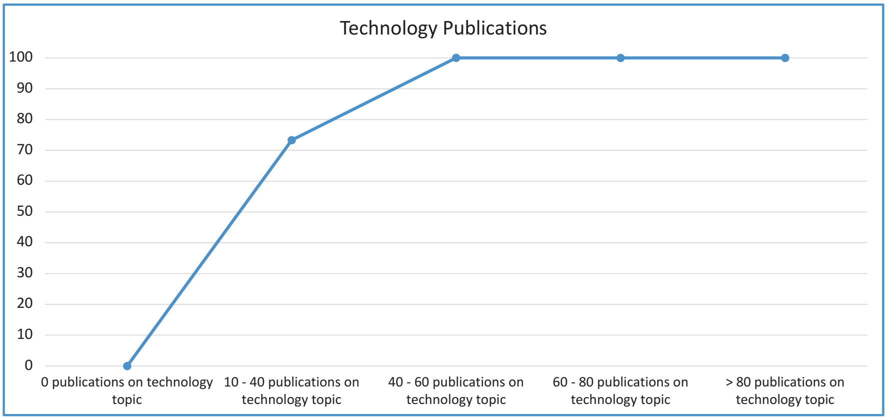

Geographic (distance) between Researcher and Tech Recipient
100
90
80
70
60
50
40
30
20
10
0
0 - 10 mile separation
10 - 250 mile separation
250 - 1500 mile separation
1500 - 3000 mile separation
> 3000 mile separation

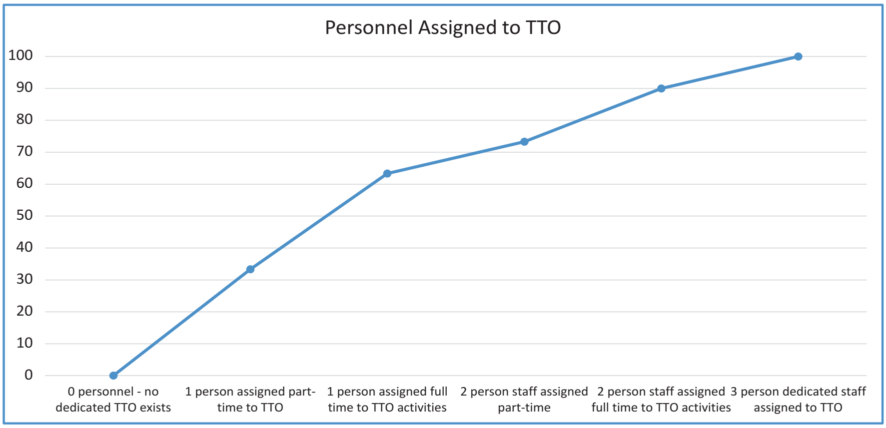

Average Time to Contract
100
90
80
70
60
50
40
30
20
10
0
0.5 month
1.5 months
6 months
12 months
> 12 months

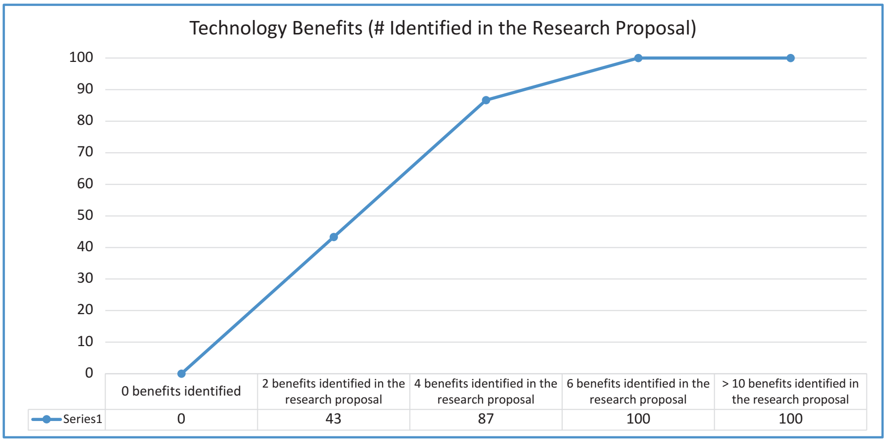

Technical Complexity (# of technical characteristics)
100
90
80
70
60
50
40
30
20
10
0
1
2
3
5
greater than 5

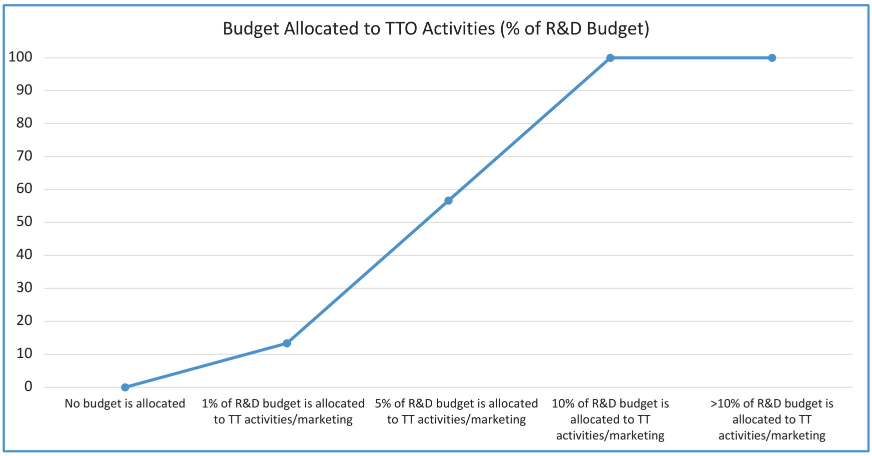

Stakeholder Complexity (# of impacted stakeholders)
100
90
80
70
60
50
40
30
20
10
0
1
2
3
5
greater than 5

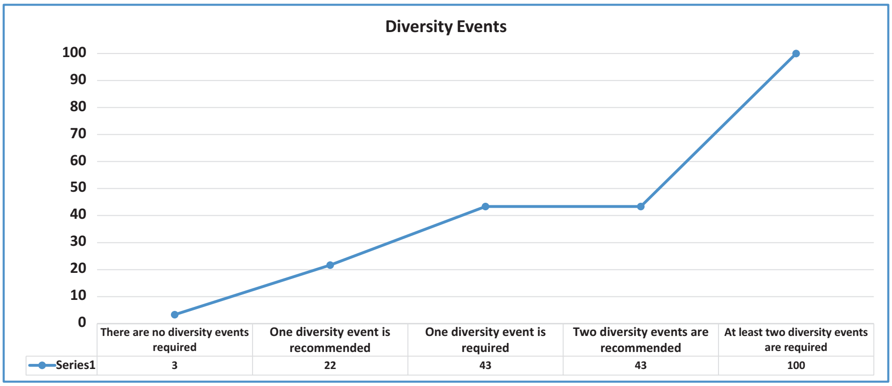

Combined Research Experience
100
90
80
70
60
50
40
30
20
10
0
0 years
15 years
25 years
50 years
>75 years

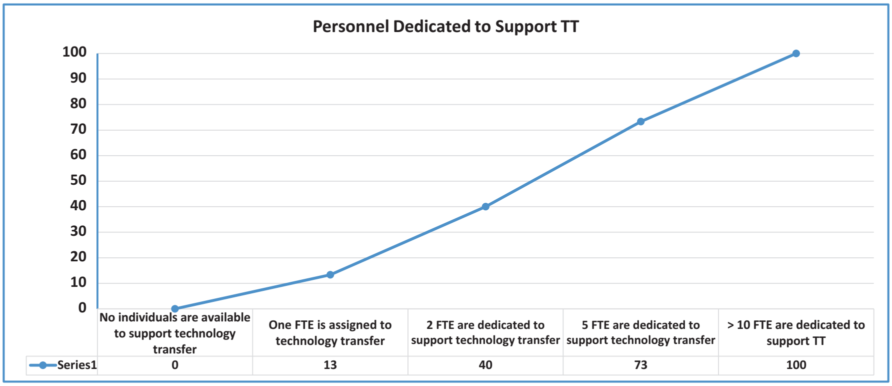

Technology Publications
100
90
80
70
60
50
40
30
20
10
0
0 publications on technology topic
10 - 40 publications on technology topic
40 - 60 publications on technology topic
60 - 80 publications on technology topic
> 80 publications on technology topic

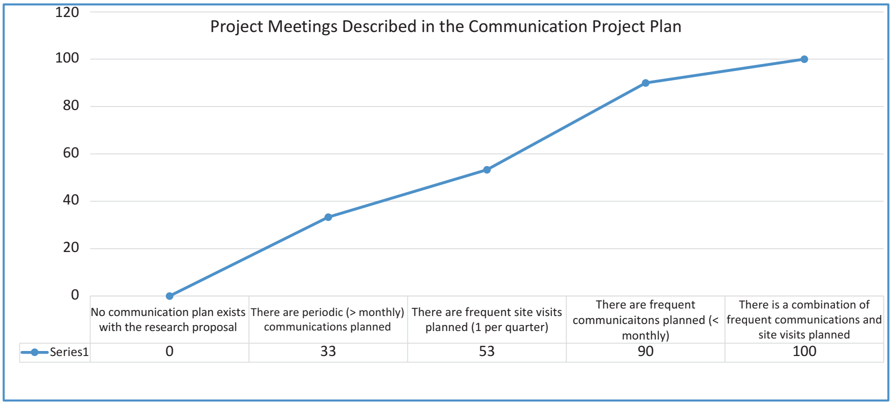

Personnel Assigned to TTO
100
90
80
70
60
50
40
30
20
10
0
0 personnel - no dedicated TTO exists
1 person assigned part-time to TTO
1 person assigned full time to TTO activities
2 person staff assigned part-time
2 person staff assigned full time to TTO activities
3 person dedicated staff assigned to TTO

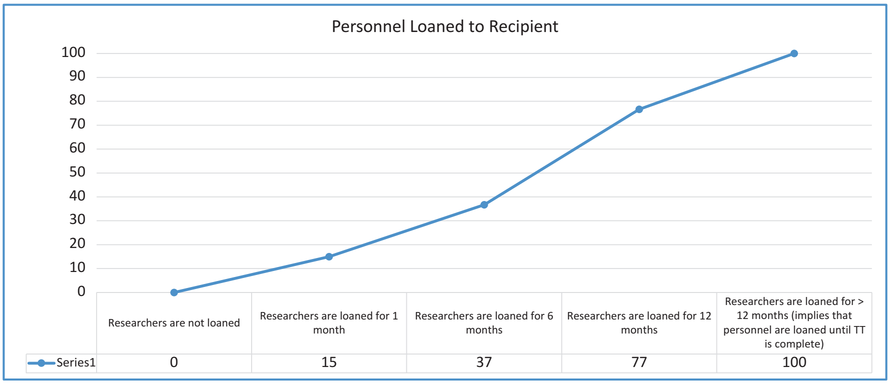

Technology Benefits (# Identified in the Research Proposal)
100
90
80
70
60
50
40
30
20
10
0
0 benefits identified
2 benefits identified in the research proposal
4 benefits identified in the research proposal
6 benefits identified in the research proposal
> 10 benefits identified in the research proposal
Series1
0
43
87
100
100

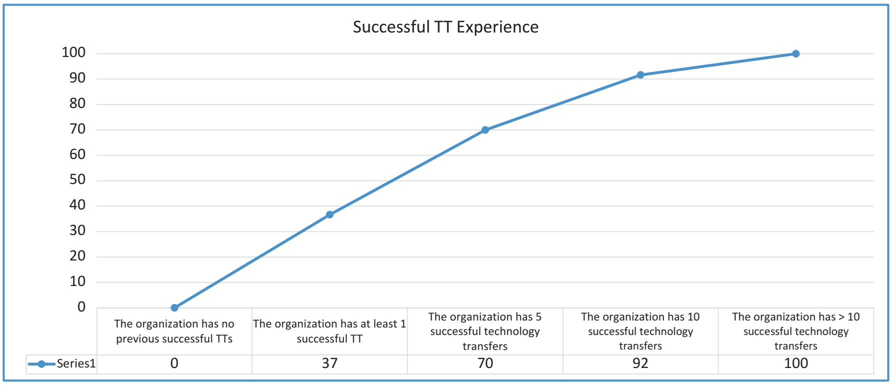

Budget Allocated to TTO Activities (% of R&D Budget)
100
90
80
70
60
50
40
30
20
10
0
No budget is allocated
1% of R&D budget is allocated to TT activities/marketing
5% of R&D budget is allocated to TT activities/marketing
10% of R&D budget is allocated to TT activities/marketing
>10% of R&D budget is allocated to TT activities/marketing

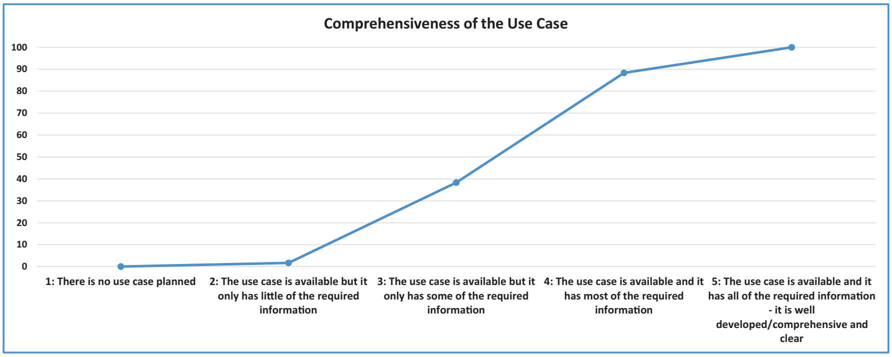

Diversity Events
100
90
80
70
60
50
40
30
20
10
0
There are no diversity events required
One diversity event is recommended
One diversity event is required
Two diversity events are recommended
At least two diversity events are required
Series1
3
22
43
43
100


Personnel Dedicated to Support TT
100
90
80
70
60
50
40
30
20
10
0
No individuals are available to support technology transfer
One FTE is assigned to technology transfer
2 FTE are dedicated to support technology transfer
5 FTE are dedicated to support technology transfer
> 10 FTE are dedicated to support TT
Series1
0
13
40
73
100

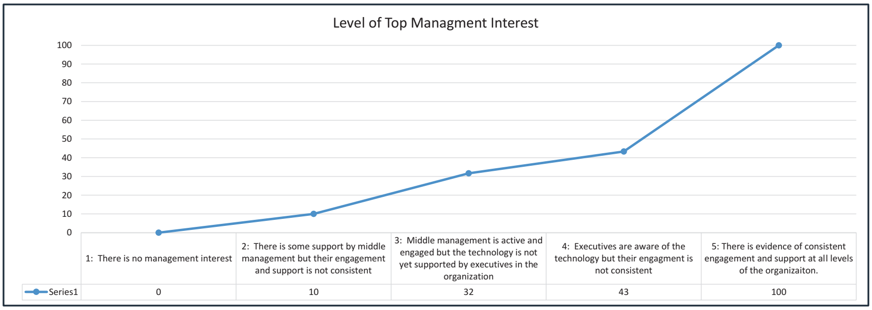

Project Meetings Described in the Communication Project Plan
120
100
80
60
40
20
0
No communication plan exists with the research proposal
There are periodic (> monthly) communications planned
There are frequent site visits planned (1 per quarter)
There are frequent communicaitons planned (< monthly)
There is a combination of frequent communications and site visits planned
Series1
0
33
53
90
100

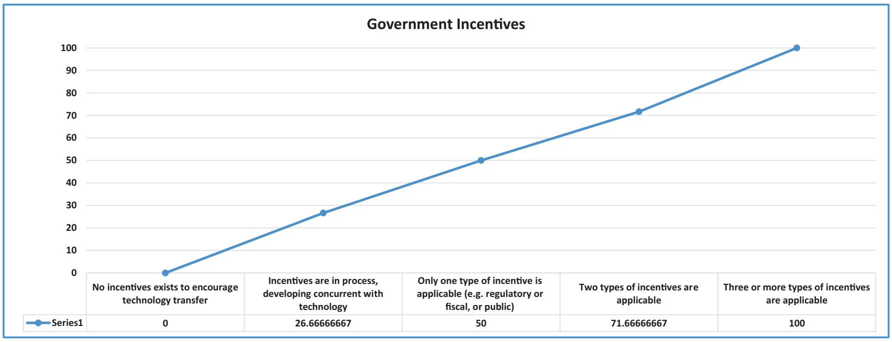

Personnel Loaned to Recipient
100
90
80
70
60
50
40
30
20
10
0
Researchers are not loaned
Researchers are loaned for 1 month
Researchers are loaned for 6 months
Researchers are loaned for 12 months
Researchers are loaned for > 12 months (implies that personnel are loaned until TT is complete)
Series1
0
15
37
77
100

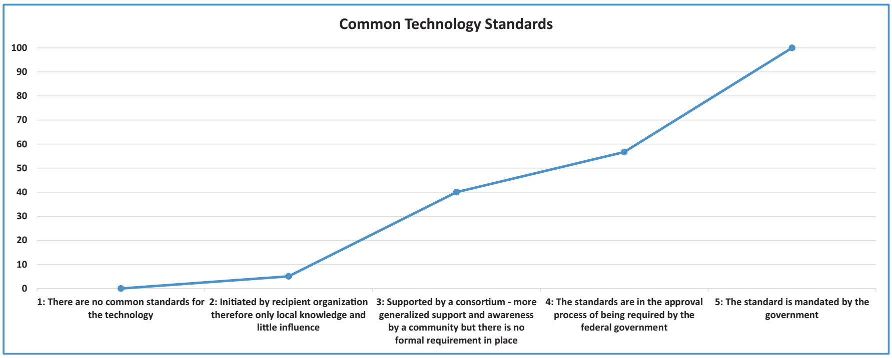

Successful TT Experience
100
90
80
70
60
50
40
30
20
10
0
The organization has no previous successful TTs
The organization has at least 1 successful TT
The organization has 5 successful technology transfers
The organization has 10 successful technology transfers
The organization has > 10 successful technology transfers
Series1
0
37
70
92
100

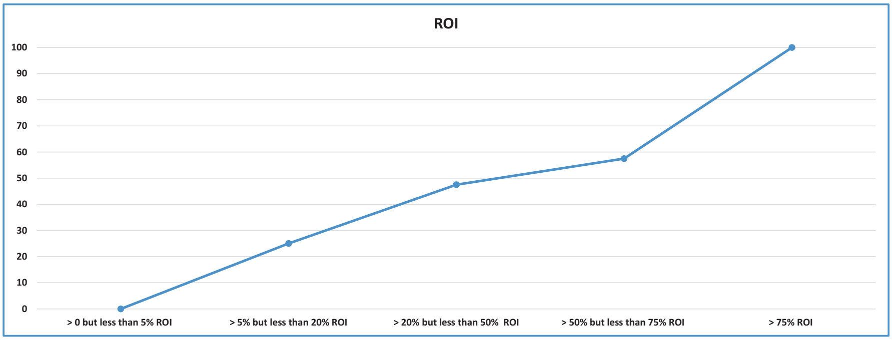

Comprehensiveness of the Use Case
100
90
80
70
60
50
40
30
20
10
0
1: There is no use case planned
2: The use case is available but it only has little of the required information
3: The use case is available but it only has some of the required information
4: The use case is available and it has most of the required information
5: The use case is available and it has all of the required information - it is well developed/comprehensive and clear


Credibility of the Organizational Champion
100
90
80
70
60
50
40
30
20
10
0
1: No champion exists
2: The champion has some technical expertise but is not a recognized expert
3: The champion has technical expertise and is recognized within the organization as an expert
4: The champion has technical expertise and is recognized within the region as an expert
5: The champion has technical expertise and is recognized within the technical community (world wide) as the leading technology expert


Level of Top Managment Interest
100
90
80
70
60
50
40
30
20
10
0
1: There is no management interest
2: There is some support by middle management but their engagement and support is not consistent
3: Middle management is active and engaged but the technology is not yet supported by executives in the organization
4: Executives are aware of the technology but their engagment is not consistent
5: There is evidence of consistent engagement and support at all levels of the organizaiton.
Series1
0
10
32
43
100


Government Incentives
100
90
80
70
60
50
40
30
20
10
0
No incentives exists to encourage technology transfer
Incentives are in process, developing concurrent with technology
Only one type of incentive is applicable (e.g. regulatory or fiscal, or public)
Two types of incentives are applicable
Three or more types of incentives are applicable
Series1
0
26.66666667
50
71.66666667
100


Common Technology Standards
100
90
80
70
60
50
40
30
20
10
0
1: There are no common standards for the technology
2: Initiated by recipient organization therefore only local knowledge and little influence
3: Supported by a consortium - more generalized support and awareness by a community but there is no formal requirement in place
4: The standards are in the approval process of being required by the federal government
5: The standard is mandated by the government


ROI
100
90
80
70
60
50
40
30
20
10
0
> 0 but less than 5% ROI
> 5% but less than 20% ROI
> 20% but less than 50% ROI
> 50% but less than 75% ROI
> 75% ROI

Success attributes for case studies

Attributes of research proposals	*Organizational*	*Success attributes*	*Units of measurement*	*Proposal 1*	*Proposal 2*	*Proposal 3*	*Proposal 4*
		Budget cost-share	% cost share required to fund research	62%	50%	50%	50%
		Geographic proximity	Proximity between research and recipient	250–1500 mile separation	250–1500 mile separation	250–1500 mile separation	1500–3000 mile separation
		Average time to contract	Average time to execute a contract	4 months	1.5 months	1.5 months	4 months
		Technical and stakeholder complexity	# of technical characteristics identified in proposal and # of impacted stakeholders	2 technology characteristics and 3 stakeholders	1 technology characteristic and 3 stakeholders	2 technology characteristics and 7 stakeholders	5 technology characteristics and 2 stakeholder
	Social	Diversity events	# of diversity events to create cultural awareness	0	0	Recommended	0
		Personnel dedicated to support TT	# of people dedicated to support TT	0.5	0.5	0	1
		Project meetings	# of comms described in the comm project plan	Monthly meetings	Weekly and site visits	Weekly	Monthly meetings
		Personnel loaned to recipient	Time that researchers are loaned to help with TT	0	0	1 year	1 week
		Successful TT experiences	# of previous successful TT experiences	0	0	0	4

(continued)

	Technology elements	Combined research experience	# years of combined research experience of principles	47 years	38 years	46 years	44 years
		Technology publications	# publications about technology	45 publications	23 publications	16 publications	16 publications
		Personnel assigned to TTO	# of personnel assigned to TTO	0	3	3	0
		Technology benefits	# technology benefits identified in the research proposal	10	7	4	7
		Budget allocated to TT	% R&D budget dedicated to TTO activities	0	5	0	0
	Market	Comprehensiveness of use case	How well is the use case defined	None	None	None	None
		Credibility of organizational champion	Credibility of the organizational champion	The champion has technical expertise and is recognized within the region as an expert	The champion has technical expertise and is recognized within the region as an expert	The champion has technical expertise and is recognized within the region as an expert	The champion has technical expertise and is recognized within the organization as an expert
		Level of top management interest	Level of organizational support for TT	There is some support by middle management but their engagement and support is not consistent	Executives are aware of the technology but their engagement is not consistent	Executives are aware of the technology but their engagement is not consistent	There is some support by middle management but their engagement and support is not consistent

		Government incentives	# and type of government incentives	No incentives for energy pods used at *utility scale*	No incentives exists to encourage technology transfer	No incentives exists to encourage technology transfer	Transient stability modeling important – 1 regulatory incentive
		Common technology standards	How are common standards supported	There are no common standards or codes for the technology	Communication standards (CEA 2045, WiFi, radio, etc.) – supported by a consortium	Communication standards (CEA 2045, WiFi, radio, etc.) – supported by a consortium	IEEE standards for PMU data used with modeling – supported by a consortium – more generalized support and awareness by a community but there is no formal requirement in place
		ROI	ROI	0	0	0	> 20% but less than 50% ROI

Corresponding desirability curve values

Corresponding desirability curve values	*Organizational*	*Success attributes*	*Proposal 1*	*Proposal 2*	*Proposal 3*	*Proposal 4*
		Budget cost share	40	60	60	60
		Geographic proximity	37	37	37	27
		Average time to contract	40	65	65	40
		Stakeholder complexity	53	53	3	87
		Technical complexity	83	100	83	17
	Social	Diversity events	0	0	22	0
		Personnel dedicated to support TT	5	5	0	13
		Project meetings	90	100	90	90
		Personnel loaned to recipient	0	0	77	10
		Successful TT experiences	0	0	0	60
	Technology elements	Combined research experience	85	81	85	82
		Technology publications	100	73	73	73
		Personnel assigned to TTO	0	100	100	0
		Technology benefits	100	100	87	100
		Budget allocated to TT	0	57	0	0
	Market	Comprehensiveness of the use case	0	0	0	0
		Credibility of organizational champion	88	88	88	63
		Level of top mgmt interest	32	43	43	32
		Government incentives	0	0	0	50
		Common technology standards	0	40	40	40
		ROI	0	0	0	48

References

1. Reisman, A. (2011). Transfer of technologies: a cross-disciplinary taxonomy. *Omega, 33*(3), 189–202, Jun. 2005. sons learned, *Energy Policy*.
2. Greiner, M. A., & Franza, R. M. (2003). Barriers and bridges for successful environmental technology transfer. *The Journal of Technology Transfer, 28*(2), 167–177.
3. Bozeman, B., & Pandey, S. (1994). Cooperative R&D in government laboratories: Comparing the US and Japan. *Technovation, 14*(3), 145–159.
4. Ham, R. M., & Mowery, D. C. (1995). Improving industry-government cooperative R&D. *Issues in Science and Technology, 11*(4), 67–73.
5. Mora-Valentin, E. M., Montoro-Sanchez, A., & Guerras-Martin, L. A. (2004). Determining factors in the success of R&D cooperative agreements between firms and research organizations. *Research Policy, 33*(1), 17–40.
6. Franza, R. M., & Grant, K. P. (2006). Improving federal to private sector technology transfer. *Research-Technology Management, 49*(3), 36–40.
7. Boulter, L., & Bendell, T. (2002). Managing the technology transfer process. *Engineering Management Conference, 2002, IEMC'02. 2002 IEEE International, 2*, 643–648.
8. Balachandra, P., Kristle Nathan, H. S., & Reddy, B. S. (2010). Commercialization of sustainable energy technologies. *Renewable Energy, 35*(8), 1842–1851.
9. Ehrhardt-Martinez, K., & Laitner, J. A. (2010). Rebound, technology and people: Mitigating the rebound effect with energy-resource management and people-centered initiatives, *Proceedings of the 2010 ACEEE Summer Study on Energy Efficiency in Buildings*.
10. Perry, T. D., IV. (2010). *Ampulse corporation: A case study on technology transfer in US Department of Energy Laboratories*. National Renewable Energy Laboratory (NREL): Golden, CO..
11. Painuly, J. P. (2001). Barriers to renewable energy penetration; a framework for analysis. *Renewable Energy, 24*(1), 73–89.
12. Wen-Hsiang, L., & C.T.Z.U. TSAI. (2008). *Analyzing influence factors of technology transfer using fuzzy set theory*. PICMET Proceedings.
13. Bozeman, B. (2000). Technology transfer and public policy: A review of research and theory. *Research Policy, 29*(4–5), 627–656.
14. Franza, R. M., Grant, K. P., & Spivey, W. A. (n.d.). Technology transfer contracts between R&D labs and commercial partners: Choose your words wisely. *The Journal of Technology Transfer*, 1–11.
15. Lutzenhiser, L. (1994). Innovation and organizational networks barriers to energy efficiency in the US housing industry. *Energy Policy, 22*(10), 867–876.
16. Mueller, M., & Wallace, R. (2008). Enabling science and technology for marine renewable energy. *Energy Policy, 36*(12), 4376–4382.
17. Lohani, B. N., & Azimi, A. M. (1992). Barriers to energy end-use efficiency. *Energy Policy, 20*(6), 533–545.
18. Siegel, D.S., D.A. Waldman, L.E. Atwater, and A.N. Link. "Toward a model of the effective transfer of scientific knowledge from academicians to practitioners: Qualitative evidence from the commercialization of university technologies." Journal of Engineering and Technology Management 21, no. 1–2 (2004): 115–142.
19. Sharma, K. J. (1973). *A new inquiring system for technology transfer and its role in planning and policymaking*. *Dissertations and Theses.* Paper 582.
20. Isaacs, E.A., Tang, J.C., Foley, J., Johnson, J., Kuchinsky, A., Scholtz, J., & Bennett, J.. (1996). *Technology transfer: So much research, so few good products*. Conference Companion on Human Factors in Computing Systems: Common Ground, pp. 155–156.
21. Spann, M. S., Adams, M., & Souder, W. E. (1995). Measures of technology transfer effectiveness: Key dimensions and differences in their use by sponsors, developers and adopters. *Engineering Management, IEEE Transactions, 42*(1), 19–29.

22. Murphy, L. M., Edwards, P. L., N. R. E. L. (US), & A. G. LLC. (2003). *Bridging the valley of death: Transitioning from public to private sector financing*. National Renewable Energy Laboratory.
23. Gopalakrishnan, S., & Santoro, M. D. (2004). Distinguishing between knowledge transfer and technology transfer activities: The role of key organizational factors. *IEEE Transactions on Engineering Management, 51*(1), 57–69.
24. Rogers, E. M., Takegami, S., & Yin, J. (2001). Lessons learned about technology transfer. *Technovation, 21*(4), 253–261.
25. Panel discussion: TT: So much research, so few good products CHI 96 Conference. Available: http://www.sigchi.org/chi96/proceedings/panels/Isaacs/eai_tech.html
26. Rogers, E. M., Carayannis, E. G., Kurihara, K., & Allbritton, M. M. (1998). Cooperative Research and Development Agreements (CRADAs) as technology transfer mechanisms. *R&D Management, 28*(2), 79–88.
27. Kok, N., McGraw, M., & Quigley, J. M. (2011). The diffusion of energy efficiency in building. *The American Economic Review, 101*(3), 77–82.
28. Carayannis, E. G., & Alexander, J. (1999). Secrets of success and failure in commercialising US government R&D laboratory technologies: A structured case study approach. *International Journal of Technology Management 18, no. 3 (January), 1*, 246–269.
29. Neshati, R. (2014). *Participation in technology standards development: A decision model for the information and communications technology industry*. Dissertations and Theses. Paper 1850.

Part II
Health Care

Chapter 6
Landscape Analysis: What Are the Forefronts of Change in the US Hospitals?

Amir Shaygan

6.1 Introduction

Compilation of information is increasingly becoming more important for health organizations from financial and time aspects. By methodical study of adaptive systems, healthcare organizations can gain new insights of burdensome issues within the organization as well as healthcare delivery management. These actions have become more important with the changes in the healthcare environment in the last couple of decades where several external entities have impacts on healthcare organizations directly and/or indirectly. One of the most onerous tasks ahead of organizations is to anticipate these changes and prepare for them. Knowing the external environment can be the key to leading a successful and competitive health system. However, identifying and behaving toward all the external changes pose great time and resource challenges for organizations. Health organizations can posit the question of "what are the current external changes that have the power to affect them?" This study will take a look into emerging extrinsic changes for the US healthcare environment in different areas. A literature review will be performed in order to pinpoint the different contemporary change perspectives and their sub-criteria. In order to better illustrate these issues, Ishikawa diagram (cause-and-effect diagram) is used in this study.

Since the legislation of prospective payment system (PPS) in the beginning of 1983, the healthcare industry in the United States has had a rise in being a volatile and hard to manage environment [1, 2]. Some of the factors influencing this capriciousness are the changes in legislative direction with each election, domestic and global economic climate, social changes, and emergence and improvement of related technologies which can affect the healthcare delivery dramatically. In the

A. Shaygan (✉)
Portland State University, Portland, OR, USA
e-mail: ashaygan@pdx.edu

T.U. Daim et al. (eds.), *Infrastructure and Technology Management*,
Innovation, Technology, and Knowledge Management,
https://doi.org/10.1007/978-3-319-68987-6_6

light of these changes, healthcare manager's task of comprehending the surrounding environment and, hence, preparing the organization to cope with or strategically take advantage of the changes in it become vital. Since the changes in the healthcare industry in the early 1980s, managers have found out that focusing solely on financial aspects of planning is not enough and health organizations should be dynamic in order to deal with the dynamic environment [3]. Thus, the constant analysis and assessment of strategy is imperative to healthcare organizations in the United States. In order to do this, managers should have a clear understanding of the prospective changes in order to act proactively and plan ahead. However, since the dynamic healthcare environment is affected by multiple elements, identifying these changes poses a big challenge to organizations. *The question is*, with respect to the limited time and financial resources, what are the issues and change forefronts that healthcare managers in the United States are currently facing and need to anticipate? One of the ways to bolster the identification and investigation of current changes is to perform environmental analysis. Environmental analysis helps companies position themselves effectively in a capricious environment. Based on Ginter, one of environmental analysis's goals is to classify and order the problems and changes generated by outside environment [2]. The mentioned book proposes a partial list of influencing perspectives based on literature, government reports, and expert domain. The emerging extrinsic changes can be categorized in "economic," "political," "social," and "technological" and "competitive" perspectives. *This paper will* take a closer look at each of these perspectives and their sub-criteria in order to help hospitals better position themselves in the current healthcare environment and mitigate their inability to anticipate the looming changes. For this goal, a *literature review* is performed to identify and classify the changes, their implications, and sources. As the first step, *a cause-and-effect diagram* is used to demonstrate the change perspectives and their sub-criteria.

As future study, a model can be developed to prioritize and rank these criteria in order to help health organizations plan accordingly and strategically. Moreover, solutions on how managers can deal with these challenge causing changes can be proposed.

6.2 Healthcare External Environment

In the turbulent environment of US healthcare – as any other business or organization – identifying ways to add more value compared to competitors in order to gain vying advantage is an important task and challenge [4]. This is a big problem for care organizations as value creation is the perceived relationship between contentedness and price [5]. Going through a smooth appointment and billing system, high quality of professionals and equipment, good insurance alliances are just some of the ways health organizations can create value internally [4, 6]. However, concurrent to these internal issues and opportunities, care organizations should pay immense attention to the factors happening and changing in their external

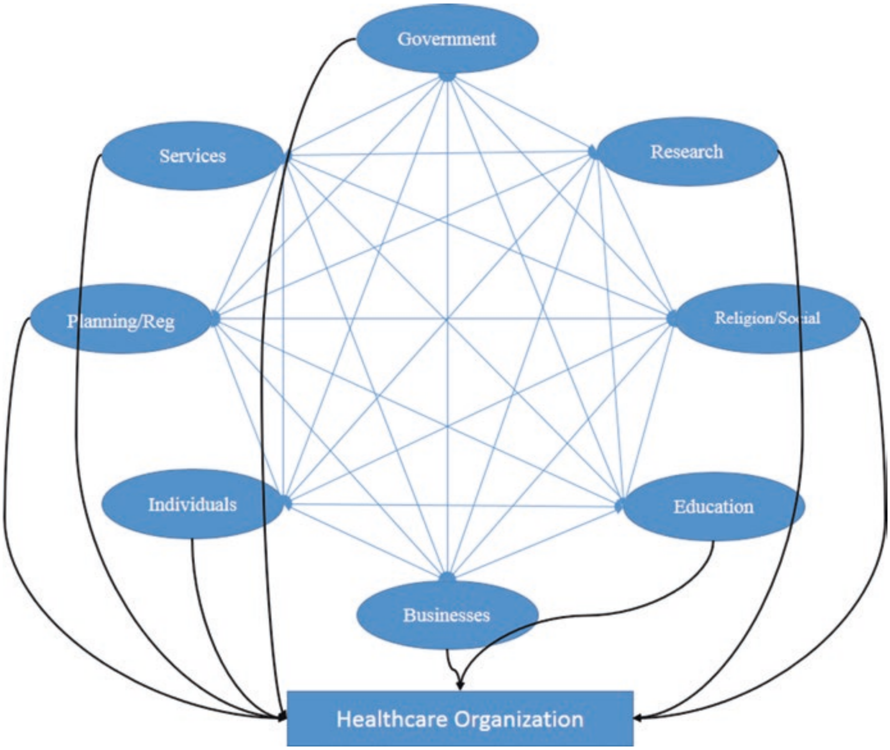


Fig. 6.1 External components of healthcare environment

environment. Out-of-date management styles, disregarding demographic changes, and emerging legislations and technologies are some of the telltales of organizations which are either unable to anticipate changes, ignoring them or resisting them before their imminent demise [7]. Although completely predicting the looming changes and opportunities is not feasible, health organizations and managers can bolster their chances of dodging or taking advantage of changes by keeping abreast of the possible changes in the healthcare environment. Perera and Peiro (2012) propose "analyzing the external environment" as the first stage in strategic planning for health organizations [8].

It is important to mention that different entities existing in a healthcare environment have impacts on each other and can affect healthcare organizations both directly and indirectly. Figure 6.1 shows the interrelationships of different components of healthcare's external environment. As an example of these interrelationships, government institutes regulate laws for businesses and education while funding some research institutions, while research institutions provide R&D for businesses and chance of better quality or access to individuals. Education institutes provide researchers for research institutes and have the power to raise care awareness for individuals. Businesses provide the government with tax money and researchers, hospital and education establishments with real-life data, sponsorship, and funding as well as jobs, products, and services for individuals. Individuals shape the demographic aspect of the environment in general while providing revenues and workforce for business, tax money for governments, individuals for education, and data for research centers. Other than the government's regulative impacts (Department of Health and Human Services, Centers for Medicare & Medicaid Services), organizations such as "Department of Public Health," "State Health Planning and Development Agency," "Joint Commission on Accreditation of Healthcare Organizations," and "Council on Education for Public Health" have regulatory and planning impacts on healthcare organizations. These interrelationships would pose great impacts on hospitals and healthcare organizations in both direct and in indirect manners. Hence, a better look into these approaching changes in order to better understand and consequently prepare to mitigate their harms or benefit from them is critical to health organizations. For this purpose, impactful perspectives and their sub-criteria will be explained in the following sections.

6.3 Methodology: Cause-and-Effect Diagram

As a brainstorming method, the cause-and-effect diagram assists decision-makers in identifying and categorizing causes of an effect, as well as pinpointing the relationships of causes [9]. Being one of the seven basic tools used in quality problem-solving processes [10], the cause-and-effect diagram has been proven to be a beneficial solution in cases where the justification behind an effect is ambiguous.

Construction of a cause-and-effect diagram requires several steps. An effect is identified first and its potential causes are uncovered through brainstorming, literature review, and interviews with experts in that domain. The potential causes are classified as major causes, as well as their sub-causes. Figure 6.2, Cause-and-effect diagram [11], represents the cause-and-effect diagram structure. The diagram is shaped as a fishbone. The effect is represented as the fish-head, and major causes are delineated as branching bones from the main bone. Each bone corresponds to a major cause and is further branched to represent sub-causes; hence, a hierarchy is created. The diagram is used by Wong (2011) to establish and describe the causes of crucial problems in clinical settings [12]. Hasin et al. (2001) demonstrate the essential features regarding customer satisfaction by using a cause-and-effect diagram created from surveys, questionnaires, and interviews, which are consequently used in finding the correlation among factors and essential features of dissatisfaction in healthcare quality [13]. The cause-and-effect diagram is also used by White (2004) to develop a method for identifying causes for underperformance in an emergency department by analyzing risk management files [14]. Furthermore, Testik et al. (2017) utilize the cause-and-effect diagram to identify healthcare improvement projects by constructing an analytical hierarchical process in a hospital setting in Turkey [11].

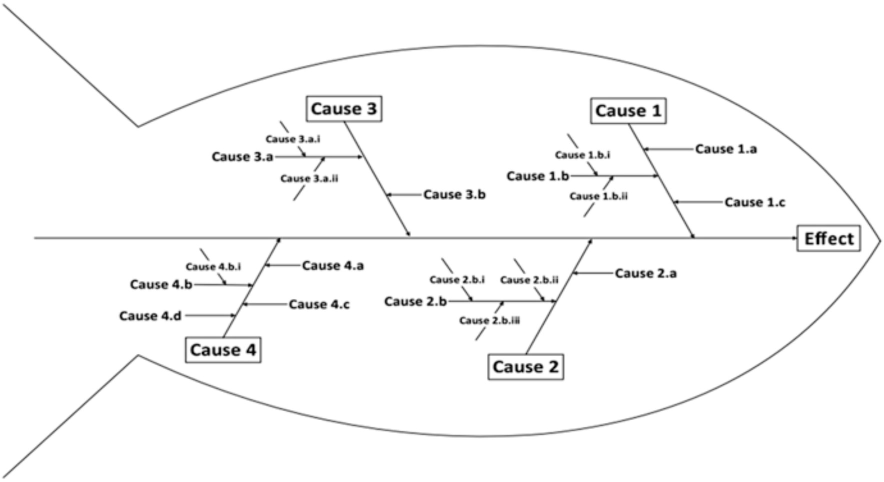


Fig. 6.2 Cause-and-effect diagram

6.4 External Change Perspectives

It is a difficult task to categorize the different perspectives affecting healthcare organizations due to the complexity and interrelationships of different categories and criteria. Schuman (2001) points out that more studies have focused on external perspectives causing concern in health organizations compared to the distress caused by internal environment of the respective organizations (such as management styles and policies) [15]. However, literature on healthcare external environmental analysis is not an abundant one. Casalino et al. (2003) discuss the effects of incentives, IT, and structured process in order to bolster the quality of care for chronic patients [16]. Also Ginter (2013) groups the external change categories as "legislative," "economic," "technological," "social," and "competitive" [2]. Although this book mentions some of the subcategories relating to the perspectives, it does not offer clear explanations on what those sub-criteria are. Santilli et al. also identify the trends affecting decision-making processes and roles in healthcare organizations in order to bolster firms' ability to act better in market transformations [17]. This study continues to use the perspectives from Ginter and Santilli while exploring the current change catalysts falling under each category.

6.4.1 Legislative/Political Changes

The legislative and political changes can significantly affect the environment for healthcare organizations, and each change in administration or swing in senate power can mean big changes coming healthcare's way. The passing of the Affordable

Care Act (ACA), for instance, undoubtedly restructured the role of healthcare stakeholders. Healthcare providers have a more serious role in terms of contributing to savings, risk, and establishing relationships compared to the time before ACA.

Also politics have significant effects on the lack of balance socioeconomic health [18]. Changes brought up by elections and union densities have the power to affect labor markets and welfare states resulting in income and socioeconomic disparities and consequently impacting healthcare and the organizations in that area. This means that not only legislations and politics can have direct effects on healthcare, but also they can have indirect impacts by influencing other change perspectives such as social/cultural.

6.4.1.1 Possible Changes Threatening Affordable Care Act

Since being passed on March 23, 2010, the Patient Protection and Affordable Care Act has had significant impacts on the healthcare environment in different ways. The bill tended to transform hospitals' way of doing things financially, technologically, and clinically in order to achieve better quality of care and its accessibility at less costs. As an example, ACA paved the way for the emergence of accountable care organizations, switching from fee-for-service to bundled payments [19], Hospital Readmissions Reduction Program [20], and new insurance standards, among other things. Also it has had great impact on the technological structures of hospitals due to cost/quality initiatives in terms of electronic health/medical records. In 2013, about 93% of hospitals had certified EHR technology, increasing by 29% since 2011 [21]. This number rose to 96% percent by 2015 in terms of EHR systems with functionality, capability, and security measures of the Department of Health and Human Services [22]. The Medicare and Medicaid EHR Incentive programs incentivize professionals, eligible hospitals, and critical access hospitals adopting and implementing and meaningful use of certified EHR technology. As mentioned in the previous section, ACA rebuilt the role of healthcare organizations by giving them a bigger role in terms of contributing to savings, risk, and establishing relationships. A more efficient system would allow hospitals to cut costs by focusing on preventive care and wellness in long term. ACA has also paved the way for more trends such as consumers with stronger roles, more structured quality measures, and healthcare consolidations which will be discussed in the next sections [17]. Also post-ACA, the attention has switched to outcomes as quality metrics such as the success rate of treatments, morbidity rate, length of hospital stay, and patient satisfaction, among others. Healthcare organizations must learn to deal with the constant challenge of providing the right mix of care concurrent to earning revenues for it [23].

Although ACA has had many great impacts on the way healthcare is provided in the United States and its shift from transaction-based rewards to outcome-based ones, it is definitely not a panacea for the problems in the healthcare structure and needs reforms. Although ACA greatly has mitigated the rise in the percentage of healthcare in US GDP (0.124% increase from 2010 to 2014 compared to 1.863%

from 2005 to 2010 [24]), it has been the constant target for the Republican Party with hopes of repealing it. While the Republican Party's American Health Care Act (AHCA) was proposed to replace ACA in 2017 and failed miserably on March 24, 2017, that does not mean that ACA will have a safe spot for years to come. This poses a great uncertainty for healthcare organizations in terms of strategic management and finding ways of achieving competitive advantage in a highly volatile political environment. The changes inherent in legislative reforms offer stakeholders numerous opportunities and threats which have to be analyzed and ways to prepare for them or take advantage of them thought through. As an example, the proposed elimination of individual mandate by the GOP healthcare bill would have changed the healthcare environment. Executive, legislative, and judicial branches of US government will all have effects on future bill changes, and companies should pay great amount of attention to changes and prepare themselves in terms of strategies for different outcomes. What makes a change in a legislation such as ACA so important is the inevitable effects it will have in different change perspectives for healthcare companies in terms of external environment.

6.4.1.2 Increase in Governance Accountability

The continuous evaluation of organizations in terms of effectiveness in order to gain trust in them by the public has become an increasingly important issue [25]. Through the years, legislations have been introduced to cope with reports of fake revenues and hidden liabilities from balance sheets in order to understate debts and related expenses. Scandals of Lehman Brothers in 2008 and Enron in 2001 are perfect examples of these problems. One of these legislations is the Sarbanes-Oxley Act of 2002 which imposed stricter financial reporting for companies [26]. The act included holding company officers accountable for the accuracy of financial report; increased the fine and sentence for defraud attempts, forcing them to be more transparent in order to gain public trust; and mandated external audits for financial reports for all US publicly traded companies, subsidiaries of foreign companies in the United States, and private companies preparing initial public offerings. For hospitals, this passage and any passage similar to it means that they have to implement a series of actions. According to SOX Act, healthcare organizations should develop criteria for board member selections as well as bolster internal control which can lead to less risk to investors by having a better system for selecting board members [27]. The risk for change again here is that through the years, SOX has had its supporters and oppositions, but the general direction is toward increase in governance accountability which can affect the healthcare environment. Literature suggests considerable limitations for policy makers' efforts in improving governance of nonprofit hospitals but the interest in growing [28]. Through different administrations, different changes can be made to level of transparency imposed on organizations (President Obama's JOBS Act). These possible changes pinpoint the importance for healthcare managers to keep abreast of the ongoing political atmosphere and possible changes. With the whole transition to the age of information, companies must learn to use governance accountability as a source for advantage. The borders of confidential and public information should be redefined by companies in terms of qualitative and quantitative data. In order to use accountability to their advantage, companies must understand the importance of transparency from their stakeholders and internal management's viewpoint [29]. Legislations such as ACA emphasize meaningful use for accountable care organizations, and this can be a great opportunity for organizations to improve patient experience and quality measurement by creative use of these new legislations and technologies.

6.4.2 Economic Changes

Issues such as increasing average age of population, healthcare and treatment costs, and changes in the number of insured people can have effects on country's economy and certainly be affected by it. Many of the changes that have led to a managed care system can be traced back to economic changes. The increasing cost of healthcare in the United States is signified both by per capita payments and also by measuring healthcare expenditures as a percentage of the gross domestic product (GDP) [30, 31]. The US care spending has grown from $3708 (per capita) to $9990 from 1996 to 2015 which is about 70 times bigger than the per capita health spending of $141 in 1996 [32]. Moreover, faster growth in total healthcare spending in 2015 was caused by bigger growth in private health insurance, hospital care, and physician and clinical service expenditures and the growth in Medicaid and retail prescription drug expenditures.

Many of the factors that have had impacts on this growth can be rooted back to other change perspectives such as social, technological, and legislative. US population has had an increase of 79.25% between 1960 and 2015 [33], and based on Kinsella and Gist (1995), the percentage aged 65 and older in the United States will be tripled from 1944 to 2033 [34, 35]. Some of the other factors which affect the economic perspective and consequently the healthcare environment are the rise in cost of insurance, increase in alliance of healthcare organizations, improvements in technology, and rise in malpractice insurance and case settlements [30].

6.4.2.1 Changes in Insurance Costs

As the cost of providing health insurance grows, employers struggle in terms of keeping up. Furthermore, many plans are covering less and include higher deductibles and co-pays. This leads to some employers to be able to cover a less amount of people and even the burden of this increase to employees. At some point certain companies may prefer to pay the fine of not insuring their employees as it would be more cost effective than paying for their insurance [2]. The trade-off here is that from one side decrease in existing plan values negatively impacts employees, but from the other side, being able to maintain insurance costs helps to cover more people even if their coverage is only for very serious illnesses. Another problem is that as the prices for insurance goes higher due to health systems' consolidations, they go under the pressure of not raising premiums [17]. This will lead them to choose less expensive hospitals and physicians and will pass fewer selection options to their employees or narrow their networks and building alliances. Consequently narrower available networks will be formed, and shared risk will become more popular through accountable care organizations (ACO). This is not necessarily a negative thing as ACOs are heralded as improving care and access, lessening complications, and effective in terms of money and time. However, while the premium will be kept lower this way, it would cause problems for the covered patients in terms of access as they have to deal with out-of-network bills [36].

From another aspect, narrower networks and more consolidated healthcare systems lead to less bargaining power for insurers. This is due to the fact that physicians and hospitals now can negotiate the prices together as a bigger entity. The Kaiser Family Foundation and Health Research & Educational Trust's Employer Health Benefits 2013 Annual Survey and Access Market Intelligence analysis of commercial trends depicts that the number of fully insured commercial health plans have dropped from 89.1 to 68.8 million members from 2008 to 2013, while self-financing commercial health plans account for 60% of health plans [37]. Moreover, as a social transformation, patients are more wary of and involved in their healthcare choices as well. This again points out the fact that all these different change perspectives are interrelated indicating the complication of the healthcare environment.

6.4.2.2 The Shift From Fee-for-Service to Value-Based Reimbursement

One of the biggest areas of competition between healthcare providers is fueled by the pressure of cutting costs and bolstering quality of care. These demands are forcing organizations to realize the advantages of value-based health models over the traditional volume-based fee for service. This means that financial incentives and penalties are dependent on measured performance, improvement and performance thresholds, and cutoffs [17]. In other words, payers are responsible for paying for the value of delivered care instead of the number of visits and tests [38]. Again due to the social change perspectives and the fact that the overall population in the United States is aging, Medicare costs are going to increase, and due to the legislative perspective, the continuation of Medicaid depends on the survival of ACA.

Furthermore, this shift poses a great financial challenge as value-based models are still mostly nascent (mostly dependent on Medicare Shared Savings Program) making the monitoring and tracking of care systems using both the traditional FFS and the new value-based model a daunting one. Moreover, in order to be compatible with the value-based model, organizations should use data analytics in order to measure their financial and quality metrics (technological change perspective). Lastly, companies can have a fall in revenue due to learning curve and adoption diffusion of value-based models, and the thing that makes this a bigger challenge is that the diffusion of adoption of value-based model has an unknown time-span (Fig. 6.3).

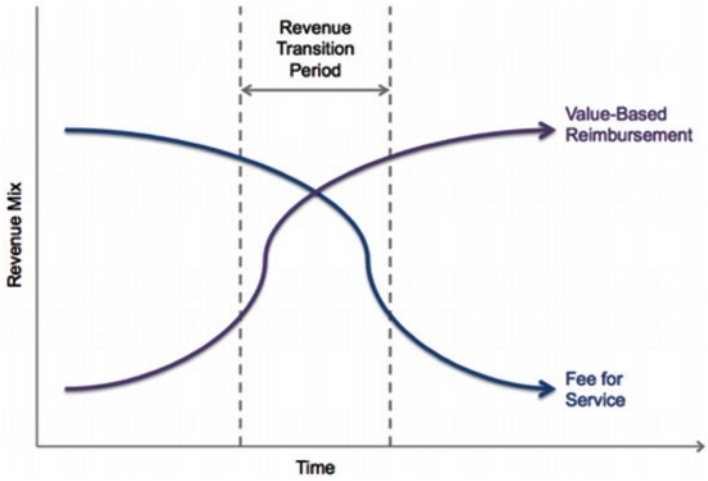


Fig. 6.3 The revenue mix for transition from FFS to value-based models [38]

In order to take advantage of this change, health organizations and managers should leverage the power data analytics (big data and data warehousing?) to make sure they are getting the possible incentives, shared savings, and bonuses (concurrent to lowering costs and improving quality of care). Furthermore, health managers should have a great understanding of the ways they can improve costs of operation while bolstering the quality of care. Concepts like kaizen, waste management, and lean management can be considered by managers in order to improve organizational and care quality. Radnor et al. (2012) explore the possibility of lean in healthcare organizations and argue that the future of lean in healthcare lies in developing structures, mindsets, and systems capable of ensuring that the significant investment in lean is justified [39]. The mentioned paper continues to discuss that lean concept as a process improvement tool has a lot to offer in healthcare operations in the right context (application of manufacturing concept in service context). Stonemetz et al. (2011) also study the reduction of regulated medical waste using lean sigma and how companies can leverage it to gain financially [40]. Finally, with reduced costs and waste and improvement in quality of care, organizations can accept a bigger amount of patients and can be seen as a better candidate in forming alliances by the other healthcare organizations in the environment leading to being positioned in better networks (as mentioned in the previous sections). This would also lead to a bigger volume of employers to select the organization as their care provider for their employees. Although facing a great amount of barriers, the shift from FFS to value-based models seems inevitable. According to a 2013 Wolters Kluwer Health Survey, nine of ten physicians cited shifting reimbursement models and the financial management of practices as their top challenges (better alignment of payment and goals of clinical quality) [41]. Some of the new models are being implemented by modifying the fee-for-service payment instead of substituting it, possibly curbing their potential to be truly transformative. The favorable outcomes of value-based models may be in the hands of its early adopters on recognizing and consolidation of their experiences [42].

6.4.3 Social/Demographic Changes

In 1991 Stromborg pointed out the dramatic change that is going to happen in the balance of the American population [43]. This change in composition of population in terms of social and demographic diversification is happening much faster today. As an example the Hispanic population has gone from around 6 to 52 million from 1960 to 2012 and Asian and Pacific Islander population from 980 thousand to 15 million in the same time frame [44, 45]. From the age aspect, based on Day (1992), from 2010 to 2030 the population of 65 and over is estimated to go from about 40 to 70 million accounting for more than 20% of the population [46]. With the increase in the number of insured people in the Obama Administration, many people who were added to the insurance pool had a lot of health conditions due to avoiding medical care for the sake of their costs. Some people also needed time to adapt to and learn the system, and this experience curve costs money and time. Although in short term the number of increased insured people has had a dramatic effect on the cost of care, it will become smoother as time goes by. These shifts will pose great demands on US healthcare organizations. In a 2010 report issued by the Institute of Medicine, healthcare workforce is estimated to be too small and under-equipped to satisfy the demands of the rising and aging population [47].

6.4.3.1 The Aging Population

The growing age of the baby boomers' generation is going to make an impact on the healthcare environment. It is estimated that by 2050, 20.2% of the US population are going to be 65 and older [48]. This demographic change will drastically increase the demand for healthcare services, and the projected healthcare workforce and equipment are thought to be insufficient in order to cope with the rising demand. In order to deal with this change, healthcare organizations may, as mentioned before, consolidate and smaller healthcare units integrate into more structured units (even with embedded insurance companies) [49]. This type of change can lead companies to form more alliances with both providers and payers in order to construct an extended healthcare system. They have to focus on diseases that older demography are more prone to (chronic and palliative diseases and hospice) in terms of equipment, training, and professionals. Again, this is healthcare managers' responsibility to successfully anticipate the needs and changes that aging population brings and manage the change into a direction that can give the organization a competitive advantage. Although the rise in demand seems formidable, it may be a great edge factor for health organizations.

6.4.3.2 Increase in Racial and Socioeconomic Diversity

One of the other occurring social changes is the rise in racial diversity in the United States. As mentioned before, Hispanic population has been multiplied by 8.6 times to 52 million from 1960 to 2012 and Asian and Pacific Islander population 15 times to 15 million in the same time frame [44, 45]. Furthermore, the African American population now accounts for more than 12.6% compared to 10% in 1960 [50]. Also due to this increase in diversity, the number of interracial people has increased as well making diversity more complicated. In terms of states, some are more diverse which should be taken into account by health organizations. As an example, California has 27.8% Latinos (even in 1986, over 50% of the population in California consisted of Hispanic, African Americans, and Asians [51]) followed by Texas with 18.7% and Florida by 8.4% [52]. Although this concentration pattern may be helpful, it should be taken into account that many minority groups are moving through country in order to find jobs and cheaper or better quality of life. There are some important information connected to these scattered population groups that can prove to be important for healthcare organizations in terms of seeing and preparing for change. Certain racial ethnicities have predispositions to certain diseases and also would be more likely to be in certain socioeconomic groups with specific needs [43]. As an example, Hispanics have more need to be given information in Spanish and are more likely to have better care experience with a Spanish-speaking professional. Another example can be Asian Americans which experience lower rates for many malignancies compared to Whites and African Americans, while there are certain types of cancers that Asian Americans are more prone to compared to the other groups [53–55]. However, Stromberg (1991) argues that socioeconomic status plays a more vital indicator of community health [43]. The poverty rate in the United States (based on data from the US Census Bureau) has remained at 13.5% from 1990 to 2015 and decreased from 15.1 in 2010. African Americans are the ethnic group with the highest population in the poverty cluster in 2015, with an amount of 24.1% (followed by 21.4% Hispanics) with an income below the poverty line. In comparison to that, only 9.1% of the White (non-Hispanic) population were in the poverty cluster in 2012 (United States; US Census Bureau; 2015). In addition to these socioeconomic and racial factors, religious diversity can have impacts on the healthcare environment in a geographical basis as well. In some religions, there is a need for a female professional to examine female patients. Also, in terms of cultural remedies, there are risks of conflict between the medicine used and the used cultural alternative remedies in addition to fasting months which should be taken into account.

All in all, there will be a continuation in racial diversity change in the United States due to changes in immigration laws (both legal and illegal), economy, jobs, etc., and health organizations must be informed and up to date with the genetic predispositions, risk factors, socioeconomic status, religion, and culture of their region's demographic and regularly evaluate their community's makeup in order to be responsive and respectful to specific health needs and circumstances and possibly gain competitive advantage.

6.4.3.3 More Informed Patients

The conventional healthcare model of behaving toward serious diseases is transforming into a model with rising concentration on the patient, disease prevention, and management of chronic illnesses. The new structure in healthcare market lets patients to chaperone their healthcare in a more involved way. Access to data and information enables patients to get more involved in decisions about diagnosis and treatment alternatives. Better estimation of costs beforehand gives patients a better understanding in terms of deciding on a blend of cost and quality in evaluating their care alternatives. Furthermore, market exchanges for health insurance enables to choose from a spectrum of insurance coverage plans leaving them with more financial responsibility and, hence, more diligent in reevaluating how and when to spend on healthcare services [17]. Fronstin et al. (2014) argue that this attention is more in people using consumer-directed health or high deductible health plan compared to people using other types of insurance plans [56]. The study continues to mention that patients are asking more about generic drugs and are more price aware and in charge of their healthcare expensing management and tracking. Epstein et al. (2010) stress the importance of establishing national policy in areas such as patient-centered care in order to increase disease outcomes and quality of life other than having large impacts on addressing socioeconomic and racial disparities [57]. Moreover, Bechtel (2010) emphasizes on the importance of asking patients about what they really want and need from healthcare organizations in order to bolster communication and coordination with their patients while supporting and empowering them [58].

All these would mean that patients are no longer passive elements of healthcare decision-making, and studying patient behavior, finding ways to maintain less insurance cost in balance to growing healthcare costs, having a better understanding of their rising demands and expectation, and learning how to be responsive to them can grow into a great intangible asset for healthcare organizations and managers.

6.4.4 Technological Changes

With all the changes in population and demand, healthcare organizations are in necessary need of leveraging the value of technology advancements in order to be cost-effective, competitive, and responsive. Technological tools assisting decision-makers in analyzing data and leveraging the power of big data and information technology systems have become pillars of improving quality of care, identifying trends, anticipating changes, and controlling costs. Electronic health records (EHR) have shown to have great benefits in increasing outcomes for healthcare organizations in 92% of studies in the literature despite low patient engagement numbers [59, 60].

Healthcare organizations should leverage the developments in technology and computing in order to increase patient engagement and satisfaction, reduce costs, anticipate changes, and learn to develop intangible assets in order to integrate and intelligently use their resources. Based on a report published by the Institute of Medicine (IOM) of the National Academy of Sciences, the quality of healthcare in the United States is weaker compared to biomedical knowledge and that this gap in quality is due to organizational incompetency, rather than of individual physicians [16, 61–63].

Every year new technologies are emerging focused on empowering patients and providers in order for organizations to better manage changes and costs. Furthermore, innovation in biotech and pharmaceutical industries have led to faster market entry and stronger research and development pipeline. As an example, a sudden change of speed in cost per genome has occurred in 2008 reflecting the transition from Sanger-based sequencing to next-generation genome sequencing technologies [64]. In addition, rare diseases have gained more attention from pharma companies due to significantly less time needed in terms of patient testing, government financial incentives, and higher approval rates from the US Food and Drug Administration (FDA) [65].

It is healthcare managers and organizations' duty to leverage, coordinate, and manage emerging technology tools to bolster increased data transparency and patient involvement. This perspective can be impacted by and simultaneously affect other change perspectives such as legislative, social, competitive, and economy is a great way as mentioned before.

6.4.4.1 Information Technology Innovations

Innovations in computing and big data services are causing transformation in the manner that health data is stored and transferred among patients and providers. Healthcare organizations are embracing technologies and innovations such as EHRs and EMRs, clinical documentation tools, big data, and telemedicine devices in order to improve the process of health information collection and consumption. Wearable technology, mobile health, and big data analytics are becoming progressively valuable in healthcare delivery systems. Although these new innovations and technologies will significantly facilitate diagnosis, prevention, and treatment more efficient, they dramatically increase the need for organizations to care about the security of their data [66]. However, Lyon et al. (2014) suggest that as more patients adopt new information technologies, the importance of data analysis for organizations surpasses the privacy and security concerns [67].

As for big data analytics, the healthcare environment is one of the areas which is going to be mostly affected by it. The cost of healthcare in the United States is undeniably high (approximately 17.6% of the nation's GDP increasing from 8.9% in 1980) [68, 69]. It is also estimated that one third of that spending is due to waste caused by (as listed by the Institute of Medicine) unnecessary services, administrative waste including unproductive and duplicate documentation, inefficiently delivered services, high prices, fraud, and missed prevention opportunities [68]. In addition to that, the current reimbursement model favors a number of patients over treatment effectiveness: “physicians have been compensated under a fee-for-service system that only considers treatment volume, not outcomes,” and patients have “little responsibility for the cost of the health care services they demand” [70]. On top of the financial loss, other consequences of this problematic system include statistics such as: “one out of five elderly patients are readmitted within 30 days of discharge for no known reason” [68]. Big data analytics may hold the key to solving some of these issues. Barham (2017) conducts a literature review on how big data can create value for organizations and discusses the challenges hindering its adoption [71]. Health organizations leverage the power of big data in order to gain competitive advantage in terms of being more cost and time effective and improve their quality and experience of care for their patients. Barham (2017) recommends companies to acquire experienced data scientist, learn from successes and failures of other organizations, embrace the benefits of data integration and sharing with partners, and finally work closely with software developers to develop more user-friendly applications for patients and professionals.

Like in other developed countries, the public sector of the United States has started to take action with regard to big data in order to leverage its potential in overcoming various complex challenges. In 2012, for instance, the Obama Administration invested $200 million in the “Big Data Research and Development Initiative.” with goals including advancing state-of-the-art core technologies of the big data era, accelerating the pace of discovery in science and engineering, strengthening national security, and transforming teaching and learning and expanding the workforce needed to develop and use big data technologies [72].

In the recent years, the government is bolstering the ease of data release and accessibility, which enables better access to and standardization of public data of patients, clinical trials, and health insurance [69]. Moreover, ACA has also started the process of fundamentally reshaping the industry and the interrelationships between healthcare entities. The private sector is also being affected. Hospitals, providers, clinics, insurance companies, pharmaceutical companies, researchers, physicians, nurses, and patients are all impacted by the changes that the use of big data is bringing into the industry. Meanwhile, traditional pharmaceutical retailers such as CVS Health are developing internal Digital Innovation Labs that are rolling out Apple Watch apps and facilitating the process of filling medications remotely [73].

All in all, new IT innovations can give health organizations in terms of insight and advantage. However, managers and organizations leveraging the fruits of these new innovations should manage the ethical, security, and privacy risks that come along with them. The use of data and analytics in patient care opens up new opportunities for boosting care effectiveness and efficiency despite the fact that the full realization of the importance of data-driven insights has been clouded by some barriers. US health information technology website lists some of these barriers as current data input and output limitations of medical record systems, scarcity of robust business models for interoperable data exchange across organizations, and wider organizational barriers that require coordinated solutions across stakeholders [74].

6.4.4.2 Increase in Specialty Drug Use and Equipment Cost

Specialty drugs are used to treat rare, complex, or chronic diseases and demand great level of involvement from the healthcare provider. In addition to special storage and shipping, they may need access to these drugs which can be limited, and they are becoming important for health organizations as they are starting to enter the market at a faster speed as the research pipeline continues to expand. This becomes a more interesting topic due to its high costs. Despite the fact that 4% of patients use specialty drugs, a quarter of the total US drug spending is due to specialty drugs [75].

Diagnostics, drugs, and equipment keep driving the total care spending. In the short term, due to the uncertainty revolving around the bio-similar market and the fast-paced innovation in personalized medicine, the concentration of pharmacy benefit managers will carry on being on unit cost savings, whereas in the long term, the focus is on commercial and self-funded plan sponsors, along with how best to manage the economic risk in the long term. This problem can solely change the structure of insurance product offerings and patient coverage [76]. Kumar (2011) discusses the reasons behind the lack of effect of digital revolution in healthcare cost reduction and the need for a measurement of the proportion of patients who do not have access to healthcare because of costs of care [77].

Another issue is that patients can access infused drug therapies in different places (hospitals, infusion centers, physician's office, and patient's home) at very different costs [78]. As an example, the costs for a standard dose of a rheumatoid arthritis infused medicine can change from $3259 for the medicine itself and $148 for administration costs when administrated at the patient's house, whereas the drug and administration cost will rise to $5393 and $425, respectively, when implemented as an outpatient procedure at a hospital according to Santilli (2015) [17]. This shows that, surprisingly, the hospital setting is the least cost-effective healthcare center for infused drugs. Regardless, according to a recent CVS report, infused drugs are increasingly being administrated in hospitals leading to highest costs and least cost efficiency [79].

In general, a lot of things are happening in terms of drugs and equipment cost. As tools, technology, applications, and new practices are being introduced at a faster rate, companies should be well abreast of all the changes. By seeing all the higher cost of doing infused drugs at hospitals as opposed to homes, healthcare organizations can increase the shift of those practices to homes.

There have also been new improvements in personalized medicine which can have great effects on healthcare industry [80]. Due to the dramatic reductions in DNA sequencing following the development of second-generation sequencing platforms in 2008, molecular diagnostics are increasingly being considered to be cost effective enough to be used as a standard medical test, both prospectively for risk assessment and for confirmation of diseases. Among the technological advancements, one that has undoubtedly had a great influence on this economic shift is DNA sequencing which is mapping of the human genome. Since 25 years ago, the cost of sequencing a human-sized genome has fallen dramatically from $100 million to $1000 [81].

Since the Second World War, the main driver of costs in healthcare has been the higher price of newer technologies which has also been impacting the insurance cover average costs as well [82]. Again we can see the impact of different change perspectives on each other. The legislative aspects have effects on technological aspects in terms of R&D funding and consequently the cost of those incoming technologies and eventually people in specific demographics and socioeconomic status.

6.4.4.3 Social Media

In the second decade of the twenty-first century, social media has become a significant part of many industries and organizations, and the healthcare environment is not an exception. Vance et al. (2009) hint at the increasing evidence showing that social media use among patients and health professionals is rising significantly [83]. Personal social network use between health professionals and physicians-in-training reflects the general trend in the environment, and as for the patient-doctor interactions, the majority of them are initiated by patients which demonstrates the level of awareness and interest from patients' perspective.

There is also a growth in online social media awareness in Western European hospitals, but different countries have applied social media to address different issues. Van der Belt et al. (2012) mention that other than the Netherlands and the United Kingdom, there is a small proportion of hospitals using social media among European countries. As an example, hospitals use LinkedIn in order to hire professionals. Again, there is a need for further research in order to define metrics and connect the effects of social media in healthcare quality improvement [84]. Chou et al. (2009) suggest that new technologies such as social media are reshaping the patterns in communication in the United States [85].

A very important issue in leaning toward social media for health organizations is the consideration of targeted group's age, socioeconomic status, and racial ethnicity in order to assure sufficient awareness and interest among that specific target. In more rural structured areas, there may be less inclination, awareness, and confidence by patients to use social media. This inertia, however, can be mitigated by education and promotion of the benefits and conveniences of using social media. Clinicians also use online social networks, specifically the newer generation of clinicians, for both personal and reference aims.

However, a big portion of respondents have a cynical attitude toward the online interactions and see them as being ethically problematic [86]. Quantification of social media effects is a nascent area of research due to lack of used terminology and research methods [87]. Antheunis et al. (2013) argue that the literature has mostly focused on the benefits of social media on healthcare and suggest that their study has found dis-concordance in patients' and professionals' motives, barriers, and expectations regarding health-related social media use [88]. Hawn (2009) discusses the impact of social media on healthcare and its benefits such as "improving quality through "better communication" and "empowering patients" resulting in happier patients". The study also pinpoints the privacy, standard, and cost downsides of social media in healthcare [89].

In sum, health organizations and managers should carefully monitor the potential effects and implications of social media in the environment and industry in order to be prepared for the challenges and clinch opportunities in order to reach or manage competitive advantage.

6.4.5 Competitive Changes

Last change perspective reviewed in this study is the competitive change perspective. As the healthcare environment is becoming a harsher vying one for providers, there is significant pressure for providing better quality of care at a lower cost. As mentioned before, these changes are causing a paradigm shift from the conventional fee-for-service models to value-based ones and focus on quality of care as supposed to quantity of services provided. This pressure is stronger in areas with more demand which there is buyer power. According to a report by Stanford Medicine, physician practices in less vying areas cost more for office visits compared to more competitive areas of care [90]. From another aspect, these pressures are leading to consolidation of healthcare entities in order to increase efficiency, cost-effectiveness, and share risks. Although there is research evidence for the benefits of consolidation of healthcare entities in terms of information sharing and flow, there is not much supporting the same effect for cost-effectiveness. Dranove and Lindrooth (2003) finds robust, significant, and persistent results showing that consolidations into systems does not create, savings whereas acquisitions and mergers generate savings from 3rd and 2nd consolidation years, respectively [91]. However, if these consolidations lead to prevention in medical errors, avoidable hospital admissions and readmissions, and/or improved hospital efficacy, increase of shared decision-making and improvement of targeting costly services, achieving better quality at lower costs, may be possible [92]. Other change sub-criteria such as healthcare networks becoming narrower and health quality measure becoming tighter will be discussed in this section.

6.4.5.1 Expansion of Healthcare Organizations and Shrinkage of Networks

One of the consequences of increase in competition in terms of costs and quality has been the consolidation of some healthcare organizations. The mentioned consolidation is typically regional and national health organizations forming bigger systems with other health entities to gain competitive advantage [93] . This trend is similar for regional hospitals as they are inclined to gain more local power by joining forces, acquiring more physicians, and getting bigger. Some of the reasons behind these consolidations can be organizations' move toward more standardization, gaining more negotiating power as a bigger entity, and finally bigger financial power in order to make efforts to raise quality of care and decrease cost of care. Furthermore, consolidation would enable healthcare organizations to be more versatile in their offerings and target a wider spectrum of market segments. Most of these consolidations tend to be horizontal ones as a larger hospital acquires smaller independent health centers or when integrated providers join forces with other health systems in order to penetrate new product, service, or regional markets or expanding the current ones. This has led to a decrease in the number of independent hospitals in many states as they integrated into bigger systems. According to the American Hospital Association and Irving Levin Associates Inc. in its 2014 report, 1307 healthcare transaction had taken place which was 25% higher than 2013 as multi-billion healthcare deals were struck almost weekly [94].

Healthcare consolidations tend to be increasing as organizations are seeking a bigger scale to deal with complex market and government volatilities, reimbursement policies (ACA, Acceleration of Medicaid enrollments), emerging technological innovations, legislations, financial needs, changes in patient care, and other issues which hand in hand have made the healthcare environment and organizational independence in it more daunting [95]. Healthcare consolidations enable a better coordination among different practitioners and organizations leading to a greater market power (decrease in insurance company bargain power) which can in turn cause higher prices [96]. From another aspect, the shift from FFS to value-based models is connecting reimbursements more strongly to quality, safety, reductions in avoidable readmissions, and other critical measures, and in order to achieve those, healthcare organizations must possess reliable information infrastructures to track compliance with federal regulations and document their performance. Therefore, organizations will keep growing in order to gain access to the IT systems and advantages needed to keep on complying with healthcare reforms [38]. There is also a term called consolidation lite which refers to affiliation of healthcare entities for a specific goal which are increasing due to expanding market and legislative pressure [95].

Moreover, with the increase in specialty practices, hospitals may increase outsourcing patients to outside specialty physicians [97]. Casalino (2004) suggests that the increase in specialty groups' efficiency may give them the possibility of cutting overall costs of care. In Casalino (2003) an important question is asked from hospitals which is "Should they cooperate or compete with specialists owning specialty facilities?" while proposing that each route is rife with risks [98].

Gaynor and Haas-Wilson (1998) discuss the changes that healthcare structural transformations would have on healthcare industry in terms of insurance, services, and professionals markets [99]. The working paper continues to emphasize that only the structure that bolster efficacy and quality will survive as opposed to the ones with biggest market power.

Another implication of healthcare consolidations is that due to the price pressures put on insurance company (because of consolidated centers bargaining power), they implement their own consolidations. Based on Santilli (2005), Memorial Hermann Physician Network teamed up with Blue Cross Blue Shield of Texas in 2013 in order to form an accountable care organization for more than a million Houston area Blue Cross members [17, 100]. In order to minimize the risk because of healthcare environmental changes, Memorial Hermann has also struck accountable care organization deals with firms like Aetna (in order to save $1.2 million in saving, reduce the costs of surgery by 40%, 8.4% fewer hospitalizations, $8.07 lower monthly member claims, and 6.6 saved physician hours) and accepted and formed alliance with many insurance affiliates (medical home model with Humana) [101]. Despite the fact that narrower networks will mitigate high premium prices, it can cause unintentional out-of-network bills for patients (70% of exchanged plans are in narrow or ultra-narrow networks which can cause access problems for patients) [102].

To sum it up, as costs and revenue constraints are becoming alarming issues for many health organizations, health systems are consolidating in horizontal integrations through hospital mergers and acquisitions. The bigger size of systems could lead to more efficiency, risk sharing, and less costs across the enterprise [103]. However, companies must answer some serious questions (as posed by Casalino (2003)) and avoid driving up costs due to bigger market shares. In addition, companies must focus on enhancing their efficacy and quality of care in order to gain competitive advantage as opposed to focus solely on market power.

6.4.5.2 More Structured Quality Measures

As mentioned before, the shift from FFS to value-based models enables care organizations to be incentivized for the quality of the provided service as opposed to the number of service given. This change magnifies the importance of quality measurement and improvement for providers. Although some organizations develop their own set of metrics and quality measurement tools, there are some public and private metrics for healthcare quality such as the ones included in the Centers for Medicare & Medicaid Services and the Agency for Healthcare Research and Quality and public measure developers such as nonprofit private developers that include the Joint Commission and the National Committee for Quality Assurance. Other health quality measurement professional societies include the American Heart Association, the American College of Cardiology, the Society of Thoracic Surgeons, and the American College of Surgeons (through guidelines, publications, members societies, and industry relations) [104].

Healthcare providers can use these metrics to evaluate their draft measures. Companies should clearly determine what they are trying to measure as quality can be a quite fuzzy term. Some of the steps suggested in the literature are defining clinical metrics and reviewing evidence-based literature in order to pinpoint the best practices for the relevant area of care [105, 106]. Also compliance with proved clinical solutions and treatment guideline is becoming more important as implications of not following guidelines can cost health organizations in terms of penalty.

Transparency also plays a significant part in quality metrics as private health firms need to provide real information on their performance to their sponsors and stakeholders [17].

While the quality in the past meant meeting and exceeding customer experience in healthcare, currently there are added regulatory, sponsor, and competitive expectations to be met as well. To make matters more complicated, definition of customer and stakeholders and the criteria for quality are far more complicated in healthcare context compared to other industry [107]. Another way that healthcare organizations seek competitive advantage is by obtaining certifications and winning prestigious quality awards (healthcare related or standardization ones (ISO)) resulting in more patient confidence and eventually stronger market presence. Some other organizations used methods such as Six Sigma for quality improvement as a systematic and project-oriented management strategy which comprises total quality management (TQM) philosophy, strong customer focus, and advanced data analysis [108, 109]. Six Sigma as a project-based methodology often deploys statistical methods and scientific tools during the whole project life cycle, from earlier project defining efforts until to the project closure. Since Six Sigma approach is very useful in decreasing variability, eliminating waste, and improving processes, it has gained a significant popularity in organizational management [110].

In conclusion, there is rising concentration on single measures that are beneficial throughout healthcare settings and are more lined up with the whole patient course of treatment. Narrowing down the large number of similar but different quality measures to more efficiently apply change for better clinical and economic results has gained more importance in the past few years. The application quality measures are growing and escalating the demand for new, innovative care-delivery measures that can deliver needed care performance for both sponsors and patients. Healthcare organizations may be able to gain competitive advantage by leveraging the power of methods such as Six Sigma, control charts, cause-and-effect diagrams, etc. combined with great attention to details in changes in regulations and incentives and quality requirements.

6.4.5.3 Intensified Competition

Despite the unsatisfactory quality and high costs of healthcare, it is surprising that US healthcare is subjected to more competition compared to anywhere else in the world [111]. Patients in the United States are typically not satisfied with healthcare costs and quality deficits and worried about the increase in the amount of uninsured people (due to potential legislative changes). Enthoven (2005) argues that the right type of competition can lead organizations to provide for those deficiencies [112]. Enthoven (2005) continues to suggest high-quality, efficient, integrated delivery systems and delineates Porter's (2004 [111]) model which focuses on individual provider competition as not useful in solving the industry's problems. Although competition between organizations has been seen as a solution to increase value for patients, there are a number of complex issues and relationships related to

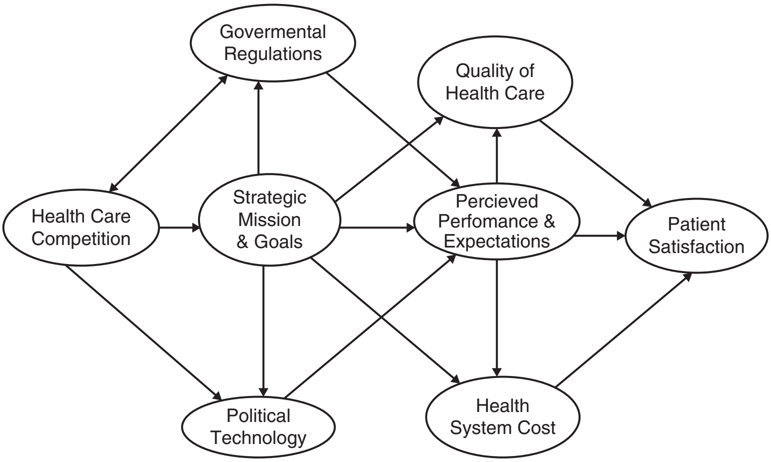


Fig. 6.4 Competition and patient satisfaction [113]

competition in the healthcare industry which should be taken into account by organizations. Rivers et al. (2008) study six types of relationships between competition and other variables in a healthcare organization [113]. Rivers et al. (2008) conclude that with the increase in level of competition in an environment, things like patient satisfaction and quality of healthcare increase, while healthcare system costs decreases. Furthermore, patient satisfaction will be bolstered by cost cuts and increased quality of care. Finally, as the health system costs increases, the quality of healthcare will increase (as seen in Fig. 6.4).

Rivers et al. (2008) add that a more intense competition environment leads to a rise in hospitals becoming different in the process of growth or development, and stronger push for price per share increases specializations [113, 114]. However, in another study in the United Kingdom, higher competition rate is associated negatively with quality of care and tends to result in higher death rates while suggesting that the overall effect of competition on quality is not significant [115]. Another outcome of increased competition as suggested by Kessler and Geppert (2005) is that higher vying health environment leads to more attention to high-risk patients and consequently leads to better treatment and results for them [116]. Gowrisankaran and Town (2003) conclude that increasing competition in health maintenance organizations leads to price cuts, better quality of care, and improved healthcare, while the same change tends to be detrimental in terms of quality and welfare for Medicare [117].

To conclude, as literature suggests, the impacts of increase competition on quality of care is rather a case-specific one and is not necessarily beneficial or detrimental to it. As Rivers et al. (2008) argue, the vagueness revolving around the effects of competition on quality, cost, welfare, and healthcare environment in general is due to the fact that these issues have not been studied in a collective and simultaneous way.

6.5 Conclusion

Accumulation of information is becoming more significant for health organizations [118]. The methodical study of adaptive systems, healthcare organizations can provide managers with great insights and assistance of the preparation for emerging issues within the organization as well as healthcare delivery management [119, 120]. In this sense, being familiar with the external environment can be the key to leading a successful and competitive health system [2].

Due to the involvement of several volatile change perspectives, the healthcare environment is currently a very erratic one making the extrinsic environmental analysis a daunting task for health organizations and managers. This study aims at contemplating on emerging extrinsic changes happening in the US healthcare environment in different areas. A literature review is performed in order to define and identify the different current change perspectives and their subcategories. In order to better illustrate these issues, Ishikawa diagram (cause-and-effect diagram) is used in this study as shown in Fig. 6.5. Five perspectives were identified (political/legislative, economic, social/demographic, technological, and competitive), and each of their sub-criteria was studied.

An interesting finding of this study is the interdependence of different change perspectives through literature, and in order to better reflect that finding, some modifications were applied to the cause-and-effect diagram with aims of better showing the effectiveness of change perspectives on each other (Shown in Fig. 6.6).

Healthcare industry in general is a very complicated and dynamic industry as there are many nascent trends and potential political changes emerging and happening nationally and globally. This is even a bigger issue in the United States which is

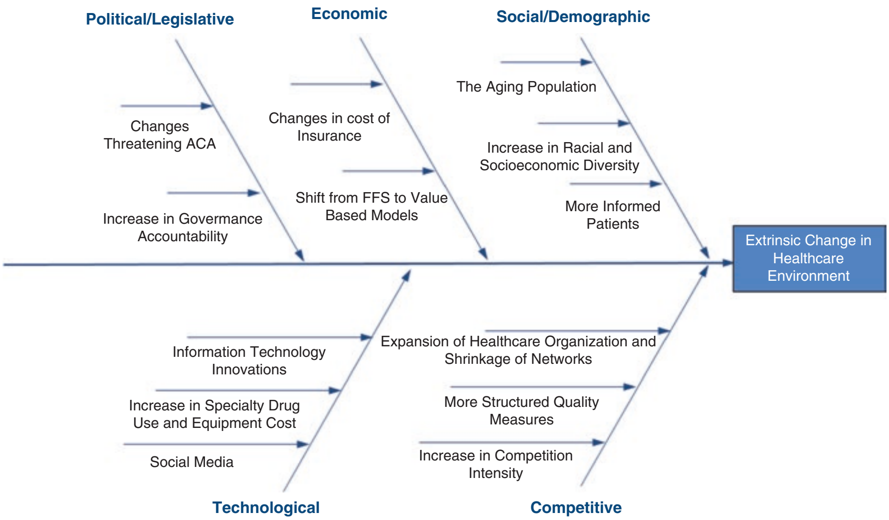


Fig. 6.5 Cause-and-effect diagram for extrinsic change in healthcare environment

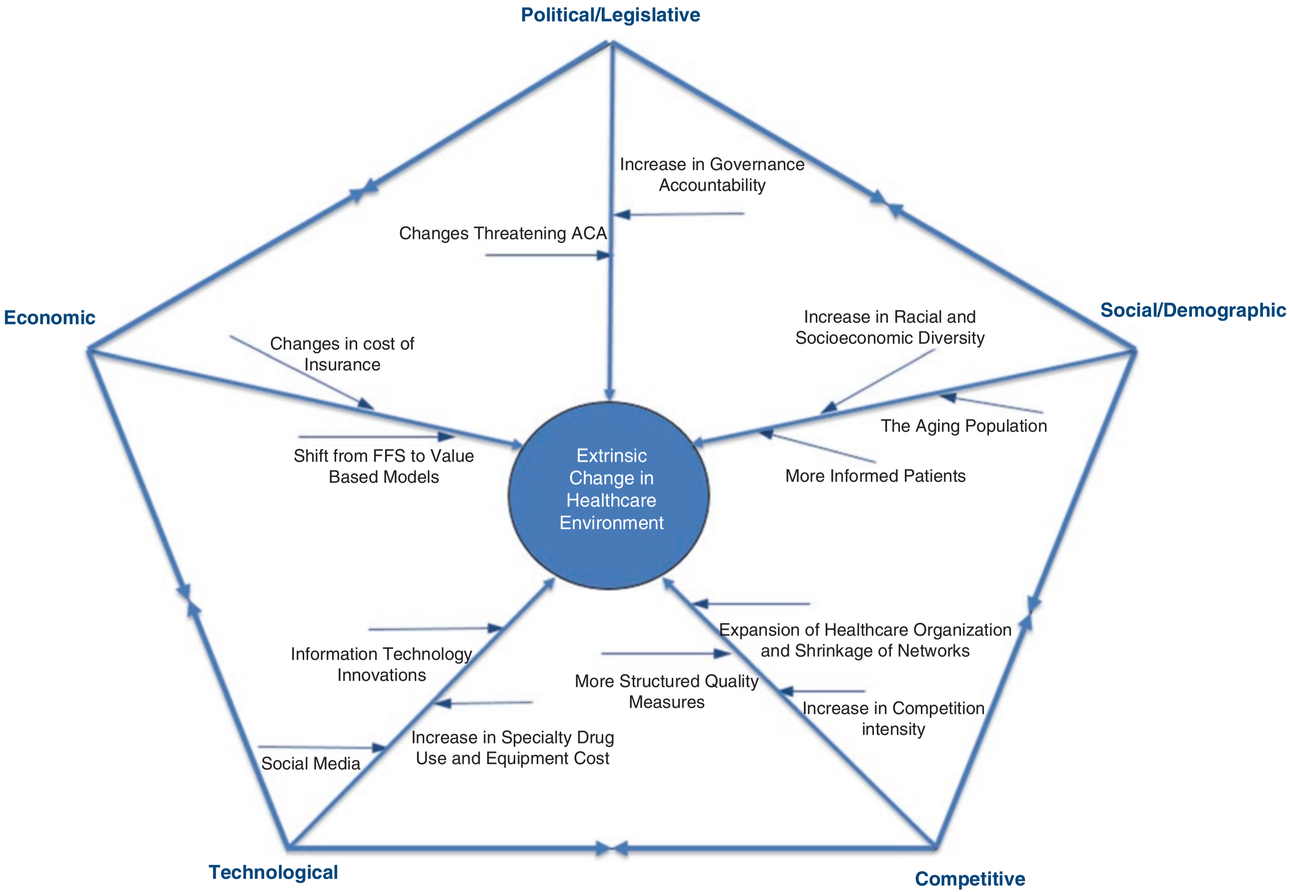


Fig. 6.6 Modified cause-and-effect diagram for extrinsic change in US healthcare

facing waves of political, social, economic, competitive, and technological changes. Healthcare organizations need to be better prepared in predicating, identifying, adapting, being proactive, and taking advantage of these changes and cope with the potential harms coming their way. They should be vigilant in sensing valuable tangible and intangible assets, seizing them in an efficient way, and finally be flexible enough as an organization to transform and mold these resources to their advantage [121].

In the same sense, healthcare organizations should sense the changes, seize the opportunities or dodge the threats, and develop organizational flexibility in order to reconfigure themselves and gain competitive advantage in the industry through learning mechanisms, alliances, innovation, and being cognizant of surrounding changes on national and global levels. As Eisendhardt (2000) suggests, in the high dynamic environments (such as healthcare) no matter how valuable, rare, inimitable, and non-substitutable the resources (such as tacit and explicit knowledge), they are going to give companies fleeting and finite competitive advantage as opposed to a sustained one, and the important thing is how firms reconfigure their "best practices" in unique ways [122]. Health managers need to sense new opportunities and threats, seize them for the advantage of company, and reconfigure them in order to provide organization with sustained competitive advantage [121].

As future research, more study can be put into how healthcare firms can develop and leverage "dynamic capabilities" in order to mitigate the damage caused by environmental changes and even take beneficial advantages of them by being proactive in the "healthcare industry." Moreover, future studies can dig deeper into the interrelationships among perspectives and even sub-criteria existing in different change perspectives using techniques such as fuzzy cognitive maps (FCM) in order to indicate their positivity or negativity and strength of these causal relationships. FCM can also be used to understand how a change or even elimination in one issue would affect the other causes in the environment [123].

Finally, by using decision-making models such as the analytical hierarchical process (AHP) or hierarchical decision model (HDM), the prioritization and ranking of these perspectives and criteria can be studied for case-specific healthcare firms in order to provide empirical literature on this subject.

References

1. Gutterman, S., & Dobson, A. (1986). Impact of the Medicare prospective payment system for hospitals. *Health Care Financing Review, 3*(7), 97–114.
2. Ginter, P. M., Duncan, W. J., & Swayne, L. E. (2013). *Strategic management of health care organizations*. John Wiley & Sons. West Sussex, UK
3. Zook, C. (2007). Finding your next core business. *Harvard Business Review, 85*(4), 66–75.
4. Mallard, S. D., Leakeas, T., Duncan, W. J., Fleenor, M. E., & Sinsky, R. J. (2004). Same-day scheduling in a public health clinic: A pilot study. *Journal of Public Health Management and Practice, 10*(2), 148–155.

5. Hart, S. L., & Milstein, M. B. (2003). Creating sustainable value. *The Academy of Management Executive, 17*(2), 56–67.
6. Aydin, O. M., Shaygan, A., & Dasdemir, E. (2014). *A cause and effect diagram and AHP based methodology for selection of quality improvement projects*. Linz, Austria: European Network for Business and Industrial Statistics.
7. Barker, J. A. (1992). *Future edge: Discovering the new paradigms of success*. Morrow. William Morrow & Company. New York.
8. Perera, F. D. P. R., & Peiro, M. (2012). Strategic planning in healthcare organizations. *Revista Española de Cardiología (English Edition)/Focus on: Healthcare Management (II), 65*(8), v.
9. Ishikawa, K. (1968). *Guide to quality control*. Tokyo: JUSE.
10. Montgomery, D.C., 2009. *Introduction to statistical quality control*. John Wiley & Sons (New York).
11. Ozelm, T. M., Shaygan, A., Dasdemir, E., & Soydan, G. (2017). Selecting health care improvement projects: A methodology integrating cause-and-effect diagram and analytical hierarchy process. *Quality Management in Healthcare, 26*(1), 40–48.
12. Wong, K. (2011). Using an Ishikawa diagram as a tool to assist memory and retrieval of relevant medical cases from the medical literature. *Journal of Medical Case Reports, 5*(1), –120.
13. Hasin, M., Seeluangsawat, R., & Shareef, M. (2001). Statistical measures of customer satisfaction for health care quality assurance: A case study. *International Journal of Health Care Quality Assurance, 14*(1), 6–14.
14. (2004). Cause-and-effect analysis of risk management files to assess patient care in the emergency department. *Academic Emergency Medicine, 11*(10), 1035–1041.
15. Suchman, A. L. (2001). The influence of health care organizations on well-being. *Western Journal of Medicine, 174*(1), 43–47.
16. Casalino, L., Gillies, R. R., Shortell, S. M., et al. (2003). External incentives, information technology, and organized processes to improve health care quality for patients with chronic diseases. *Journal of the American Medical Association, 289*(4), 434–441.
17. Santilli, J., & Vogenberg, R. F. (2015). Key strategic trends that impact healthcare decision-making and stakeholder roles in the new marketplace. *American Health and Drug Benefits, 8*(1), 15–20.
18. Borrell, C., Espelt, A., Rodriguez-Sanz, M., & Navarro, V. (2007). Politics and health. *Journal of Epidemiology & Community Health, 61*(8), 658–659.
19. CMS.GOV. (2017). *Bundled Payments for Care Improvement (BPCI) initiative: General information*. Centers for Medicare and Medicaid Services. [Online]. Available: https://innovation.cms.gov/initiatives/bundled-payments/. Accessed 2017.
20. CMS.GOV. *Readmissions Reduction Program* (*HRRP*). Centers for Medicare and Medicaid Service, 18 04 2016. [Online]. Available: https://www.cms.gov/medicare/medicare-fee-for-service-payment/acuteinpatientpps/readmissions-reduction-program.html. Accessed 2017.
21. Charles, D., Gabriel, M., & Furukawa, M. F. (2014). *Adoption of electronic health record systems among U.S. Non-federal Acute g U.S. Non-federal acute*. The Office of National Coordinator for Health Information Technology (Report) available at: https://www.healthit.gov/sites/default/files/data-brief/2014HospitalAdoptionDataBrief.pdf.
22. Henry, J., Oylpchuk, Y., Searcy, T., & Patel, V. *Adoption of electronic health record systems among U.S. non-federal acute care hospitals: 2008–2015*, Healthit.gov, 2016.
23. Gest, J. *How the health care landscape is evolving through internal and external pressure*, Smart Business, 2012. [Online]. Available: http://www.sbnonline.com/article/how-the-health-care-landscape-is-evolving-through-internal-and-external-pressure-findleydavies/. Accessed 2017.
24. The World Bank. *US Health expenditure, total* (*% of GDP*) *1995–2014*. The World Bank, [Online]. Available: http://data.worldbank.org/indicator/SH.XPD.TOTL.ZS?locations=US. Accessed 2017.
25. World Bank Group. *Accountability in*, https://siteresources.worldbank.org/PUBLICSECTORANDGOVERNANCE/Resources/AccountabilityGovernance.pdf

26. Act, Sarbanes-Oxley. *Sarbanes-Oxley act of 2002*. Public Law 107–204, 2002.
27. Venkataraman, I. M., & Watkins, M. (2008). Adoption of Sarbanes-Oxley measures. *Accounting Horizons, 22*(3), 255–277.
28. Alexander, J., et al. (2008). Governance and community benefit: Are nonprofit hospitals good candidates for Sarbanes-Oxley type reforms? *Journal of Health Politics, 2*, 199–224.
29. Epstein, M. J., & Birchard, B. (2000). *Counting what counts*: Turning Corporate Accountability to Competitive Advantage, Basic Books. ISBN-13: 978-0738203133.
30. Weiss, G. L., & Lonnquist, L. E. (2000). *The sociology of health, healing, and illness*. Upper Saddle River, NJ: Prentice Hall.
31. Conklin, T. P. (2012). Health care in the United States: An evolving system. *Michigan Family Review, 7*(1), 5–17.
32. National Health Expenditure Data, Centers for Medicare & Medicaid Services, 2016. [Online]. Available: https://www.cms.gov/research-statistics-data-and-systems/statistics-trends-and-reports/nationalhealthexpenddata/nationalhealthaccountshistorical.html. Accessed 2017.
33. U.S. Population, United Census Bureau, 2017. [Online]. Available: tps://www.census.gov. Accessed 2017.
34. Kinsella and Gist, Older workers, retirement, and pensions: A comparative international chartbook, US Department of Commerce, Economics and Statistics Administration, Bureau of the Census, 1995.
35. He, W., Goodkind, D., & Kowal, P. (2016). *An aging world: 2015: International population reports*. U.S. Department of Health and Human Services/ US dept of Commerce. https://www.census.gov/content/dam/Census/library/publications/2016/demo/p95-16-1.pdf
36. Bauman, N., Coe, E., Ogden, J., & Parikh, A. *Study on the impact of narrow networks on exchange plans*. McKinsey & Company, June 2014. [Online]. Available: http://www.e-mds.com/mckinsey-study-impact-narrow-networks-exchange-plans. Accessed May 2017.
37. Top Healthcare Market Trends, Access Market Intelligence, 11 Jan 2016. [Online]. Available: http://accessmarketintell.com/category/market-intelligence/. Accessed 5 May 2017.
38. Brown, B., & Crapo, J. *The key to transitioning from fee-for-service to*, Health Catalyst, 2014. http://www.healthcatalyst.com/wp-content/uploads/2014/07/Transitioning-from-Fee-for-Service-to-Value-Based-Reimbursement.pdf.
39. Radnor, Z. J., Holweg, M., & Waring, J. (2012). Lean in healthcare: The unfilled promise? *Social Science & Medicine, 74*(3), 364–371.
40. Stonemetz, J., Pham, C., Necochea, A. J., McGready, J., Hody, R. E., & Martinez, E. A. (2011). Reduction of regulated medical waste using lean sigma results in financial gains for hospital. *Anesthesiology Clinics, 29*(1), 145–152.
41. Ritchie, A., Marbury, D., Verdon, D. R., Mazzolini, C., & Salynn, B. *Shifting reimbursement models: The risks and rewards for primary care :Value-based payment models emerge, but fee-for-service models will remain*, Modern Medicine Network, 8 Apr 2014. [Online]. Available: http://medicaleconomics.modernmedicine.com/medical-economics/content/tags/aca/shifting-reimbursement-models-risks-and-rewards-primary-care?page=full. Accessed 1 May 2017.
42. Lauren, R. (2013). *Research insights: New models to pay for health care*. Academy Health. http://www.academyhealth.org/files/publications/files/FileDownloads/AH%255FRI%252013%2520New%2520Models.pdf
43. Stromborg, F. M. (1991). Changing demographics in the United States: Implications for health professionals. In *Changing demographics in the United States: Implications for health professionals,* pp. 1772–1778.
44. United Census Bureau, *Most children younger than age 1 are minorities*. Census Bureau Reports, United Census Bureau, May 2012. [Online]. Available: https://www.census.gov/newsroom/releases/archives/population/cb12-90.html. Accessed May 2017.
45. Gratton, B., & Gutmann, M. (2006). *Historical statistics of the United States: Millennial edition*. Cambridge: University Press.
46. Day, J. C. Population projections of the United States, by age, sex, race, and Hispanic origin: 1992 to 2050.No. 1092, S Department of Commerce, Economics and Statistics Administration, Bureau of the Census, 1992.

47. *Aging and the health care workforce*. Washington, DC: Population Reference Bureau, 2010.
48. Shrestha, L. B., & Heisler, E. J. (2011). *The changing demographic profile of the United States*. Congressional Research Service.
49. Alpert, J. S., & Shapiro, E. (2012). The anatomy and physiology of the US health care system in 2050? An exercise in prognostication, fantasy, and hope. *The American Journal of Medicine, 125*(12), 1151–1152.
50. U.S. Census. (2005). *Numbers from years 1920 to 2000 are based on U.S. Census figures as given by the Time Almanac of 2005*, p. 377.
51. Bouvier, L., & Gardner, R. (1986). Immigration to the U.S.: The unfinished story. *Population Bulletin, 41*(*4*)*,* 3–50.
52. Friedman, E. *Who we are: Implications of the 2010 census for health care*. Hospitals & Health Networks OnLine, Dec 2011. [Online]. Available: http://www.emilyfriedman.com/columns/2011-12-06-who-we-are-2.html. Accessed May 2017.
53. Goodman, M. (1989). Cancer incidence among Asian Americans. In *Minorities and cancer* (pp. 35–44). New York: Springer.
54. Yu, S. E. (1986). Health of the Chinese elderly in America. *Research on Aging, 8*(1), 84–109.
55. Sutherland, J. E., Avant, R. F., Franz 3rd, W. B., Monzon, C. M., & Stark, N. M. (1983). Indochinese refugee health assessment and treatment. *The Journal of family practice, 16*(1), 61–67.
56. Fronstin, P., & Elmlinger, A. *Findings from the 2014 EBRI/Greenwald & Associates*, EBRI. Org, 2014.
57. Epstein, R. M., Fiscella, K., Lesser, C. S., & Stange, K. (2010). Why the nation needs a policy push on patient-centered health care. *Health Affairs, 29*(8), 1489–1495.
58. Bechtel, C., & Ness, D. L. (2010). If you build it, will they come? Designing truly patient-centered health care. *Health Affairs, 29*(5), 914–920.
59. Buntin, M. B., Burke, M. F., Hoaglin, M. C., & Blumnetal, D. (2011). The benefits of health information technology: A review of the recent literature shows predominantly positive results. *Health Affairs, 30*(3), 464–471.
60. Furukawa, M. F., King, J., Patel, V., Hsiao, C.-J., Adler-Milstein, J., & Jha, A. K. (2014). Despite substantial progress in EHR adoption, health information exchange and patient engagement remain low in office settings. *Health Affairs, 33*(9), 1672–1679.
61. Institute of Medicine. (2001). *Crossing the quality chasm: A new health system for the 21st century*. Washington, DC: National Academy Press.
62. Beckles, G., Engelgau, M., Narayan, K., Herman, W., Aubert, R., & Williamson, D. (1998). Population-based assessment of the level of care among adults with diabetes in the US. *Diabetes Care, 21*, 1432–1438.
63. Chassin, M., & Galvin, R. (1998). The urgent need to improve health care quality: Institute of Medicine national roundtable on health care quality. *The Journal of the American Medical Association, 280*, 1000–1005.
64. Mardis, E. R. (2008). The impact of next-generation sequencing technology on genetics. *Trends in Genetics, 24*(3), 133–141.
65. Seoane-Vazquez, E., Rodriguez-Monguio, R., Szeinbach, S. L., & Visaria, J. (2008). Incentives for orphan drug research and development in the United States. *Orphanet Journal of Rare Diseases, 3*(1), 33.
66. PricewaterhouseCoopers(PWc) (2017). Top health industry issues of 2017: A year of uncertainty and opportunity, available at https://www.pwc.com/us/en/health-industries/pdf/pwc-hri-top-healthcare-issues-2017.pdf.
67. Lyon, E. J., Lewis, Z. H., Mayrsohn, B. G., & Rowland, J. L. (2014). Behavior change techniques implemented in electronic lifestyle activity monitors: a systematic content analysis. *Journal of Medical Internet Research, 16*(8) e 192, 1–15.
68. Nambiar, R., Bhardwaj, R., Sethi, A., & Vargheese, R. (2013). A look at challenges and opportunities of big data analytics in healthcare. *IEEE International Conference on Big Data*, 17–22.
69. Worley, C. G., & Mohrman, S. A. (2014). Is change management obsolete? *Organizational Dynamics, 43*(3), 214–224.

70. Kayyali, B., Knott, D., & Steve, V. K. (2013). *The big-data revolution in US health care: Accelerating value and innovation*. Mc Kinsey & Company. Mc Kinsey & Company. Available at: https://www.mckinsey.com/industries/healthcare-systems-and-services/our-insights/the-big-datarevolution-in-us-health-care
71. Barham, H. (2017). *Achieving competitive advantage through big data*. Portland, Oregon: PICMET.
72. Kyongyoung, J., & Gang-Hoon, K. (2013). Potentiality of big data in the medical sector: Focus on how to reshape the healthcare system. *Healthcare informatics research, 19*(2), 79–85.
73. *CVS Health Opens Digital Innovation Lab in Boston*, CVSHealth, 18 June 2015. [Online]. Available: https://www.cvshealth.com/newsroom/press-releases/cvs-health-opens-digital-innovation-lab-boston. Accessed May 2017.
74. healthit.gov, *Meaningful use definition & objectives*, Health information technology (health IT), Feb 2015. [Online]. Available: https://www.healthit.gov/providers-professionals/meaningful-use-definition-objectives. Accessed May 2017.
75. Price waterhouse Coopers, (2017). *Medical cost trend: Behind the numbers 2018* (Report), available at https://www.pwc.com/us/en/health-industries/health-research-institute/behind-the-numbers/reports/hri-behind-the-numbers-2018.pdf.
76. Falit, B. P., Singh, S. C., & Brennan, T. A. (2015). Biosimilar competition in the United States: Statutory incentives, payers, and pharmacy benefit managers. *Health Affairs, 34*(2), 294–301.
77. Kumar, K. R. (2011). Technology and healthcare costs. *Annual Pediatric Cardiology, 4*(1), 84–86.
78. The Moran Company. (2013). *Cost differences in cancer care across settings* (Report). Available at: http://www.communityoncology.org/UserFiles/Moran_Cost_Site_Differences_Study_P2.pdf
79. *2015 Drug trend: Tackling rising drug costs*. CVSHealth, 2015.
80. Piccart-Gebhart, M. J. (2013). The 41st David A. Karnofsky memorial award lecture: Academic research worldwide—quo vadis? *Journal of Clinical Oncology, 4*(32), 347–354.
81. *DNA sequencing costs: Data from the NHGRI Genome Sequencing Program* (*GSP*). National Human Genome Research Institute, NIH, 2016.
82. Weisbord, B. A. (1991). The health care quadrilemma: An essay on technological change, insurance, quality of care, and cost containment. *Journal of Economic Literature, 29*(2), 523–552.
83. Vance, K., Howe, W., & Dellavalle, R. P. (2009). Social internet sites as a source of public health information. *Dermatologic Clinics, 27*(2), 133–136.
84. Van de Belt, T. H., Berben, S. A., Samsom, M., Engelen, L. J., & Schoonhoven, L. (2012). Use of social media by Western European hospitals: Longitudinal study. *Journal of Medical Internet Research, 14*(3).
85. Chou, W.-Y. S., Hunt, Y. M., Beckjor, E. B., Moser, R. P., & Hesse, B. W. (2009). Social media use in the United States: Implications for health communication. *Journal of Medical Internet Research, 11*(4).
86. Bosslet, G. T., Torke, A. M., & Hickman, S. E. (2011). The patient–doctor relationship and online social networks: Results of a national survey. *Journal of General Internal Medicine, 26*(10), 1168–1174.
87. von Muhlen, M., & Ohno-Machado, L. (2012). Reviewing social media use by clinicians. *Journal of the American Medical Informatics Association, 19*(5), 777–781.
88. Antheunis, M. L., Tates, K., & Nieboer, T. E. (2013). Patients' and health professionals' use of social media in health care: Patients' and health professionals' use of social media in health care. *Patient Education and Counseling, 92*, 426–431.
89. Hawn, C. (2009). Take two aspirin and tweet me in the morning: How twitter, facebook, and other social media are reshaping health care. *Health Affairs, 28*(2), 361–368.
90. Baker, L. *Competition keeps health-care costs low, researchers find*. Stanford Medicine, 21 Oct 2014. [Online]. Available: https://med.stanford.edu/news/all-news/2014/10/competition-keeps-health-care-costs-low--researchers-find.html. Accessed May 2017.

91. Dranove, D., & Lindrooth, R. (2003). Hospital consolidation and costs: Another look at the evidence. *Journal of Health Economics, 22*(6), 983–997.
92. Olsen, L., Saunders, R. S., & Yong, P. L. (2010). *The healthcare imperative: Lowering costs and improving outcomes: Workshop series summary*. National Academies Press, Washington DC.
93. Evans, M. (2014). *Consolidation creating giant hospital systems*. Modern Healthcare. [Online]. Available: http://www.modernhealthcare.com/article/20140621/MAGAZINE/306219980. Accessed 2017.
94. Meredith, E. B. (2015). *The health care services acquisition report* (21st ed.). Norwalk, CT: Irving Legin Associates.
95. Wirtz, R. A. (2015). *Health care consolidation: Which way is up, and why are we going there?* Minneapolis: Fed Gazette Regional Business & Economics Newspaper.
96. Cutler, D. M., & Morton, F. S. (2013). Hospitals, market share, and consolidation. *JAMA:Clinical Review & Education, 310*(18), 1964–1970.
97. Casalino, L. P., Pham, H., & Bazzoli, G. (2004). Growth of single-specialty medical groups. *Health Affairs, 23*(2), 82–90.
98. Casalino, L. P., Devers, K. J., & Brewster, L. R. (2003). Focused factories? Physician owned specialty facilities. *Health Affairs, 22*(6), 56–67.
99. Gaynor, M., & Haas-Wilson, D. (1998). *Change, consolidation, and competition in health care markets*, NBER Working Paper No. 6701.
100. *Memorial hermann health system and blue cross and blue shield of Texas announce contract agreement*, Memorial Hermann, 28 June 2013. [Online]. Available: http://www.memorialhermann.org/news/memorial-hermann-health-system-and-blue-cross-and-blue-shield-of-texas-announce-contract-agreement/. Accessed May 2017.
101. Memorial Hermann and Aetna. *Advancing health and health care in Houston*, Memorial Hermann, [Online]. Available: http://www.memorialhermann.org/aetna/
102. *Study on the impact of narrow networks on exchange plans: MDe insights june 18, 2014*, McKinsey, www.mdeverywhere.com/mckinsey-study-on-the-impact-of-narrow-networks-on-exchange-plans, 2015.
103. *Acquisition and affiliation strategies: An HFMA value project report*. Healthcare Financial Management Association, 2014.
104. Berenson, R. A., Pronovost, P. J., & Krumholz, H. M. (2013). *Achieving the potential of health care performance measures*. (Report) Robert Wood Johnson Foundation: Urban Institute.
105. Grol, R., & Wensing, M. (2004). What drives change? Barriers to and incentives for achieving evidence-based practice. *Medical Journal of Australia, 180*(6), S57.
106. Bonow, R. O., Masoudi, F. A., Rumsfeld, J. S., DeLong, E., et al. (2008). ACC/AHA Classification of care metrics: Performance measures and quality metrics. *Circulation, 118*(24), 2662–2666.
107. Ozcan, Y. A. (2005). Quantitative methods in health care management: techniques and applications (Vol. 4). John Wiley & Sons, San Francisco.
108. Linderman, K., Schroeder, E., Zaheer, S., & Choo, A. S. (2003). Six sigma: A goal-theoretic perspective. *Journal of Operations Management, 21*(2), 193–203.
109. Young Hoon, K., & Anbari, F. T. (2006). Benefits, obstacles, and future of six sigma approach. *Technovation, 26*(5), 708–715.
110. Montgomery, D. c., & Woodall, W. H. (2008). An overview of six sigma. *International Statistical Review, 76*(3), 329–346.
111. Porter, M., & Teisberg, E. (2004). Redefining competition in healthcare. *Harvard Business Review, 82*(6), 65–76.
112. Enthoven, A. C., & Tollen, L. A. (2005). Competition in health care: It takes systems to pursue quality and efficiency. *Health Affairs, 24*, W5.
113. Rivers, P. A., & Glover, S. H. (2008). Health care competition, strategic mission, and patient satisfaction: Research model and propositions. *Journal of Health Organization and Management, 22*(6), 627–641.

114. Zwanziger, J., & Menick, G. A. (1996). Can managed care plans control health care costs. *Health Affairs, 15*(2), 189–199.
115. Popper, C., Burgess, S., & Green, K. (2004). Does competition between hospitals improve the quality of care?: Hospital death rates and the NHS internal market. *Journal of Public Economics, 88*(7–8), 1247–1272.
116. Kessler, D. P., & Geppert, J. J. (2005). The effects of competition on variation in the quality and cost of medical care. *Journal of Economics and Management Strategy, 14*(3), 575–589.
117. Gowrisankaran, G., & Town, R. J. (2003). Competition, payers, and hospital quality. *Health Services Research, 38*, 1403–1422.
118. Sutcliffe, K. M., & Weber, K. (2003). The high cost of accurate knowledge. *Harvard Business Review, 5*(81), 74–82.
119. Pisek, P. E., & Wilson, T. (2001). Complexity, leadership, and management in healthcare organisations. *BMJ: British Medical Journal, 323*(7315), 746.
120. Ducker, P. F. (2004). *Managing the non-profit organization: Practices and principles*. Taylor & Francis. New York.
121. Teece, D. J. (2007). Explicating dynamic capabilities: The nature and microfoundations of (sustainable) enterprise performance. *Strategic Management Journal, 28*(13), 1319–1350.
122. Eisenhardt, K. M., & Martin, J. A. (2000). Dynamic capabilities: What are they? *Strategic Management Journal, 21*(10/11), 1105–1121.
123. Papageorgiou, E. I., & Stylios, C. D. (2008). Fuzzy cognitive maps. In *Handbook of granular computing* (pp. 755–774). Publisher: John Wiley & Sons, Ltd.

Chapter 7
Technology Assessment: Patient-Centric Solutions for Transfer of Health Information

Paul Atkinson, Shabnam Jahromi, Paweena Kongsansatean, and Leong Chan

7.1 Introduction

A significant contributor to high-quality healthcare is current, accurate information about the patient. With an increase in use of electronic health records in the United States, one might be forgiven for imagining that missing or tardy health data is a thing of the past, but there is a problem. Health information is stored in silos, and information transfer is sometimes difficult, even in 2014. Technologies exist that can improve the portability of electronic health records, and this study surveys a few of those technologies from the patient perspective to determine which is most likely to meet the need.

Personal health information, whether electronic or paper, is often fragmented and stored in different places. Relocations, changing health providers, using personal health monitoring tools, or having specialty care can result in disparate health information in multiple locations [1]. Patients' health information is usually isolated in hospitals, clinics, and laboratories. Effective and efficient healthcare cannot be provided with fragmented health information. Individuals want their health providers to have access to their health information anytime and from anywhere.

P. Atkinson
Vigillo LLC, Portland, OR, USA
e-mail: paul.j.atkinson@gmail.com

S. Jahromi
Jama Software, Portland, OR, USA
e-mail: sh.razeghian@gmail.com

P. Kongsansatean
SIAM Sanitary Ware, Bangkok, Thailand

L. Chan (✉)
Pacific Lutheran University, Tacoma, WA, USA
e-mail: chanla@plu.edu

T.U. Daim et al. (eds.), *Infrastructure and Technology Management*,
Innovation, Technology, and Knowledge Management,
https://doi.org/10.1007/978-3-319-68987-6_7

They also expect the transfer of health information from one provider to another to occur with little latency, securely, and accurately to receive the highest-quality healthcare [1].

Health information exchange (HIE) has been recognized by policy makers and researchers as a solution to the problem above and is defined as "the electronic transfer of patient-level information between organizations" [2]. The American Recovery and Reinvestment Act of 2009 requires electronic health records (EHR) to be "connected in a manner that provides … for the electronic exchange of health information to improve the quality of healthcare." Although the act is fairly new, the efforts to facilitate interoperability of health information and an adoptable solution have been going on for over two decades with results that are less than promising [2]. Whether exchange of health information through EHRs is the most efficient and effective solution is still not determined, and policies by themselves cannot guarantee the adoption of a technology.

In this study, we identified four health information management solutions and assessed each one with regard to their interoperability and other criteria that are important from the patient's perspective with regard to transfer of health information. We identified six criteria from literature and conducted a Delphi survey to ascertain the weights of each criterion. Three different scenarios were considered based on possible changes in the US healthcare policy; respondents were asked to weight the criteria in each different scenario. Further we used TOPSIS (Technique for the Order Preference by Similarity to Ideal Solution) to select the preferred solution.

7.2 Literature Review

7.2.1 Health Information Exchange

The US healthcare industry has been experiencing significant growth in the past few years, especially around the implementation of information technology to enhance the efficiency of service. In 2009, the US government invested around 19 billion dollars to digitize US health records [3]. Health information exchange (HIE) is the process of sharing electronic patient information between different organizations [1]. HIE has been adopted in the United States for a while; however, there is more to resolve around HIE including issues of interoperability, privacy, security, and so on [4]. HIE allows the healthcare stakeholders such as doctors, nurses, pharmacists, other health providers, and of course patients to access data appropriately and to transfer and share electronic health data securely. Hence, HIE can improve the quality, speed, safety, and cost of patient care [5]. HIE can help to replace paper-based information which may cause problems such as storage difficulties, lost or damaged records, and so on. Since HIE can improve the speed of sharing of data, it can provide better decision making support which can help providers to avoid errors, improve diagnoses, and decrease duplicate testing of patients [5]. There are currently three key forms of HIE [5]:

- Directed exchange – health providers are able to transfer information from and to other health providers.
- Query-based exchange – health providers are able to request patient records from other health providers. This form often happened for unplanned care.
- Consumer-mediated exchange – patients can get directly involved to aggregate and control the use of data among providers.

Healthcare Information and Management Systems Society or HIMSS categorizes three models of HIE: centralized, federated, and hybrid [4]. The model comprises sharing clinical information such as imaging studies, medication lists, lab results, and demographics of the user. These data will be transferred across stakeholders, e.g., physicians, specialists, and patients themselves.

1. *The federated or decentralized model*

   Healthcare records are distributed across regions under a framework of data sharing, so the healthcare provider owns the data, and a record locator service manages the information. Updates and access to the data are only provided per request. Since the healthcare provider owns the data, the boundary of responsibility is clear, and it is easy to identify authorized personnel which can reduce conflicts of ownership. Moreover, if the system were to fail, it will not affect the whole system. The downside of this model is a high cost to local organizations to implement the system and a lack of a guarantee of data control and availability due to the limit of providers. To modify or transfer data requires patient consent; without an opt-in, the data cannot be legitimately accessed. Moreover, the standard form needs to be concerned in order to perform in the common practice [4].
2. *The centralized model*

   Patients' records are collected from local sources and stored in a central repository. If a record is requested, the transaction will be transferred through the central repository. The advantage of this model is the speed with which it responds to queries because the data is centrally stored. Since data is centrally collected, it can facilitate community-wide data analysis, and so it is effective to manage as a central resource. However, it needs to be carefully managed in order to prevent duplicate data, and it needs a large central database system. The centralized model is likely to be expensive in technical and organizational implementation [4].
3. *The hybrid model*

   The hybrid model contains aspects of both the centralized and decentralized models. Data is locally produced and stored where it is produced, but only some of the data is duplicated to the central data repository. The central database will store a "minimum clinical data set" of the patient which comprises information such as current medications, current diagnoses, and allergies [4]. This model does not allow data to be fully controlled by the patient, and it does not have clear boundaries of data ownership.

7.2.2 Technology Assessment Tools

There are many tools to assess appropriate technologies, but in this paper we will focus on using the Delphi technique to weight our criteria and TOPSIS to make the selection, and we did so under three distinct scenarios – we were curious whether US Government policy on healthcare would have an impact on which candidate technology would be chosen.

7.2.2.1 Delphi

Delphi refers to a process of iteratively asking questions to identified experts so that experts may lead themselves to a consensus [6]. The technique involves identifying a group of experts and submitting to them a carefully designed questionnaire to gauge group opinion. Once the results of this survey are tallied by the researcher(s), a measure of consensus can be made, and the process completes when the experts are in consensus.

Each round of questioning that produces a lack of consensus prompts a new round during which the survey participants receive feedback from the previous round. Feedback may include answers from other survey participants (either raw or aggregated), explanations or rationales for others' responses, and the subject's own previous responses, among other data. The goal is to help each participant understand the position of the other participants in the survey group until they converge on value that represents the best considered judgment of the group.

Because the Delphi technique is at its heart a measure of opinion, it is useful in a limited set of circumstances. Hasson et al. (2000), referencing previous work on Delphi, enumerate the following areas in which Delphi is appropriate [7]:

- To explore or expose underlying assumptions or information leading to differing judgments
- To seek out information which may generate a consensus on the part of the respondent group
- To correlate informed judgments on a topic spanning a wide range of disciplines
- To educate the respondent group as to the diverse and interrelated aspects of the topic

7.2.2.2 TOPSIS

TOPSIS, the Technique for Order of Preference by Similarity to Ideal Solution, refers to a method of multi-criteria decision making (MCDM) that expresses a result geared to be closest to an ideal solution while simultaneously maintaining an optimal distance from a worst or negative ideal solution. TOPSIS was first described by Yoon (1980) and can be used to select the best of a set of scored options based on weighted criteria [8].

Among MDCM methodologies, TOPSIS is useful when decision makers have reasonably good information about how to score each attribute, where the scores are cardinal rather than ordinal and where those scores are either increasing or decreasing steadily relative to their value to the end solution. Values that are not monotonically increasing or decreasing (such as criteria whose optimal value is in the center of a scale, with both larger and smaller values representing suboptimal solutions) are not appropriate to measure with TOPSIS unless they can be mapped onto a monotonic scale [9].

7.2.2.3 Scenario Analysis

Finally, we performed our analysis under multiple scenarios. Scenario analysis is useful when expert opinion might help gauge future macroeconomic or policy impacts on a current decision [10]. This kind of analysis is predictive in nature and helps to promote the long perspective; it is also a way of incorporating input regarding future regulatory issues or politics into an otherwise purely descriptive process.

7.3 Gap Analysis

This section provides the problem statement and the gap analysis for technology assessment. As previously discussed, the problem statement is as follows:

- Fragmented health information and storage due to relocation, multiple providers, personal health monitoring tools, and specialty care
- Need to access information anytime and anywhere
- Latency in data transfer that impacts quality of healthcare provided
- Lack of connection between personal health information gathered by patient and EHR
- Isolated health information in hospitals and clinics and lack of patient control on health information data

The technical, organization, and personal needs for health information management solutions that facilitate health information transfer and exchange are as follows:

Technical:

- Secure and reliable infrastructure
- Privacy control mechanism

Organizational:

- Trust among health provider on the health information that is exchanged.
- Adopt common standards on the health information records.
- Health information model that is cost-efficient and patient-centric.

Personal:

- One source of truth for all the information.
- Access anytime and anywhere.
- Privacy and security of health information.
- Ease of use.
- Quality of healthcare: avoid redundant tests.

The next step is to determine the capabilities in each category:

Technical:

- Cloud-based infrastructure and technical ability to store and maintain humongous data ("Healthcare Big Data Debate," n.d.)
- Privacy, security protocols

Organizational:

- Government policies and incentives that promote the adoption of health information technology toward a "meaningful use" of electronic health records and that also include ability of health information exchange.
- Transferrable data.
- Acknowledge the gap and make initiatives, e.g., S&I framework (http://www.siframework.org/).

Personal:

- Availability of personal health information management tools like Microsoft Vault, iHealth, etc.
- Patient empowerment and educating patients to get more involved with their healthcare and health information management

Gap analysis is by looking into the current capabilities and the needs that are yet to be addressed. The technical, organizational, and personal gap for a health information management solution that would cover the above need is as follows:

Technical:

- Reliable, secure, and private infrastructure that is also not isolated; cloud-based solutions are still not perceived as a secure solution to store patients' health information

Organization:

- Trust among different health providers; health providers should trust the health information that is being transferred.
- Adopt a solution model that enables widespread transfer of health information (As of 2009, only 11.9% of hospitals have either a basic or comprehensive electronic health record).

Table 7.1 Gap analysis summary

	Needs	Capabilities	Gap
Technical	– Secure and reliable infrastructure – Privacy control mechanism	– Cloud-based infrastructure – Big data – Privacy, security protocols	– Reliable infrastructure (people still do not trust cloud) – Privacy protocols
Organizational	– Trust among different health providers – Health information mgmt Model that is cost-efficient and patient-centric	– EHR standards – Transferrable data – Acknowledge the gap and make initiatives, e.g., S&I framework	– Build trust among different health providers – Adopt a common health information model
Personal	– One source of truth for all the health information – Access anytime and anywhere – Privacy – Security – Ease of use – Quality of healthcare: avoid redundant tests	– Personal health information management tools – Involved more with personal health information	– Cognitive burden on managing lots of health information – Different needs – Distrust cloud

Personal:

- Cognitive burden on managing of health information; health information can grow rapidly and becomes a burden for patients and especially individuals who are responsible for managing information of a household.
- Different needs; an effective solution may vary for each patient depending on their needs, cognitive capacities, preferences, goals, and environments (Table 7.1).

7.4 Literature Analysis

7.4.1 Criteria

We selected the criteria for a solution to fulfill the gap in health information management and its interoperability that was discussed above based on literature review. Table shows each criteria and the frequency each one has been mentioned as important factors when it comes to health information management solutions (Table 7.2).

Table 7.2 Criteria selection

Literature	A	B	C	D	E	F
Criteria						
Security	✓	✓	✓	✓		✓
Ease of use					✓	
Availability of solution					✓	
Privacy	✓	✓	✓	✓	✓	✓
Trust and accuracy	✓	✓	✓	✓		✓
Portability	✓			✓	✓	✓

(a) J. Vest, L. Gamm (2010) [1]
(b) A. Hoerbst, E.Ammenwerth (2010) [11]
(c) R Agrawal et al. (2004) [12]
(d) S Simon et al. (2008) [13]
(e) K Unertl et al. (2013) [14]
(f) HIMSS HIE Guide Work Group (2009) [4]

7.4.2 Technology Alternatives

We identified four solution models as our technology alternatives for health information management and how health information is transferred or accessible through other interested parties in each model. This section describes each solution model and the way health information is transferred from one health provider to the other in each one of them.

1. *Alternative one: EHR Portal*

Currently health providers give patients access to their information through web portals. Patients can view their lab results, prescription, or next doctor appointment. Kaiser Permanente portal is an example of accessing and viewing health information that reside at health provider facilities through a portal or an application. All the information is stored and maintained by the health provider, and therefore, it is private and secure. Health information at the clinics and hospitals are subject to many regulations and policy in terms of information disclosure and patient's information privacy. Patients can only view the information and do not have the ability to update any of that. If patients switch health provider, they may need to subscribe to the new health provider portal.

Yet, not all EHR solutions have interoperability capabilities, and it might be limited. If a health information transfer is required from health provider A to health provider B, patient needs to be involved and approve the transfer and the time it takes for the information to be transferred may vary depending on the EHR solution used by each party. The health information transfer can only be done nationwide.

2. *Alternative two: Private Cloud Storage*

With emergence of cloud technology, the cloud-based personal health information management also became available. These solutions are fairly new and with low adoption rate [15]; however, they provide patients with more control on their data and can integrate with different health monitoring tools to capture results, and physicians can transfer lab results directly to those. Unlike alternative one, patients can insert and update their health information, and they can aggregate their health data from different places to one source. Patients can allow access to their physician if required, and health information transfer can be done instantly. An example of these solutions is Microsoft Vault, a free-of-charge online PHIM tool by Microsoft. The software can integrate with over 200 medical devices and other health information management systems if the patient sets it up accordingly.

Despite the benefits that cloud-based solutions provide in terms of being a once source of truth for fragmented health information that can be accessed anytime and anywhere, there are serious security and privacy concerns involved with these solutions. There is news from time to time of serious cloud security breaches [16] which increases the security concerns in cloud-based solutions. Another concern with this solution model where patient has the power to insert and update data is trust in health information accuracy and making sure patient would not input invalid data. Although patient inserts the data, the owner of the data is the cloud service provider.

3. *Alternative three: Private Storage*

This solution model has similarities with alternative two; all fragmented health information can be stored in one storage managed and maintained by patient. Example of this solution model is iHealth, which is an Apple health information management and monitoring tool. The tool gathers health information, and patient can view, insert, update, and delete those information. Patient is also responsible for security of the health information, and for those who are not tech savvy, this could be a concern, e.g., choosing no password or a very simple one for their device, yet more secure than cloud-based solutions. Using a private storage is also more private than the cloud-based solution as the patient is the owner of the data.

The transfer of health information can be very simple with this solution model as patient is carrying information with them and is able to provide them to the required parties. The transfer can also be done internationally.

4. *Alternative four: Public Storage*

Alternative four is the public storage; health information is stored by a third party that is trusted by different healthcare providers and physicians. Similar to alternative one, patient can only view its health information and have limited control of it.

An example implementation of such solution model is RHIO (Regional Health Information Organization) which "is a type of health information exchange organization (HIO) that brings together healthcare stakeholders within a defined geographic area and governs health information exchange among them for the purpose of improving health and care in that community" [17].

Public storage is private and secure and trusted by all health providers involved. The transfer of health information is very fast as there is one source that different health providers can access and view the required information. The main challenge

Table 7.3 Summary of alternatives

Solutions / Attributes	EHRs	Private cloud	Private storage	Public repository
Owner	Hospital/health provider	Cloud service provider	Patient	Trusted third party
Patient control	View only	View/enter/augment	View/enter/augment	View
Portability	Limited: dependent on organization process	Limited: may not subscribe	High	High
			Low trust	High trust
	Fair trust	Low trust	International	National
	National only	International	Low latency	Regional
	High latency	Low latency		Very low latency
Cognitive burden for user	Low	High	High	Low
Privacy	Fair	Low	High	Fair
Security	High	Far	Low	Fair

in these solutions is its scalability; it's an expensive solution. RHIOs are currently only regional and limited to specific geographical areas.

This table summarizes the discussion above and shows the characteristics of each alternative (Table 7.3).

7.5 Methodology

In trying to weigh the criteria, we needed to poll a group of experts to determine what aspects of an EHR portability solution would be most important by using the online survey tool "Qualtrics." Because our research was attempting to get at this from the patient perspective, the group of experts needed to consist of anyone who has used the US healthcare system. Participants with some knowledge of EHR storage technology would be an advantage, but the opinions of any patient were relevant. Hasson, discussing previous use of Delphi in the health and social space, makes a point of ensuring the participants meet a minimum level of expertise [7], and for our topic this was a relatively low bar.

The criteria weight obtained from the Delphi survey needs to be in consensus; there are many ways to measure consensus in a Delphi survey, but one that was relevant and easy to apply given our five-point Likert scale measurements was the use of a variance threshold of 0.5 [18].

Then we will use TOPSIS to calculate the most appropriate HIE alternative. TOPSIS works when each criterion is either steadily increasing or decreasing to represent a better outcome, and our criteria worked well with that. We were concerned early in our project about whether we would be able to use the same scale for each criterion, but that is not a problem for a TOPSIS evaluation.

7.6 Analysis

We used the online Delphi survey question in five-point Likert scales to identify criteria weight. The experts give the rank of importance of each criterion with regard to three different scenarios: the ACA is forced, the ACA repealed, and single payer. The criteria in the questions come from the literature review analysis, and we want to identify which criterion is the most important toward experts' opinions.

7.6.1 Criteria Weighting

The survey question was distributed for two rounds because the result from the first round was not consensus. From the first round, we received 53 responses from target groups who reside in the United States. (See Appendix A for detail.) The variance of most criteria scores are over threshold, which is 0.5 meaning the result is not consensus. The feedback from the first round suggested the team to write more explanation for each scenario.

The survey question was modified and resend to those responses regarded to given email addresses. The result from the first round was attached in the second round survey in order to motivate the direction of opinions. We have 25 responses, but the variance is still over the threshold. Therefore, the team identified the outlier response and decided to eliminate this opinion as a result of unified opinions. While we could have chosen to employ a third round asking the one participant to justify his answers given their divergence from everyone else's, a response that is sufficiently far from the others can sometimes be disregarded. We relied on the work of Seo (2006) who evaluated six different methods of detecting and removing outlier data and, using the decision tree he provided (symmetric normal distribution without a large gap or masking problem), chose the most permissive method that suited our data distribution [19]: data outside three standard deviations was omitted. This method identified a single respondent as an outlier in more than one response area, so that respondent was omitted from the final result (see Appendix A for detail) (Table 7.4).

The criteria weight from the final round is shown in the below table. The result indicates that experts ranked criteria as security, trust and accuracy, privacy, ease of use, availability of solution, and portability, respectively, in every scenario (Table 7.5).

Table 7.4 Convergence of opinions (the variance of 0.5 is the consensus threshold)

	Security		Ease of use		Availability of solution		Trust and accuracy		Portability		Privacy	
	R1	R2	R1	R2	R1	R2	R1	R2	R1	R2	R1	R2
Scenario 1	0.71	0.15	0.73	0.26	0.70	0.17	0.21	0.11	0.78	0.49	0.78	0.20
Scenario 2	0.67	0.08	0.72	0.22	0.63	0.25	0.42	0.08	0.77	0.35	0.64	0.11
Scenario 3	0.87	0.11	0.74	0.17	0.80	0.30	0.60	0.08	0.98	0.49	0.83	0.20

Table 7.5 Criteria weights

Criteria	Security	Ease of use	Availability of solution	Trust and accuracy	Portability	Privacy
Scenario 1	4.833	4.000	3.917	4.875	3.667	4.750
Scenario 2	4.917	3.958	3.917	4.917	3.500	4.875
Scenario 3	4.875	4.000	4.042	4.917	3.667	4.750

During our research into EHR options, a new congress was elected in the United States, consolidating congressional power into the hands of the Republican Party. Republicans have been trying for years to repeal the Affordable Care Act, and with this election it became at least marginally more likely they might succeed (though the prospect of a presidential veto means the new, higher chance is still somewhat remote). This could be a significant change to US healthcare policy, and we were curious whether the decisions people made would be impacted by the ACA. For the sake of completeness, we included a third scenario: the advent of national, single-payer health coverage.

These represented unambiguous, nonintersecting scenarios that we felt might affect the criteria weights submitted in our survey, and they certainly fit the standards for scenario analysis laid down by Huss [10].

7.6.2 Solution Selection Analysis

TOPSIS was implemented in this step to assess and select the proper technology platform for HIE. The team managed to give scores of alternatives with respect to the criteria by using the results from literature review and the expertise of team members in the HIE realm. This paper proposed four alternative technology platforms of HIE regarding the data transfer model:

1. Portal – the data is stored locally and managed by a health provider or hospital. This model allows patients to view only, so patients cannot modify or augment records. Health providers or hospitals own the patient data, so the data is quite accurate and trustworthy. To request data transfer, patients must explicitly grant

consent; therefore, this model is highly secure and private. There are some limitations for portability among providers because the data is managed locally, and interoperability among EHR portal platforms is limited.

2. Private cloud service – the data is uploaded to a private cloud provider. Patients have some control over their data which may feel like ownership, but in practice the cloud providers own the data once it is uploaded. Therefore, there is a chance of data exploitation from cloud providers that can be seen as harmful to the security and/or privacy of the data. This model allows users to augment their data, creating a more complete health record. Providers such as Microsoft HealthVault or Google Health (now defunct) exist in this space, and their service offers good portability as a centralized source of data.
3. Public storage – the data is stored in a public repository controlled by a Regional Health Information Organization (RHIO) or equivalent agency. An RHIO is typically a public-private partnership that helps to support information exchange among providers in order to enhance quality of HIE. RHIOs may adopt any HIE architectural model, e.g., the centralized database, the federated database, or the hybrid [1]. This model is quite safe for privacy and security of data, but patients will not have flexibility to augment data. Since the data is stored publicly, other health providers can access data more easily.
4. Private storage – the data is stored in the private device such as a mobile phone or tablet, thereby allowing patients almost complete control of their data and an exceptional level of portability. However, the issue of trust and accuracy can be raised in the absence of any certificate or guarantee by a third party as to the accuracy or provenance of the data.

We evaluated these options using a weighted MCDM model and a TOPSIS analysis (Table 7.6).

Then, we used the normalized weight of each criteria to be coefficient value to calculate the proper alternative which is most close to the positive ideal solution (PIS) and avoid the negative ideal solution (NIS) (Table 7.7).

The results show that the portal which is currently used, is still the most proper alternative with regard to criteria even if it has a low score in the portability criterion. We can assume that the portal is the most suitable alternative for every scenario and it satisfies the important criteria that patients are concerned about. However the quality can be improved by increasing the capability of portability.

Table 7.6 Alternative scores

	Security	Ease of use	Availability of solution	Trust and accuracy	Portability	Privacy
EHR Portal	10	5	10	10	4	10
Private cloud service	3	10	10	8	8	1
Public storage	9	3	3	10	7	8
Private storage	6	7	7	4	10	10

Table 7.7 TOPSIS result

	Scenario1: ACA in force	Scenario2: ACA repealed	Scenario3: single payer
1. Portal	0.67	0.68	0.68
2. Personal storage	0.59	0.59	0.59
3. Public storage	0.54	0.55	0.54
4. Private cloud service	0.47	0.46	0.47

7.7 Conclusions and Recommendation

The vital population of today that relocates periodically needs accessibility to health information anytime and from anywhere. An efficient and effective healthcare service can only be provided when the health information is easily transferred to the right person at the right time.

Patient's health information is currently fragmented and isolated in different health provider's health information management tools. There is a need for a health information management that facilitates transfer of health data and provides instant and easy accessibility to those information to both patient and the required party.

In this study, we identified four alternative solutions for health information management and assessed each one based on the important criteria for health information transfer. The result revealed that EHR is still a preferred method for health information management and transfer from patient perspective. The second preferred method is private storage followed by public storage and cloud-based one. Despite the limitations that exist in transferring of data in EHRs, it is still the most private, secure, and trusted solution for healthcare, which are the top three most important criteria from patient's perspective.

The personal storage is the second most preferred solution and is aligned with the recent emphasize on patient empowerment. The main barrier of adopting such solution could be trust and accuracy of the data. Despite the accessibility and transferability of data in cloud-based solutions, the security and privacy concerns are still strong barriers in adopting these solutions by patients.

7.8 Limitations and Future Research

7.8.1 Methodology Limitations

The combination of Delphi, TOPSIS, and scenario analysis is very flexible and permitted us to use a broad base of experts to produce reasonable data for multiple scenarios in a fairly short period of time.

We can see that there were ways in which we could improve our methodology, specifically by using fuzzy TOPSIS and/or improving how we scored our options. Nevertheless the project results appeared fairly stable. The respondents did not distinguish much among the three scenarios, but they came into consensus quickly with Delphi (all but one person). Adjusting our data by dropping the outlier was one way to resolve to consensus, but we had to question ourselves – and the literature – before deciding that was valid.

Another method we might have chosen is AHP [20], originally by Saaty but evolved since then into additional methods. AHP permits additional complexity in terms of hierarchy levels but is difficult to compute for large numbers of criteria; further, it recommends the closest to optimal without regard to the distance from a negative optimal solution, which was among our goals.

In conclusion, this methodology is sound for the work we were doing. In the future, we'd make similar choices, though we might adjust slightly in favor of fuzzy TOPSIS if the scores are ambiguous. Fuzzy Delphi was an alternative we evaluated before settling on Delphi. In fuzzy Delphi, each participant is asked to provide multiple opinions each round, including what they believe to be an upper bound ("max") and lower bound ("min") to each question [21]. This is better suited to predictive questioning than attempting to determine current attitudes, and so we stuck with traditional Delphi.

Appendix

Appendix A: Delphi Survey

We used Qualtrics (www.qualtrics.com) to present a survey to a group of experts to gather data about weighting our criteria.

Round 1

Criteria

The first round defined the criteria as follows (presented as is; there were a couple of typos in the first-round survey):

Security
The solution guarantees that health information data is secured and prune to any unauthorized access.

Ease of use
The solution is intuitive and easy to use

Availability of solution
The solution is available to all users, required infrastructure is in place and any tools to use it is easily obtainable.

Privacy
Patient's information is only available by those that patient approves and used for the purposes that patient has approved.

Trust and accuracy
The solution guarantees that the health information being transferred is accurate.

Portability
The ease of data transfer through the solution i.e. *how much process is involved, how vast the transfer can be,* i.e.*, regional, national, international*

Questions

The respondents were asked to rate each on a five-point scale, i.e., Unimportant, Slightly Unimportant, Moderately Important, Very Important, and Critically Important. They were asked to do this once for each scenario.

Round 2

Updated Introduction

In the second round, we provided some feedback on the first-round outputs. The second round was presented as follows:

The questionnaire below is intended for our Technology Assessment course project titled "Technology Assessment for patient-centric solutions for transfer of health information." The goal of the questions below is to understand the importance of each criterion with respect to health information management solutions and how health information can, from a patient's viewpoint, be transferred among health providers.

We are using the Delphi method, which is a well-established technique to come to a consensus among survey participants. Delphi works by mathematically measuring the level of consensus in the answers and allowing participants to learn the results of each round, changing their answers based on others' responses if they so desire. This is the second round and so will contain the first round's *results in each question. Please review this before selecting your second answers.*

Electronic health records (EHR) are becoming more common, but it is not always easy for you to access your own medical records or ensure your data is transported to each doctor you see. With regard to services or technologies that can store your data and allow you to view it or transport it from provider to provider, please rate your opinions regarding the importance of each criterion.

Criteria

The criteria for the second round were corrected for typos but otherwise barely changed:

Security

The solution guarantees that health information data is secured and not prone to any unauthorized access.

Ease of use

The solution is intuitive and easy to use

Availability of solution

The solution is available to all users: required infrastructure is in place and any tools needed to use it are easily obtainable.

Trust and accuracy

The solution guarantees that the health information being transferred is accurate.

Privacy

Sensitive information is only available to those that patient approves and is only used for the purposes that patient has approved.

Portability

How easy it is to transfer information between providers, e.g.*, how much process is involved; who accepts and uses the system (hospitals, clinics, pharmacies, others); whether transfer is easy regionally, nationally, or internationally.*

Questions

Each question in the second round was introduced including the previous round's results and an enhanced description of the scenario, as follows:

Scenario 1: Assume there are no changes to current US government healthcare policy, e.g., that the Affordable Care Act (ACA)/Obamacare is still in force.

This scenario implies such conditions as (1) private health insurance is still the most common way Americans pay for healthcare, (2) medical practitioners have limited government mandates to collect EHR but limited incentives to share it, (3) the uninsured population is relatively small, and (4) preexisting conditions are not relevant to obtaining coverage.

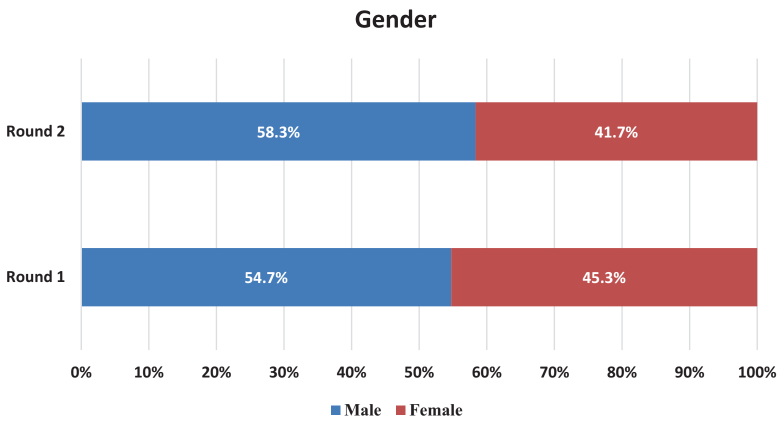
Given a value of 1 for Unimportant and 5 for Critically Important, the results from 53 responses in the first round were:

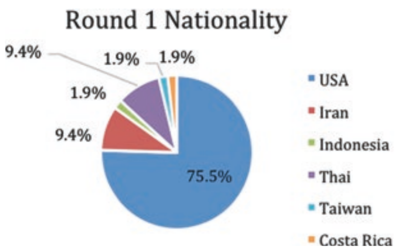
Criteria	Mean	Unimportant/ slightly	Moderate	Very important	Critically important
Security	4.43	2	6	12	33
Ease of use	3.96	2	11	26	14
Availability	3.91	4	9	28	12
Privacy	4.38	3	5	14	31
Trust and accuracy	4.79	0	1	9	43
Portability	3.74	2	23	15	13

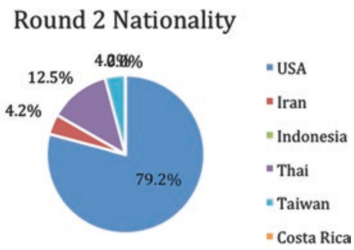
Based on these responses from your fellow patients, how would you rate the importance of each of the following criteria in this scenario?

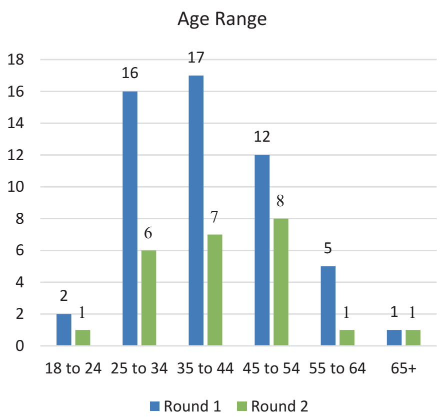
Demographics

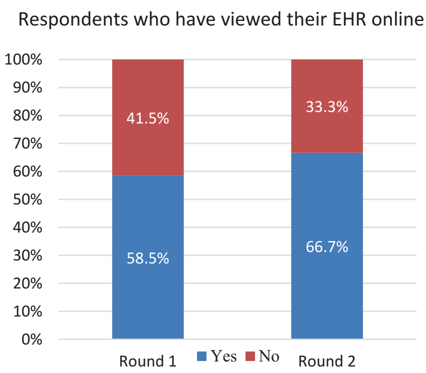
In the first round, we received 53 valid responses. These fell to 24 for the second round. A demographic breakdown of both groups is presented here:

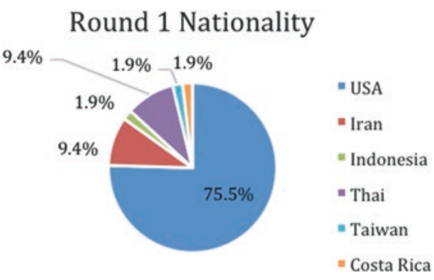

Gender
Round 2
58.3%
41.7%
Round 1
54.7%
45.3%
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
Male
Female

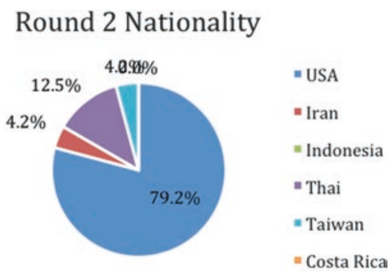

Round 1 Nationality
9.4%
1.9%
1.9%
1.9%
9.4%
75.5%
USA
Iran
Indonesia
Thai
Taiwan
Costa Rica

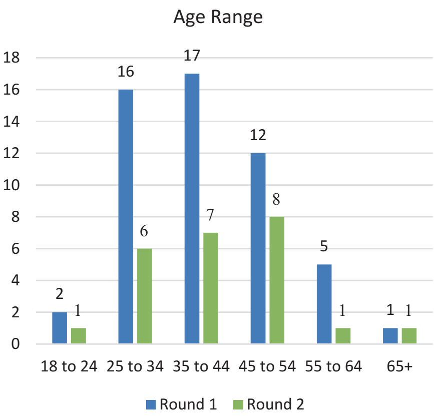

Round 2 Nationality
12.5%
4.2%
79.2%
USA
Iran
Indonesia
Thai
Taiwan
Costa Rica

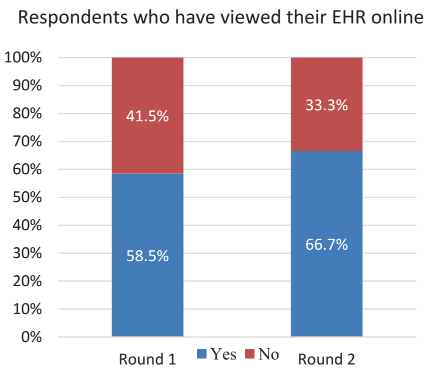

Age Range
0
2
4
6
8
10
12
14
16
18
2
1
16
6
17
7
12
8
5
1
1
1
18 to 24
25 to 34
35 to 44
45 to 54
55 to 64
65+
Round 1
Round 2


Respondents who have viewed their EHR online
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
41.5%
58.5%
33.3%
66.7%
Round 1
Yes
No
Round 2









Appendix B: TOPSIS Calculation

Option scoring matrix

	Security	Ease of Use	Availability	Trust and Accuracy	Portability	Privacy
Portal	10	5	10	10	4	10
Private Cloud	3	10	10	8	8	1
RHIO	9	3	3	10	7	8
Personal Storage	6	7	7	4	10	10

Scenario 1

Weight matrix

Criteria	Security	Ease of Use	Availability	Trust and Accuracy	Portability	Privacy
Weights	4.833	4.000	3.917	4.875	3.667	4.750

Normalized ranking

	Security	Ease of Use	Availability	Trust and Accuracy	Portability	Privacy
Portal	0.665	0.370	0.623	0.598	0.264	0.614
Private Cloud	0.200	0.739	0.623	0.478	0.529	0.061
RHIO	0.599	0.222	0.187	0.598	0.463	0.491
Personal Storage	0.399	0.517	0.436	0.239	0.661	0.614

Weighted ranking

	Security	Ease of Use	Availability	Trust and Accuracy	Portability	Privacy
Portal	3.215	1.478	2.438	2.913	0.969	2.918
Private Cloud	0.965	2.957	2.438	2.331	1.938	0.292
RHIO	2.894	0.887	0.732	2.913	1.696	2.334
Personal Storage	1.929	2.070	1.707	1.165	2.423	2.918

Ideal and negative ideal solutions

Security	Ease of Use	Availability	Trust and Accuracy	Portability	Privacy
A*					
3.215	2.957	2.438	2.913	2.423	2.918
A'					
0.965	0.887	0.732	1.165	0.969	0.292

Distance from positive ideal

	Security	Ease of Use	Availability	Trust and Accuracy	Portability	Privacy	D*
Portal	0.000000	2.185792	0.000000	0.000000	2.113537	0.000000	2.073482
Private Cloud	5.065020	0.000000	0.000000	0.339509	0.234837	6.896462	3.540597
RHIO	0.103368	4.284153	2.913464	0.000000	0.528384	0.340566	2.858310
Personal Storage	1.653884	0.786885	0.535126	3.055580	0.000000	0.000000	2.455906

Distance from negative ideal

	Security	Ease of Use	Availability	Trust and Accuracy	Portability	Privacy	D'
Portal	5.065020	0.349727	2.913464	3.055580	0.000000	6.896462	4.275541
Private Cloud	0.000000	4.284153	2.913464	1.358036	0.939350	0.000000	3.081396
RHIO	3.721239	0.000000	0.000000	3.055580	0.528384	4.171934	3.387792
Personal Storage	0.930310	1.398907	0.951335	0.000000	2.113537	6.896462	3.505788

Final rank

Portal	0.67
Private Cloud	0.47
RHIO	0.54
Personal Storage	0.59

Scenario 2

Weight matrix

Criteria	Security	Ease of Use	Availability	Trust and Accuracy	Portability	Privacy
Weights	4.917	3.958	3.917	4.917	3.500	4.875

Normalized ranking

	Security	Ease of Use	Availability	Trust and Accuracy	Portability	Privacy
Portal	0.665	0.370	0.623	0.598	0.264	0.614
Private Cloud	0.200	0.739	0.623	0.478	0.529	0.061
RHIO	0.599	0.222	0.187	0.598	0.463	0.491
Personal Storage	0.399	0.517	0.436	0.239	0.661	0.614

Weighted ranking

	Security	Ease of Use	Availability	Trust and Accuracy	Portability	Privacy
Portal	3.271	1.463	2.438	2.938	0.925	2.995
Private Cloud	0.981	2.926	2.438	2.351	1.850	0.299
RHIO	2.943	0.878	0.732	2.938	1.619	2.396
Personal Storage	1.962	2.048	1.707	1.175	2.313	2.995

Ideal and negative ideal solutions

Security	Ease of Use	Availability	Trust and Accuracy	Portability	Privacy
A*					
3.271	2.926	2.438	2.938	2.313	2.995
A'					
0.981	0.878	0.732	1.175	0.925	0.299

Distance from positive ideal

	Security	Ease of Use	Availability	Trust and Accuracy	Portability	Privacy	D*
Portal	0.000000	2.140492	0.000000	0.000000	1.925764	0.000000	2.016496
Private Cloud	5.241181	0.000000	0.000000	0.345337	0.213974	7.264210	3.614513
RHIO	0.106963	4.195365	2.913464	0.000000	0.481441	0.358726	2.838302
Personal Storage	1.711406	0.770577	0.535126	3.108036	0.000000	0.000000	2.474903

Distance from negative ideal

	Security	Ease of Use	Availability	Trust and Accuracy	Portability	Privacy	D'
Portal	5.241181	0.342479	2.913464	3.108036	0.000000	7.264210	4.343889
Private Cloud	0.000000	4.195365	2.913464	1.381349	0.855895	0.000000	3.057135
RHIO	3.850664	0.000000	0.000000	3.108036	0.481441	4.394399	3.440136
Personal Storage	0.962666	1.369915	0.951335	0.000000	1.925764	7.264210	3.531839

Final rank

Portal	0.68
Private Cloud	0.46
RHIO	0.55
Personal Storage	0.59

Scenario 3

Weight matrix

Criteria	Security	Ease of Use	Availability	Trust and Accuracy	Portability	Privacy
Weights	4.875	4.000	4.042	4.917	3.667	4.750

Normalized ranking

	Security	Ease of Use	Availability	Trust and Accuracy	Portability	Privacy
Portal	0.665	0.370	0.623	0.598	0.264	0.614
Private Cloud	0.200	0.739	0.623	0.478	0.529	0.061
RHIO	0.599	0.222	0.187	0.598	0.463	0.491
Personal Storage	0.399	0.517	0.436	0.239	0.661	0.614

Weighted ranking

	Security	Ease of Use	Availability	Trust and Accuracy	Portability	Privacy
Portal	3.243	1.478	2.516	2.938	0.969	2.918
Private Cloud	0.973	2.957	2.516	2.351	1.938	0.292
RHIO	2.919	0.887	0.755	2.938	1.696	2.334
Personal Storage	1.946	2.070	1.761	1.175	2.423	2.918

Ideal and negative ideal solutions

Security	Ease of Use	Availability	Trust and Accuracy	Portability	Privacy
A*					
3.243	2.957	2.516	2.938	2.423	2.918
A'					
0.973	0.887	0.755	1.175	0.969	0.292

Distance from positive ideal

	Security	Ease of Use	Availability	Trust and Accuracy	Portability	Privacy	D*
Portal	0.000000	2.185792	0.000000	0.000000	2.113537	0.000000	2.073482
Private Cloud	5.152724	0.000000	0.000000	0.345337	0.234837	6.896462	3.553781
RHIO	0.105158	4.284153	3.102397	0.000000	0.528384	0.340566	2.891480
Personal Storage	1.682522	0.786885	0.569828	3.108036	0.000000	0.000000	2.479369

Distance from negative ideal

	Security	Ease of Use	Availability	Trust and Accuracy	Portability	Privacy	D'
Portal	5.152724	0.349727	3.102397	3.108036	0.000000	6.896462	4.313855
Private Cloud	0.000000	4.284153	3.102397	1.381349	0.939350	0.000000	3.115646
RHIO	3.785675	0.000000	0.000000	3.108036	0.528384	4.171934	3.405001
Personal Storage	0.946419	1.398907	1.013028	0.000000	2.113537	6.896462	3.516867

Final rank

Portal	0.68
Private Cloud	0.47
RHIO	0.54
Personal Storage	0.59

References

1. Vest, J. R., & Gamm, L. D. (2010). Health information exchange: Persistent challenges and new strategies. *Journal of the American Medical Informatics Association, 17*(3), 288–294.
2. Vest, J. R. (2010). More than just a question of technology: Factors related to hospitals' adoption and implementation of health information exchange. *International Journal of Medical Informatics, 79*(12), 797–806.
3. Benaloh, J., Horvitz, M. C. E., & Lauter, K. (2009). *Patient controlled encryption: ensuring privacy of electronic medical records*, Proceedings of the 2009 ACM workshop on Cloud computing security.
4. HIMSS, *HIE Technical models from the HIMSS guide to participating in HIE*, Healthcare Information and Management Systems Society (HIMSS), November 2009. [Online]. Available: http://www.himss.org/files/HIMSSorg/content/files/2009HIETechnicalModels.pdf. Accessed 1 Dec 2014.
5. DHSS, *Health Information Exchange* (*HIE*)., Office of the National Coordinator for Health Information Technology, U.S. Department of Health and Human Services, 12 5 2014. [Online]. Available: http://www.healthit.gov/providers-professionals/health-information-exchange/what-hie. Accessed 1 Dec 2014.
6. Hsu, C.-C., & Sandford, B. A. (2007). The Delphi technique: Making sense of consensus. *Practical Assessment Research & Evaluation, 12*(10), 1–8, available at http://pareonline.net/getvn.asp?v=12&n=10.
7. Hasson, F., Keeney, S., & McKenna, H. (2000). Research guidelines for the Delphi survey technique. *Journal of Advanced Nursing, 32*(4), 1008–1015.
8. Yoon, K. (1980). *Systems selection by multiple attribute decision making*. Kansas State University. Kansas, USA.
9. Yoon, K. P., & Hwang, C.-L. (1995). Multiple attribute decision making: An introduction, vol. 104, Sage Publications. California, USA.
10. Huss, W. R. (1988). A move toward scenario analysis. *International Journal of Forecasting, 4*(3), 377–388.
11. Hoerbst, A., & Ammenwerth, E. (2010). Electronic health records. A systematic review on quality requirements. *Methods of Information in Medicine, 49*(4), 320–336.
12. Agrawal, R., Lefevre, K., Xu, Y., Road, H., Jose, S., & Street, W. D. (2004). *Managing healthcare data hippocratically*, Proceedings of the 2004 ACM SIGMOD international conference on Management of data, pp. 3–4.
13. Simon, S. R., Evans, J. S., Benjamin, A., Delano, D., & Bates, D. W. (2009). Patients' attitudes toward electronic health information exchange: Qualitative study. *Journal of Medical Internet Research, 11*(3).
14. Unertl, K. M., Johnson, K. B., Gadd, C. S., & Lorenzi, N. M. (2013). Bridging organizational divides in health care: An ecological view of health information exchange. *JMIR Medical Informatics, 1*(1), e3.
15. Liu, L. S., Shih, P. C., & Hayes, G. R. *Barriers to the adoption and use of personal health record systems*, in Proceedings of the 2011 iConference, Seattle, WA, 2011.
16. Blue, V., "ZDNet," ZDNet, 30 09 2014. [Online]. Available: http://www.zdnet.com/article/trust-in-cloud-security-at-all-time-low-execs-still-betting-on-the-cloud/. Accessed 01 Dec 2014.
17. DHSS, *What is a regional health information organization (RHIO)?*, hrsa.gov, [Online]. Available: http://www.hrsa.gov/healthit/toolbox/RuralHealthITtoolbox/Collaboration/whatisrhio.html. Accessed 01 Dec 2014.
18. Gracht, H. A. V. D. (2012). Consensus measurement in Delphi studies. *Technological Forecasting and Social Change*, 1525–1536.
19. Seo, S. (2006). *A review and comparison of methods for detecting outliers in univariate data sets*, Dissertation.
20. Saaty, T. L. (1977). A scaling method for priorities in hierarchical structures. *Journal of Mathematical Psychology, 15*(3), 234–281.
21. Ishikawa, A. e. a. (1993). The max-min Delphi method and fuzzy Delphi method via fuzzy integration. *Fuzzy Sets and Systems, 55*(3), 241–253.

Chapter 8
Technology Assessment: Nosocomial Infection Solutions

Chris Imondi, Arundhati Shastri, Tom Shott, Jayanth Siddappa, and Tugrul U. Daim

8.1 Introduction

This study presents a technology assessment for reducing nosocomial infections. Nosocomial infections (also known as hospital-acquired infection or HAI) present numerous problems for healthcare institutions including increased costs, increased use of hazardous cleaners, and patient reluctance toward treatment. The goal is to incorporate more than the traditional economic point of view in evaluating alternatives for reducing infections. The Analytical Hierarchy Process is used to assess the feasibility of candidate technologies. Traditional criteria such as infection reduction and cost are used in addition compatibility with existing procedures, and staff acceptance was used for evaluating technologies. Infection reduction and staff acceptance were determined to be the most important criterion through expert interviews. The analysis established that utilizing RFID for handwashing compliance was the superior technology given its superior reduction in HAIs and good staff and patent acceptance.

C. Imondi • T. Shott • T.U. Daim (✉)
Portland State University, Portland, OR, USA
e-mail: chrisimondi@gmail.com; tshott@pdx.edu; tugrul.u.daim@pdx.edu

A. Shastri
Intel Corp, Santa Clara, CA, USA
e-mail: arundhati.shastri@intel.com

J. Siddappa
BorgWarner Inc, Auburn Hills, MI, USA
e-mail: jayanthjsiddappa@gmail.com

T.U. Daim et al. (eds.), *Infrastructure and Technology Management*, Innovation, Technology, and Knowledge Management,
https://doi.org/10.1007/978-3-319-68987-6_8

The increase in nosocomial infections has drawn tremendous attention in the healthcare industry and from the public. The industry is concerned with the growing problem of multidrug-resistant strains. Healthcare administrators are looking for ways to reduce nosocomial infection rates and costs while not contributing to increases in multidrug-resistant strains. Any technology solution has to meet stringent regulations, with respect to quality and effectiveness in controlling nosocomial infections. It has to be cost-effective, but to be integrated into the existing system it must be easy to use and compatible with existing processes. The authors of this paper believe that the increasing trend in hospital-associated infections has provided the impetus to examine technology solutions for the problem.

This paper latches onto the momentum described above and hopes to further explore the assessment of four technology solutions toward infection rates in the USA, both in terms of capabilities and impediments to implementation. The Analytical Hierarchy Process (AHP) is used to evaluate a number of candidate technologies. Interviews with infection control professionals were used to validate the proposed methodology and establish the relative importance of the selection criteria.

8.2 Study Methodology

The reminder of this paper proceeds to establish the problem and evaluate alternative technological solutions.

A literature review examines the current problem of HAIs, existing solutions, methods for technology acquisition, and assessment (TAA) in healthcare and the application of multicriteria models to healthcare. The analysis of the literatures identifies key areas that play an important role in reducing hospital-acquired infections.

The problem of HAIs was considered in detail, and a gap analysis was used to evaluate the problem from multiple perspectives. From the gap analysis and previous healthcare studies, an AHP model was developed. Selection of a technology for reducing hospital infections is a complex problem involving qualitative and quantitative decisions; we used a hierarchical decision model (HDM) to aid hospitals in determining the right technology to meet their objective. HDM is a tool to present a large decision problem as a hierarchy of smaller and less complex decisions [1].

A list of proposed technologies applicable to solving the problem was developed through scanning the literature.

The model and solution set were validated with selected experts, and an interview script was developed to interview experts in hospital infection control. Expert pairwise comparisons were used to compare criteria and subcriteria two at a time in order to determine their value relative to each other.

The experts input were used to evaluate the relative importance of the model criteria and the solutions.

Using the AHP model, the selected technologies were evaluated and the results analyzed.

8.3 Literature Review

To understand the problem of HAIs, existing literature was examined. We investigated the current problem of infections and current solutions. We reviewed methods for healthcare TAA, AHP, and the use of AHP multicriteria models in healthcare.

8.3.1 Hospital Infections

The Center for Disease Control (CDC) estimates that roughly 1.7 million hospital-associated infections, from all types of bacteria combined, contribute to 99,000 deaths each year [2]. The increase of antibiotic-resistant bacteria is a worrisome trend, with few options to control the growth of these bacterial strains. The cost increase attributable to managing an episode of *multidrug-resistant Staphylococcus aureus (*MRSA) compared with managing nonresistant strain ranges between $2500 and $17,422 [3]. Litigation costs are also skyrocketing. Medicare announced that it will no longer pay for treatment of nosocomial infections effective October 2008, thereby making hospitals fiscally responsible for reducing the occurrence rate of these infections. Also there is an increasing awareness of the bacteria problem among consumers. Hospitals and other healthcare providers could gain a differential advantage by more effectively addressing this problem.

The US Department of Health and Human Services estimates the national health expenditures in the USA to increase at an annual average growth rate of 6.3% between 2009 and 2019 [4]. With an average cost per infection of $15,275 [5], hospitals feel the incentive is to put preventative controls in place.

8.3.2 Infection Prevention

Hospitals currently use a wide range of treatments and preventative measures to counter nosocomial infections. For certain procedures, prophylactic antibiotic treatment is used. This a preventative measure to prevent bacterial growth during or after the procedure. However, the overuse of prophylactic antibiotics can lead to the creation of drug-resistant organisms [6]. Patients are also given antibiotics posttreatment if signs of infection occur. This approach can also contribute to the creation of drug-resistant organisms.

8.3.3 Healthcare Technology Assessment and Acquisition

Much of the previous work in TAA in healthcare (Health Technology Assessment (HTA)) has focused on regulatory compliance and evaluating technologies using single criteria economic analysis of alternatives or expected mortality rate [7]. In this study, a larger set of criteria was considered so an AHP model was developed.

8.3.4 Analytical Hierarchy Process

AHP was developed to consider a devise set of criteria for selecting the best of a set of alternatives. It's been widely used in many areas. An overview can be found in [8, 9]. In a survey of TAA methodologies [10], it was one of the primary methods used for evaluating alternatives. As an example in [11], it was applied to technology choices in the energy sector to select the best candidate fusing multidimensional criteria. A variant of AHP is HDM – very similar but uses a pairwise raying scheme [12].

8.3.5 Analytical Hierarchy Process in Healthcare

AHP has been used in healthcare, although not for technology assessment. Liberatore and Nydick [13] reviewed the use of AHP in the health field – finding many examples. Since 1988 the number of papers published has been increasing to about three per year. In their article, they reviewed over 50 papers using AHP in the health field. They show examples for both patient care decisions (best type of treatment, diagnostic decisions) and for hospital management decisions (project evaluation, operational assessment). In an interesting series of papers by Dey [7, 14, 15], it was used to develop a multifactor set of criteria to rate intensive care units. In an area related to technology assessment, it has been used to evaluate alternative medical equipment selection. In [16] AHP was used to select the most appropriate diagnostic equipment for the types of procedures the hospital performed, and in [17] it was used to evaluate alternative neonatal ventilators.

It was used in [18] to select the most suitable medical waste disposal method for hospitals in developing countries. Meetings were held in multiple locations to brainstorm on the criteria and interactively determine the weighting criteria. Then the groups jointly evaluated the selected technologies. Although surveying the experts individually reduces the biases effect of influential contributors, the joint development of the decision model improves buy-in to the solution selected.

Although there are papers on evaluating the best medical device to purchase or for assisting in defining what product development projects to pursue [19, 20], no prior uses of AHP for technology acquisition and assessment were found.

8.4 Problem

8.4.1 Gap Analysis

A gap analysis was conducted, arranging the problem into the following categories: technical, organizational, and personal. Solution needs were first established through literary review. Once compiled, the needs were verified through expert interviews. With the needs established, additional research was conducted to match existing capabilities to the need. The capabilities were then evaluated to determine gaps in the current solutions. For example, the need to reduce infection rates has been stated by several sources [6]. The same sources listed prophylactic antibiotic treatment as the primary existing solution. This information was then verified with several interviewed experts. Finally, the gap of increased drug resistance was given by both literature and expert sources (Figs. 8.1–8.3).

8.4.1.1 Criteria/Metrics

Through the literature review, a list of major criteria and subcriteria was established for use in the model. These criteria were verified through initial expert interviews. Several items were added after the expert interviews. An expert who was

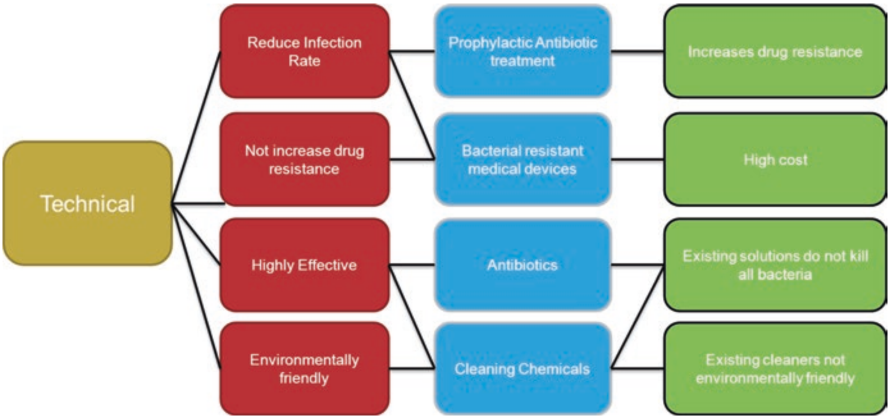


Fig. 8.1 Gap analysis (technical)

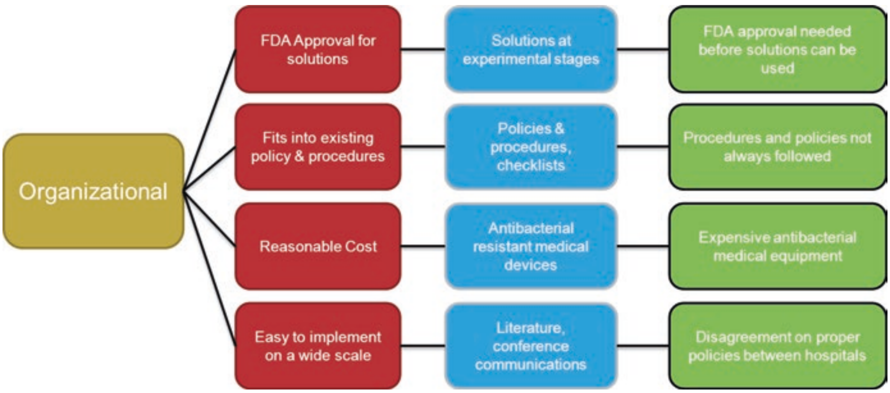


Fig. 8.2 Gap analysis (organizational)

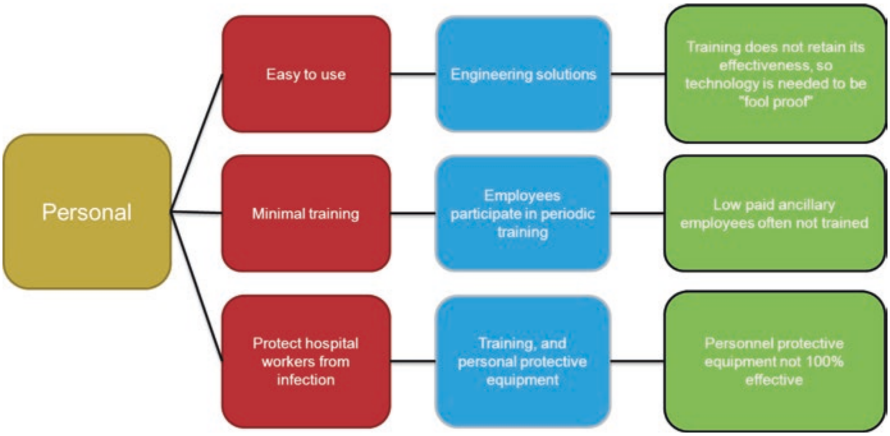


Fig. 8.3 Gap analysis (personal)

interviewed, for example, stated that one of significant problems they are facing is the excessive waste due to personal protective equipment. When traveling on rounds, students are less likely to enter the patient's room to observe the doctor's work because they need to put on a large amount of protective equipment. This equipment must then be taken off and thrown away by all students once the doctor leaves the room [21]. The complete list of criteria and subcriteria can be found below:

- Infection reduction
  – % reduction in infection rate of process
  – Ability to prevent creation of drug-resistant bacteria
- Cost
  – Initial cost
  – ROI
- Compatibility with existing policies and procedures
  – Hospital
  – FDA, OROSHA
- Level of training required
  – Hospital worker acceptance
  – Patient acceptability
- Environmental impact
  – Minimal environmental waste
  – Occupational safety: risk to workers

8.5 Technical Solutions

8.5.1 Biomimicry Solution

This emerging area of engineering thought and design principles could be described as an innovation method that seeks to solve engineering problems by seeking sustainable solutions inspired by nature's processes and strategies [22]. By emulating natural models, using the principles of biomimicry results in new product designs that coexist with the natural ecosystems around us and utilize the strategies that nature has developed over billions of years of evolution. By looking to nature to solve design problems, engineers engaged in biomimicry strive to follow nature's principles such as building from the bottom up, optimizing rather than maximizing, and utilizing ecologically friendly materials and processes [23].

Sharklet Technologies (SLT) markets surface technologies that inhibit microorganism growth without the use of chemicals. The company's core product, called Sharklet SafeTouch, emulates the functionality of Galapagos shark skin denticles which enable the animal's surface to remain bacteria-free despite the fact that it is slow-moving underwater. SafeTouch, a breakthrough cost-saving surface technology, provides an incremental, nonchemical, passive, and persistent defense against the spread of bacteria and nosocomial infections including antibiotic-resistant strains, by inhibiting bacterial growth. SafeTouch is a no-kill, nontoxic surface designed to inhibit bacterial growth including *methicillin-resistant Staphylococcus aureus (MRSA), E. coli*, *Staph a., Pseudomonas aeruginosa, vancomycin-resistant enterococci (VRE),* and a host of other bacteria. The SafeTouch durable skin surface is topography of billions of tiny raised, microscopic diamond-shaped patterns called Sharklet. This unique microtopography is inhospitable for bacterial growth and *inhibits bacterial biofilm development.* The Sharklet pattern has been shown to reduce bacterial growth by 86% versus an untreated surface [24].

Though using the SafeTouch product is easy, it requires time and energy to apply, inspect, maintain, and replace the product when necessary. This surface has proven effective at inhibiting bacterial colonization for up to 21 days. Primary users of the product include anyone who comes in contact with the SafeTouch product, such as patients and families, physicians, nurses, janitors, and equipment technicians. Administrators are not only the primary decision makers, but also approvers and buyers. In addition, government health agencies, like the FDA, will enforce product regulations for using these in healthcare facilities.

8.5.1.1 Costs and Pricing

For hospitals, the opportunity to reduce hospital-related nosocomial infections helps control costs associated with treating these infections. The product guidelines suggest replacing SLT SafeTouch skins on average every 3 months. There is no upfront capital cost required for this solution. The price per square foot for SafeTouch is $12.36 (see the Appendix: Tables 8.4 and 8.5 for price, cost-saving calculations). According to Ken Chung, the product director at SLT, five square feet of SLT skin is sufficient to cover the high-traffic area of a single-patient room.

8.5.2 RFID Solution

One of the new technologies being applied to reduce hospital infections is RFID. There have been numerous papers on the use of RFID in healthcare [25– 27]. These authors have suggested using RFID for tracking patents, equipment, and staff to improve workflow, efficacy, and patient safety. They have even suggested tracking surgical sponges so they are not inadvertently left in the patent during surgery [28].

To reduce infection RFID can be used to monitor handwashing compliance, to collect data for post-infection analysis, and to prevent infections by tracking if equipment has been properly sanitized before being used on the next patient. Papers by Do and Jain et al. [29, 30] have proposed the idea of using RFID to monitor handwashing.

One limited trial found a significant increase in handwashing compliance resulting in a 22% reduction in HAIs [31]. While the $1500–$2000 capital per room to install the systems [32] is relatively expensive, a typical infection can cost $15,000–$20,000.

8.5.3 Silver Catheter Technology Solution

Urinary tract infections compose 35–45% of all nosocomial infections. Nearly all of these infections are caused by catheter-related infections [6]. Another solution that is showing promise in the fight to reduce hospital infections is the application of nano-silver coatings on medical devices. Samuel notes that contaminated catheters are responsible for over 40% of nosocomial sepsis in acute-care hospitals. Sepsis is a severe bacterial infection of the bloodstream, resulting in blood pressure drops and patient shock.

He proposes a solution to the problem: nano-silver-coated catheters.

> This technology describes an even distribution of billions of nanoparticles (3–8 nm) of silver (0.8–1.5 wt.%) in the catheter matrix (polyurethane, silicone) on a carrier, preferably barium sulphate (Fig. 8.2). Free silver ions are liberated on the surface exhibiting a strong antimicrobial activity against a variety of organisms irrespective of their resistance to antibiotics. Various prototypes have been manufactured with an increasing surface of silver0. Presently, a catheter with a surface of silver0 nanoparticles of 2500 cm^2/g polyurethane or silicone is manufactured. [33]

The stated benefits of silver catheters vary greatly. Tables 8.6 and 8.7 in the appendix outline several studies and list their impact. While catheters cost roughly 25% more on a per-unit basis, they yield a 7% median reduction in infection rate [34]. Another stated benefit of the silver catheter technology is that it is effective against existing drug-resistant bacteria. This is important for any solution, as drug-resistant bacteria are increasing in prevalence. The selected solutions must address this problem in some way.

8.5.3.1 Costs and Pricing

As stated, catheter costs increase with silver technologies. In one case, a per-unit cost of $16.78 for traditional catheters increases to $20.87 for silver alloy urethral catheters [35]. While this increases the costs for hospitals, the 7% reduction in procedure infection rate more than makes up for the increased costs [34].

Silver catheters show promise as a potential technology to reduce nosocomial infections. They have shown to be effective against bacterial growth and do not contribute to the creation of drug-resistant bacteria. However, the catheters have a much higher cost when compared to their traditional counterparts. This problem must be resolved if they are to see more mainstream use.

8.5.4 Targeted Cleaning Solution

As reported by prior research [36–38], environmental contamination is observed during regular healthcare services through multiple room surfaces. These organisms are very resistant to antibiotic and result in longer hospital stays and further expenses.

Although the goal of environmental cleaning and disinfection is not sterilization, adequate cleaning requires sufficient removal of pathogens to minimize patients' risk of acquiring infections from hospital environments. This is particularly true in areas serving high-risk patients, such as intensive care units (ICUs). Although the Centers for Disease Control and Prevention recommends that "close attention be paid to cleaning and disinfecting high touch surfaces in patient care areas" and that hospitals "ensure compliance by housekeeping staff with cleaning and disinfecting procedures" [39], the literature findings identified that there are areas of substantial improvement to achieve thoroughness of cleaning in the hospitals.

Given the need to achieve this increased thoroughness of cleaning in the hospitals without having to go too far from the regular norm of cleaning process, target cleaning technology was identified as the best fit. The targeting solution consists with an environmentally stable, nontoxic base to which a chemical marker is added so that it fluoresces brightly when exposed to ultraviolet light. Also, it is developed so that it would be inconspicuous, dries rapidly on surfaces, remains environmentally stable for several weeks, and can be easily removed with water-based disinfectants. Although the dried marking solution resists abrasion, once it is moistened, it can be completely removed by wiping with a damp cloth for less than 5 s using light, fingertip pressure.

The target solution is applied on "high- touch objects" (HTO), which includes, toilet handles, horizontal surface of toilet bowls, bedpan flushing devices, horizontal surface of sinks adjacent to a faucet, doorknobs (or push/grab plates), toilet area handholds immediately adjacent to the toilet, bedside tables, telephone receivers, call buttons, overbed tables, seats of patient chairs, and frequently contacted areas on bedrails [40].

Studies have indicated that, in general, hospitals maintain consistently high cleaning rates (between 80% and 90%) for sinks, toilet seats, bedpans, and tray

Table 8.1 Summary of solutions

Criteria	Sub-Criteria	RFID	Spot Cleaning	Silver Catheter	Biomimicry
Infection	Reduce Infection rate	22%	10%	3%	12%
	Drug Resistance	No	No	No	No
Cost	Initial Cost	$1,300	No	No	No
	ROI	< 3 Months	Positive	Positive	< 2 Months
Compatibility	Fit Existing Procedures	Very	Somewhat	Very	Somewhat
	Regulations (OROSHA/FDA)	Yes	Yes	Yes	Yes
Acceptance	Staff	Yes	Yes	Very	Maybe
	Patients	Very	Yes	Yes	Maybe
Environment	Toxicity	No	No	Some	Some
	Minimal Waste	Yes	Yes	Yes	Some

tables, but the rest of the HTOs have a very low cleaning rate. The results of clinical trials in ten hospitals which used target solution to clean showed that at least two types of HTOs had a cleaning rate of more than 90% [37] (Table 8.1).

8.6 Model

8.6.1 Hierarchical Decision Model

The design of the hierarchical decision model (HDM) must satisfy the goal of developing a model that will allow hospitals/healthcare institutions to choose a technology that will help reduce the hospital-acquired infection (HAI) rate. The model developed in this paper consists of four levels as shown in Fig. 8.4.

There are many technological solutions available for the hospitals which address the issue of reducing hospital-acquired infections. Each technology has their unique advantages and functionalities for addressing the infection growth. Often accessing these functionalities in accordance to a hospital requirement can be a complex, time-consuming, and mostly subjective decision. HDM can be used to quantify a subjective decision process, and by doing so, it reduces the complexity of accessing various technologies. HDM is very commonly used tool and model for ranking alternatives with complex criteria.

The criteria for the model were determined through literature studies and also from the expert interviews. The survey questionnaire can be found in Appendix II. The top level represents the goal of reducing HAI. The last level is represented by the four alternative technologies available to achieve the goal. The criteria of selecting the technology should meet the requirements of hospital/healthcare institutions in five major categories, reduction in infection rate, cost, compatible with existing policies and procedures, level of training required, and environmental impact. Thus, these criteria were assigned to the level just below the top level.

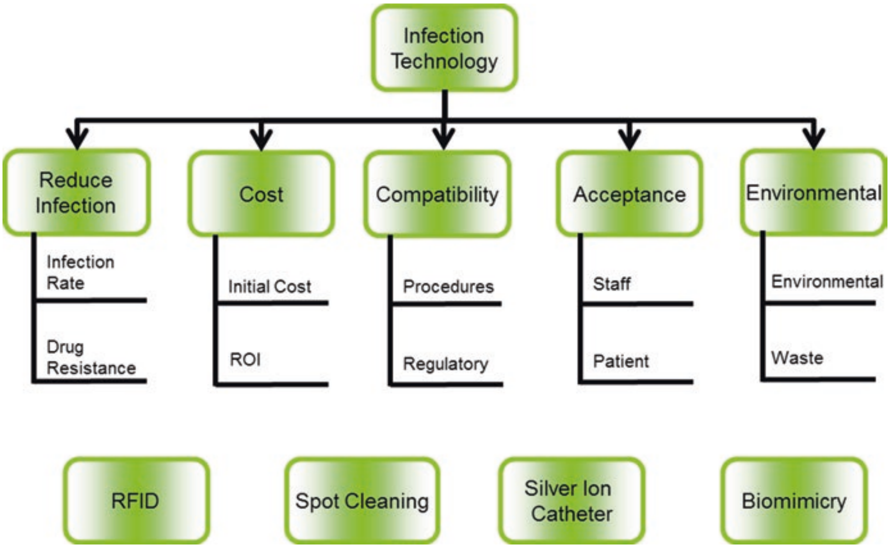


Fig. 8.4 Hierarchical decision model (HDM) for reducing hospital-acquired infection

The third level constitutes the subcriteria of these major criteria. Under reduction in infection rate, the subcriteria included are the percentage in reduction rate and prevention of furthering drug-resistant bacteria. The cost includes capital cost and return of investment (ROI). The compatibility with existing policies and procedures might vary between institutions and states and may include hospital, Federal Drug Administrative (FDA), and Oregon Safety and Health Administration (OROSHA) regulations. Under acceptance, the new technology must be acceptable to both hospital workers as well as to patients. The environmental impact might also vary between institutions and states, but they mainly include environmental waste and occupational safety of workers (Fig. 8.4).

8.6.2 Weights for Criteria from Experts

The survey was administered to various hospital heads for infectious disease control. These surveyed hospitals are mostly located in Portland metro area. The survey was designed as a judgment quantification instrument in the collection of information in the relative importance of the different criteria and subcriteria that can impact the decision of choosing the right technology.

The respondents were asked to compare different subcriteria for each major criterion with respect to their relative importance and to compare the major criteria to each other. In each comparison, a total of 100 points should be allocated between two elements in pair to indicate a judgment of how much one element is more important than the other element.

Table 8.2 Summary of final weights for the model

Criteria	Weight	Relative	Final
Reduce Infection	0.27		
Infection Rate		0.57	0.1539
Not Increase Drug Resistance		0.43	0.1161
Cost	0.12		
Capital Cost		0.44	0.0528
ROI		0.56	0.0672
Compatibility	0.16		
Fits Existing Procedures		0.202	0.0323
Regulatory Approved (OROSHA/FDA)		0.798	0.1277
Acceptance	0.26		
Staff		0.482	0.1253
Patients		0.518	0.1347
Environment	0.19		
Not Environmentally Toxic		0.58	0.1102
Minimal Waste		0.42	0.0798

PCM™ software was used to calculate the relative weights of each major criterion and the weights of each subcriterion under each major criterion. The summary of the calculated weights for the model is shown in Table 8.2.

8.6.3 Solutions and Weights

To more precisely define the preferences for the decision criteria and subcriteria, we surveyed our experts again and calculated utility scores. The survey questionnaire can be found in Appendix II.

Each alternative was compared against each other to find their preferred score. The preference for each subcriterion was measured based on expert's preference for each of the different subcriterion types. The preference for cost was measured based on expert's preference between capital cost and return of investment. To determine the infection reduction attribute, we used percentage in reduction of the infection rate in a hospital and at the same time not to increase the creation of drug-resistant bacteria. For the compatibility attribute, the preference was measured based on the hospital policies and the Oregon State Occupational Safety and Health Association (OROSHA) and US Food and Drug Administration (FDA). The preferences for acceptance of the new technology should have both employee and patient. To determine the preference for environment, the new technology should produce minimal waste and also should not be environmentally toxic to both the personal that is using it and for the environment itself.

Table 8.3 Alternative scoring

Criteria	RFID	Spot cleaning	Silver ion	Biomimicry
Infection	0.084429	0.058266	0.061344	0.065961
Reduce infection rate	0.055404	0.029241	0.032319	0.036936
Not increase drug resistance	0.029025	0.029025	0.029025	0.029025
Cost	0.019344	0.032016	0.026592	0.041376
Minimal initial cost	0.000528	0.020592	0.01584	0.01584
ROI	0.018816	0.011424	0.010752	0.025536
Compatibility	0.040646	0.040646	0.042584	0.036124
Existing procedures	0.008721	0.008721	0.010659	0.004199
Regulations (OSHA/FDA)	0.031925	0.031925	0.031925	0.031925
Acceptance	0.07327	0.063935	0.083983	0.037559
Staff	0.028819	0.027566	0.047614	0.020048
Patients	0.044451	0.036369	0.036369	0.017511
Environmental impact	0.059394	0.057798	0.05339	0.02052
Minimal toxic	0.03306	0.03306	0.028652	0.01653
Less waste	0.026334	0.024738	0.024738	0.00399
Total	0.277083	0.252661	0.267893	0.20154

8.6.4 Results

In order to determine the best technology to reduce hospital infections based on the model, each of the alternatives was compared against one another, and the alternative with the highest preference score is recommended below. The final preference scores for each alternative were calculated by multiplying the relative weight of each criteria and subcriteria with the utility values of each attribute for the alternative and adding up all the values – resulting in one final score for each alternative based on their attributes. The total possible preference score is 1.0, indicating that the alternative perfectly matched all desired criteria. Table 8.3 below shows the scoring for all alternatives.

It can be seen from the Table 8.3 that all the alternatives scored very closely. Even though RFID obtained the highest score, silver ion and spot cleaning were not too far behind. RFID obtained the best infection reduction score even though it had worst cost of all the alternatives. Silver ion managed to get highest acceptance score and managed to maintain a good scoring for the rest of the criteria. Spot cleaning had the worst infection reduction but managed to get good score in all the other criteria. Biomimicry was the least expensive in terms of capital cost but had poor scores in acceptance and environmental criteria.

8.7 Analysis

The results of our analysis using the AHP model show that RFID was a somewhat superior technical solution to reducing hospital infections but that silver ion catheters and spot cleaning are also viable solutions.

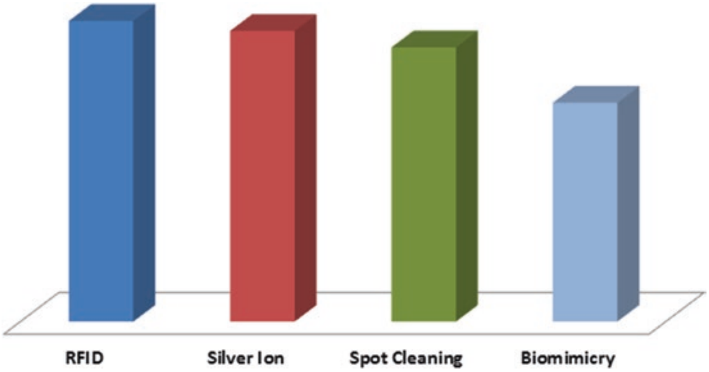


Fig. 8.5 Technical Solutions

The RFID-enabled handwashing system was the highest-rated technology. RFID systems with 28% reduction in patent infections had the greatest infection reduction which was the most heavily weighted criteria. For the second highest criteria, acceptance it was in the middle of the solutions with it having the highest patent acceptance. Although it was the only solution that had a capital cost, cost was not an important criterion.

Silver-Ion catheters were the second highest-rated solution. It had the highest acceptance, especially among hospital staff. For all the rest of the areas, it showed moderate results.

The spot cleaning technology had the worst infection reduction of all the solution but was moderately good in all over categories.

Of all the data for the model, ROI data was the least accurate due to the difficulty in estimating costs for future solutions. But the cost was also the least important criteria so it's likely that the results would show little difference with more accurate cost information (Fig. 8.5).

8.8 Conclusion

This paper presented results for technology assessment of four solutions alternatives. Healthcare administrator opinions were used to rank the criteria to the AHP model. The best option among the solutions was the RFID solution. The interesting part is this was the solution with the most upfront cost for installation. This solution scored best in terms of reducing MRSA levels while not further contributing to aggravating the problem and also in terms of acceptance by hospital personnel.

Based on the analyses, additional should be identified as part of future research. These include:

- UV room cleaning: In this solution an empty hospital room could be decontaminated with UV rays for a timed exposure to minimize MRSA levels of bacterial colonization.

- Data mining: This was recommended by several experts. Data mining systems keep stringent records on all patients before and after procedures. If a patient develops an infection after they have left the hospital, the system will link that infection to the associated procedure. This allows hospitals to keep more effective records on infection rates for procedures.
- Education and training: This happens to be the most traditional and deep-rooted solution that most experts believe would solve the problem. The experts believe that the solution is all about embedded culture and mindset toward clean practices.

8.8.1 Future Work

For future improvements, we would consider revising our model by removing and refining some criteria.

An improved economic analysis by collecting additional cost data from local hospitals and existing infections rates would help refine the methodology. Extending experts used for expert input via online surveys and additional contact with Portland APIC chapter would provide more accurate datasets for analysis.

The economic analysis assumes no interaction among solutions and the same starting point for all hospitals. The analysis does not use time value of money calculations. Net present value calculations for each of the solutions would be more effective for capital costs and return on investment. By incorporating these changes, one can easily adjust the model, and it will provide more accurate financial estimate.

Appendix

Appendix I: Tables

Table 8.4 Biomimicry infection reduction

SafeTouch reduces MRSA by 86%
% of hospital infections caused by surfaces/environment = 13%
Overall infection reduction = 86% × 13% = 12%
1% in infection reduction saves 250$/year/room
SafeTouch solution total cost savings = 12% × 250 = 3000$/year

Table 8.5 Biomimicry SafeTouch ongoing costs

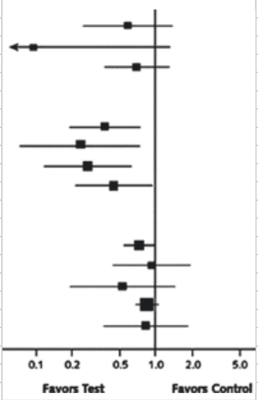
Price per kit: $12.36 × 5 sq.ft = $61.78
Price of materials per year = $61.78 × 4(quarters) = ~$ 247
Price of labor for applying per year = ~$ 247 (assumed equal to price of materials)
Total cost per year = $ 494
Payback period < than 2 months

Table 8.6 Silver catheters (impacts and infection reduction) [33, 35, 41–46]

Research paper	Catheter type	Method of entry	Control infection rate	Experiment infection rate	Control cost	Experiment catheter cost
Gentry, scope : using silver to reduce catheter-associated urinary tract infections	Silver alloy hydrogel-coated Foley catheter	Urethral catheter	7.70%	5.10%		2,654 GBP savings, which offsets the increased cost
Moretti et al.: impact of central venous catheter type and methods on catheter-related colonization and bacteremia	Silver, platinum, carbon black CVC	Intravenous	0.40%	0%	NA	NA
Rupp et al.: effect of a second-generation venous catheter impregnated with chlorhexidine and silver sulfadiazine on central catheter-related infections	Chlorhexidine and silver sulfadiazine catheter	Central venous	24.10%	13.30%	NA	NA
Dikon: silver-coated Foley catheters – initial cost is not the only thing to consider	Silver-coated Foley catheter	Urethral catheter	Nearly 40% of nosocomial infections are UTI. 90% of these are catheter-related		$37,023 per year	$65,725 per year

Saint: the potential clinical and economic benefits of silver alloy urinary catheters in preventing urinary tract infection	Silvery alloy	Urethral catheter	0.03	0.016	$16.78 per unit	$20.87
Research paper	*Catheter impact*					
Blot et al.: clinical and economic outcomes in critically ill Patients with nosocomial catheter-related bloodstream infections	Catheter-related bloodstream infection: 1.8% attributable to nosocomial infection from catheters. 27.8% vs. 26%					
Leone et al.: risk factors of nosocomial catheter-associated urinary tract infection in a polyvalent intensive care unit	(9.6)% who received an indwelling urinary catheter acquired a urinary tract infection on day 12 ± 7					
Samuel, Guggenbichler: prevention of catheter-related infections – the potential of a new nano-silver impregnated catheter	Contaminated catheters responsible for over 40% of all nosocomial sepsis in acute-care hospitals					

Table 8.7 Silver catheters (infection reduction) [34]

Study, Year (Reference)	Test Group, n/n	Control Group, n/n	Risk Ratio (95% CI)	Risk Ratio (95% CI)	Absolute Risk Reduction, %
Nitrofurazone					
Maki et al., 1997 (30)	8/170	14/174		0.58 (0.25-1.36)	3
Al-Habdan et al., 2003 (27)	0/50	18415		0.08 (0.00-1.33)	12
Lee et al., 2004 (32)	14/92	19/85		0.68 (0.36-1.27)	7
Silver (pre-1995)					
Lundeberg, 1986 (28)	9/51	24/51		0.38 (0.19-0.73)	29
Liedberg et al., 1990 (23)	3/30	25/60		0.24 (0.08-0.73)	32
Liedberg and Lundeberg, 1990 (24)	6/60	22/60		0.27 (0.12-0.62)	27
Liedberg and Lundeberg, 1993 (29)	8/75	23/96		0.45 (0.21-0.94)	13
Silver (post-1995)					
Maki et al., 1998 (31)	64/407	94/443		0.74 (0.56-0.99)	5
Verleyen et al., 1999A (25)	6/12	8/15		0.94 (0.45-1.96)	3
Verleyen et al., 1999B (25)	5/79	12/101		0.53 (0.20-1.45)	6
Karchmer et al., 2000 (14)	154/5398	189/5634		0.85 (0.69-1.05)	2
Thibon et al., 2000 (26)	9/90	13/109		0.84 (0.32-1.87)	0.5

Appendix II: Expert Pairwise Questionnaire

	Sum to 100		
Infection Reduction Criteria	A	B	
Reduce Infection			Cost
Reduce Infection			Compatibility
Reduce Infection			Acceptance
Reduce Infection			Environment
Cost			Compatibility
Cost			Acceptance
Cost			Environment
Compatibility			Acceptance
Compatibility			Environment
Acceptance			Environment
Reduce Infection	A	B	
Reduce Infection			Not Increase Drug Resistance
Cost	A	B	
Initial Cost			ROI (Return On Investment)
Compatibility	A	B	
Fits Existing Procedures			Regulatory Approved (OHSA / FDA)
Acceptance	A	B	
Staff			Patients
Environment	A	B	
Not Environmentaly Toxicity			Generate Little Waste

Appendix III: Expert Solutions Preference Questionnaire

Reduce Infection Rate	A	B	
RFID			Spot Cleaning
RFID			Silver Ion
RFID			Biomimicry
Spot Cleaning			Silver Ion
Spot Cleaning			Biomimicry
Silver Ion			Biomimicry
Not Increase Drug Resistance	A	B	
RFID			Spot Cleaning
RFID			Silver Ion
RFID			Biomimicry
Spot Cleaning			Silver Ion
Spot Cleaning			Biomimicry
Silver Ion			Biomimicry
Initial Cost (Capital)	A	B	
RFID			Spot Cleaning
RFID			Silver Ion
RFID			Biomimicry
Spot Cleaning			Silver Ion
Spot Cleaning			Biomimicry
Silver Ion			Biomimicry
ROI	A	B	
RFID			Spot Cleaning
RFID			Silver Ion
RFID			Biomimicry
Spot Cleaning			Silver Ion
Spot Cleaning			Biomimicry
Silver Ion			Biomimicry

Existing Procedures	A	B	
RFID			Spot Cleaning
RFID			Silver Ion
RFID			Biomimicry
Spot Cleaning			Silver Ion
Spot Cleaning			Biomimicry
Silver Ion			Biomimicry

Regulations (OHSU & FDA)	A	B	
RFID			Spot Cleaning
RFID			Silver Ion
RFID			Biomimicry
Spot Cleaning			Silver Ion
Spot Cleaning			Biomimicry
Silver Ion			Biomimicry

Staff	A	B	
RFID			Spot Cleaning
RFID			Silver Ion
RFID			Biomimicry
Spot Cleaning			Silver Ion
Spot Cleaning			Biomimicry
Silver Ion			Biomimicry

Patients	A	B	
RFID			Spot Cleaning
RFID			Silver Ion
RFID			Biomimicry
Spot Cleaning			Silver Ion
Spot Cleaning			Biomimicry
Silver Ion			Biomimicry

Environmental Toxicity	A	B	
RFID			Spot Cleaning
RFID			Silver Ion
RFID			Biomimicry
Spot Cleaning			Silver Ion
Spot Cleaning			Biomimicry
Silver Ion			Biomimicry

Waste	A	B	
RFID			Spot Cleaning
RFID			Silver Ion
RFID			Biomimicry
Spot Cleaning			Silver Ion
Spot Cleaning			Biomimicry
Silver Ion			Biomimicry

References

1. Wang, B., Kocaoglu, D. F., Daim, T. U., & Yang, J. T. (2010). A decision model for energy resource selection in China. *Energy Policy, 38*(11), 7130–7141.
2. Pollack, A. (2010). Rising threat of infections unfazed by antibiotics. *New York Times*.
3. Brown, C. (2011). Sharklet Technologies Inc, bioorganism control surfaces. From http://www.research.ufl.edu/otl/pdf/startup/Sharklet.pdf
4. National Health Statistics Group. (2011). National Health Expenditure Projections 2009–2019. From http://www.cms.gov/NationalHealthExpendData/Downloads/NHEProjections2009to2019.pdf
5. Cosgrove, S., & Carmeli, Y. (2003). The impact of antimicrobial resistance on health and economic outcomes. *Clinical Infectious Diseases, 36*(11), 1433–1437.
6. McMillan, G. (2001). Minimizing the threat of nosocomial infection. *JAAPA : Official Journal of the American Academy of Physician Assistants, 14*(1), 55–58.

7. Dey, P. K., Hariharan, S., & Clegg, B. T. (2006). Measuring the operational performance of intensive care units using the analytic hierarchy process approach. [Article]. *International Journal of Operations & Production Management, 26*(8), 849–865.
8. Saaty, T. L. (1977). A scaling method for priorities in hierarchical structures. *Journal of Mathematical Psychology, 15*(3), 234–281.
9. Saaty, T. L. (1996). *Multicriteria decision making : The analytic hierarchy process*. Pittsburgh: RWS Publ.
10. Tran, T. A., & Daim, T. (2008). A taxonomic review of methods and tools applied in technology assessment. *Technological Forecasting and Social Change, 75*(9), 1396–1405.
11. Daim, T., Yates, D., Peng, Y., & Jimenez, B. (2009). Technology assessment for clean energy technologies: The case of the Pacific Northwest. *Technology in Society, 31*(3), 232–243.
12. Kocaoglu, D. F. (1983). A participative approach to program evaluation. *IEEE Transactions on Engineering Management* (ISSN 0018-9391), *30*, 112–118.
13. Liberatore, M. J., & Nydick, R. L. (2008). The analytic hierarchy process in medical and health care decision making: A literature review. *European Journal of Operational Research, 189*(1), 194–207.
14. Dey, P. K., Hariharan, S., & Despic, O. (2008). Managing healthcare performance in analytical framework. *Benchmarking: An International Journal, 15*(4), 444–468.
15. Dey, P. K., Hariharan, S., Kumar, A., & Moseley, H. (2004). Performance measurement of intensive care services in hospitals: The case of Barbados. *International Journal of Services Technology and Management, 5*(5), 579–595.
16. Abaza, H. H., & Tawfik, B. S. (2008). *Appropriate medical technologies for developing countries: Application to cardiovascular disorders.* Paper presented at the Biomedical Engineering Conference, 2008. CIBEC 2008, Cairo International.
17. Sloane, E. B., Liberatore, M. J., Nydick, R. L., Luo, W., & Chung, Q. (2003). Using the analytic hierarchy process as a clinical engineering tool to facilitate an iterative, multidisciplinary, microeconomic health technology assessment. *Computers & Operations Research, 30*(10), 1447–1465.
18. Brent, A. C., Rogers, D. E. C., Ramabitsa-Siimane, T. S. M., & Rohwer, M. B. (2007). Application of the analytical hierarchy process to establish health care waste management systems that minimise infection risks in developing countries. *European Journal of Operational Research, 181*(1), 403–424.
19. Hummel, J., Wvan, R., Verkerke, G. J., & Rakhorst, G. (2000). Assessing medical technologies in development. *International Journal of Technology Assessment in Health Care, 16*, 4.
20. Hummel, J. M. (2001). *Supporting medical technology development with the analytic hierarchy process*. University of Groningen.
21. Townes, J., (2011). John Townes Interview (Interview with John Townes of OHSU. ed.). Expert Interviews at local medical institutes, 2011.
22. Benyus, J. M. (1997). *Biomimicry : Innovation inspired by nature*. New York: Morrow.
23. Hawken, P. (2008). *Natural capitalism: Creating the next industrial revolution*. Little, Brown and Company, Boston.
24. Sharklet Technologies. (2011). Sharklet technologies overview. From http://www.sharklet.com/wp-content/uploads/2010/02/Sharklet-Company-Overview-FEBRUARY-2011.pdf
25. Lahtela, A. (2009). *A short overview of the RFID technology in healthcare*. Fourth International Conference on Systems and Networks Communications, IEEE.
26. Wang, S. W., Chen, W. H., Ong, C. S., Liu, L., & Chuang, Y. W. (2006). *RFID application in hospitals: A case study on a demonstration RFID project in a Taiwan hospital*. Proceedings of the 39th Annual Hawaii International Conference on System Sciences (HICSS'06).

27. Yao, W., Chu, C. H., & Li, Z. (2010). *The use of RFID in healthcare: Benefits and barriers*. Paper presented at the 2010 IEEE international conference on RFID-Technology and Applications (RFID-TA). Guangzhou, China.
28. Rogers, A., Jones, E., & Oleynikov, D. (2007). Radio frequency identification (RFID) applied to surgical sponges. *Surgical Endoscopy, 21*(7), 1235–1237.
29. Do, E. (2009). *Technological interventions for hand hygiene adherence*. Available at https://wiki.cc.gatech.edu/designcomp/images/b/b0/Cf2009_303hand-hygiene.content.pdf.
30. Jain, S., Mane, S., Lopez, J., Lie, D. Y. C., Dallas, T., Dissanaike, S., et al. (2009). *A low-cost custom HF RFID system for hand washing compliance monitoring*. ASIC 2009 Conference, IEEE.
31. Brazzell, B., Yarbrough, R., Davenport, P., Dietz, G., & Tucker, B. (2011). Efficacy of an electronic hand hygiene surveillance and feedback monitoring device against healthcare associated infections. *American Journal of Infection Control, 39*(5), E172–E173.
32. Rosemberg, T. (2011). Better hand-washing through technology. *New York Times*. Retrieved from http://opinionator.blogs.nytimes.com/2011/04/25/better-hand-washing-through-technology/
33. Samuel, U., & Guggenbichler, J. P. (2004). Prevention of catheter-related infections: The potential of a new nano-silver impregnated catheter. *International Journal of Antimicrobial Agents, 23*(Supplement 1(0)), 75–78.
34. Johnson, J. R. M., Kuskowski, M. A. P., & Wilt, T. J. M. (2006). Systematic review: Antimicrobial urinary catheters to prevent catheter-associated urinary tract infection in hospitalized patients. *Annals of Internal Medicine, 144*(2), 116–126.
35. Saint, S. M., Veenstra, D. L. P., Sullivan, S. D. P., Chenoweth, C. M., & Fendrick, A. M. M. (2000). The potential clinical and economic benefits of silver alloy urinary catheters in preventing urinary tract infection. *Archives of Internal Medicine, 160*(17), 2670–2675.
36. Carling, P. C., & Bartley, J. M. (2010). Evaluating hygienic cleaning in health care settings: What you do not know can harm your patients. *American Journal of Infection Control, 38*(5), S41–S50.
37. Carling, P. C., Parry, M. F., Von Beheren, S. M., & Healthcare Environm Hyg Study, G. (2008). Identifying opportunities to enhance environmental cleaning in 23 acute care hospitals. *Infection Control and Hospital Epidemiology, 29*(1), 1–7.
38. Wilson, A. P. R., Smyth, D., Moore, G., Singleton, J., Jackson, R., Gant, V., et al. (2011). The impact of enhanced cleaning within the intensive care unit on contamination of the near-patient environment with hospital pathogens: A randomized crossover study in critical care units in two hospitals. *Critical Care Medicine, 39*(4), 651–658.
39. CDC. (2003). *Guidelines for environmental infection control in health-care facilities: Recommendations of CDC and the Healthcare Infection Control Practices Advisory Committee (HICPAC)*.
40. Siegel, J. D., Rhinehart, E., .Jackson, M., & Chiarello, L. (2006). *Management of multidrug-resistant organisms in healthcare settings, 2006*. Available at https://www.cdc.gov/mrsa/pdf/mdroGuideline2006.pdf.
41. Blot, S. I., Depuydt, P., Annemans, L., Benoit, D., Hoste, E., Waele, J. J. D., et al. (2005). Clinical and economic outcomes in critically ill patients with nosocomial catheter-related bloodstream infections. *Clinical Infectious Diseases, 41*(11), 1591–1598.
42. Dikon, A. (2006). Silver Coated Foley Catheters – Initial Cost Is Not the Only Thing To Consider. *AJIC: American Journal of Infection Control, 34*(5), E39–E40.
43. Gentry, H., & Cope, S. (2005). Using silver to reduce catheter associated urinary tract infections. *Nursing Standard, 19*(50), 51–54.

44. Leone, M., Albanèse, J., Garnier, F., Sapin, C., Barrau, K., Bimar, M.-C., et al. (2003). Risk factors of nosocomial catheter-associated urinary tract infection in a polyvalent intensive care unit. *Intensive Care Medicine, 29*(7), 1077–1080.
45. Morettia, E. W., Ofsteadb, C. L., Kristyc, R. M., & Wetzlerd, H. P. (2005). Impact of central venous catheter type and methods on catheter-related colonization and bacteraemia. *Journal of Hospital Infection, 61*, 139–145.
46. Rupp, M. E. M., Lisco, S. J. M., Lipsett, P. A. M., Perl, T. M. M., Keating, K. M., Civetta, J. M. M., et al. (2005). Effect of a second-generation venous catheter impregnated with chlorhexidine and silver sulfadiazine on central catheter–related infections. *Annals of Internal Medicine, 143*(8), 570–580.

Chapter 9
Technology Assessment: Study of User Preferences for Weight Loss Mobile Applications Both Globally and in the United States

Ahmed Bohliqa, Apisit Charoensupyanant, Daria Spatar, Jejung Ha, Selen Yilmaz, and Tugrul U. Daim

9.1 Introduction

People can be classified being overweight by using the number called body mass index (BMI). BMI correlates with the amount of body fat of people, and it can be calculated by dividing weight in kilograms with height in meter squared [1]. For adults who are classified overweight have a BMI between 25 and 29.9 and those who have BMI of 30 or greater are classified obese [1]. There are many causes leading people to become overweight and obesity in the USA: for example, (1) high-fat food intake such as fast food that contains high sugar and fat is the most organized cause, (2) the absence of physical activity for energy expenditure, and (3) lack of sleep which is associated with weight gain [2, 3]. In the present, there are many adults in the USA who are classified overweight. According to the prevalence of overweight, obesity, and extreme obesity among adults: USA trends 1960–1962 through 2009–2010 report from the National Center for Health and Statistics (NCHS), it has shown that there are 33% of the US adults who are classified overweight and the average trend has remained the same without a significant decline [4]. With the large percentage of overweight adults and the increase in number of dieters from Gallup survey by 33% from 2004 to 2010, the number of dieters could be anticipated to reach 108 million with 86 million of them are trying to lose weight by themselves. With the increase of number of dieters, the total of US weight loss market is also estimated to grow 4.5% to $65 billion in 2012 which is higher than the 2% growth from the last year [5].

A. Bohliqa
TAQNIA, Riyadh, Saudi Arabia
e-mail: abohliqa@gmail.com

A. Charoensupyanant • D. Spatar • J. Ha • S. Yilmaz • T.U. Daim (✉)
Portland State University, Portland, OR, USA
e-mail: mnojoke@gmail.com; spatar@pdx.edu; tugrul.u.daim@pdx.edu

T.U. Daim et al. (eds.), *Infrastructure and Technology Management*,
Innovation, Technology, and Knowledge Management,
https://doi.org/10.1007/978-3-319-68987-6_9

There are many risks and health problems associating with being overweight which lead to several reasons why overweight people should reduce their weights. One major reason is to increase their hearth health. Being overweight can cause greater risks for heart disease due to its side effects such as diastolic blood pressure, systolic blood pressure, high blood pressure, and cholesterol, according to the American Heart Association. The second reason is losing weight can greatly reduce prediabetes and type 2 diabetes [6, 7]. Third reason is being overweight also leads to other health risks and diseases such as stroke, hypertension, kidney disease, metabolic disorder, and some forms of cancers. Fourth reason is people want to change their appearance. Final reason is people expect to earn other life benefits from being healthy weight more than being overweight [7].

At the present, there are many solutions available that overweight people can choose from to lose their weight, for example, (1) following complete diet plans from diet providers such as Weight Watcher and Diet-to-Go, (2) controlling calorie intake and burnout by yourself, (3) proceeding surgery, (4) taking dietary pills and supplements, and (5) utilizing technological solution such as tracking devices, e.g., Nike FuelBand; playing console games, e.g., Wii Fit and PS Active; using website and communities, e.g., SparkPeople; and using mobile applications on smart devices such as phones and tablets. As the rates of mobile technology adoption and numbers of mobile applications are increasing, it is now becoming a new technological solution for overweight people [8, 9]. There are over 150 weight loss and exercise applications found on iOS and Android platforms with 10% share of weight loss applications and 34% of exercise applications, Appendix A. The number of weight loss and exercise applications eclipses other health mobile applications with more than 24 million downloads [9]. After reviewing and searching in mobile application market on both iOS and Android platforms, weight loss mobile application can be subcategorized into five types: (1) calorie tracker, (2) activity and workout tracker, (3) building habits, (4) social and motivation, and (5) building awareness. Calorie tracker is a type of weight loss mobile application that functions on tracking calories that users consume from food, while activity and workout tracker functions mainly for the tracking calories that users burn out from physical activity. Building habits is a type of weight loss mobile application that helps user to improve their habits for losing weight. Social and motivation is a type of weight loss mobile application that helps users to lose weight more effectively by talking and getting advices from other people who have successfully lost weight and get motivated. Building awareness is also another type of weight loss mobile application that helps users to be aware of high calories food, and it also suggests users a better choice. Weight loss mobile application offers many advantages over other solutions mentioned earlier:

1. Weight loss mobile application is very portable and can be downloaded and installed in smart devices which allow users to access it anywhere and anytime they need.
2. It requires no purchase or costs significantly less than other weight loss solutions, Appendix B.
3. It is easy to use due to user-friendly interface and visualization.

4. Most importantly, it is also very effective to help users lose weight since many applications deploy science-based methods, and more applications are being integrated with social components which are proved to have a significant impact on weight loss [10, 11].

In this paper, we will examine the adoption factors of weight loss mobile application to identify user preference by focusing on the first two types of weight loss application, calorie tracker and activity and workout tracker which are proved to be the most effective ways to lose weight, and they have been downloaded and used by several people. The second part of the paper presents the literature review. The third part provides the research methodology and data collection. The fourth part presents the discussion of the results affecting the adoption of weight loss mobile application. The final part discusses the conclusions with reflects of this study and future work of this paper.

9.2 Literature Review

9.2.1 Technology for a Healthy Lifestyle

The growth of mobile phones in recent years has allowed new methods for health-related applications to reach out to and assist users. Technology has the ability to promote a healthy lifestyle and enhance public health initiatives [12]. One of study looked at whether improvements were made in keeping a diet record using a mobile phone versus a more traditional paper and pencil format. Results from this study suggest that additional training in using this new technology may improve user cooperation and provide an accurate, inexpensive, easy-to-use method for diet [13]. Using technology such as mobile application to improve self-monitoring of diet intake is a natural fit for success and has been shown to improve adherence to self-monitoring. This should be encouraging to people looking to make better health-related lifestyle choices.

However, mobile applications for healthcare, especially weight loss, have some limitations such as limited function, requirement of high level of motivation, and inaccurate information and only rely on user date entry and so on [14]. In fact, these problems might come from in terms of users who have specific diseases such as insulin resistance syndrome. But while we think of weight loss mobile applications as the perspective of wellness and fitness, these kinds of mobile application could have a specific function and effectiveness.

9.2.2 The Type of Weight Loss Applications

These applications contain a large number of tools useful to the user and provide a portable and relatively easy method to enable users to perform personal health tracking and diet management. We categorized weight loss mobile applications into five types in terms of the main function and characteristic:

- Calorie trackers
- Activity and workout trackers
- Building habits
- Social and motivation
- Building awareness

In each category of mobile applications, we selected the representative application in terms of the number of download in app market to look into the features [15].

My Fitness Pal [calorie trackers] has largest food database in calorie counter – over 2,000,000 foods and growing daily. It provides easy and fast entry to remember the user's favorite food. User can add multiple foods at once. User can add friends and easily track and support each other's progress. It has functions to create user's own customized foods and exercises. User can track all major nutrients and progress reports with customized goal that is based on own diet profile.

Fitness Buddy [activity and workout trackers] provides various workouts to satisfy user's goal. User can choose workouts that are suit for needs. This app has over 1000 unique exercises with detailed pictures and descriptions to make exercise easily. It can track user's fitness progress – easily checking how much user lost weight in each part of body.

Habits Pro [building habits] is a life-changing app which is based on the scientifically proven principle. It takes a continuous chain of 21 days for user to create a new habit or replace an existing habit with a new one. User starts by adding all the habits that is needed to acquire. The app has also a function to create a calendar to check the habit to follow.

Nexercise [social and motivation] provides motivation for exercise. The experience points that are given are used to level up user's score. User can choose the various activities including aerobics, biking, running, boxing, yoga, or rock climbing. This app has a function to do self-reporting and reward system. If every time user works out for at least 2 min and submit the results, user is able to be given the various free coupons based on location. User also receives points for every workout.

Fooducate [building awareness] shows the information for healthy food in app's extensive database over 200,000 unique products and growing daily. User can use mobile's camera to effortlessly scan UPC barcode. It also provides scientific algorithms grade each food with simple, concise explanations. In particular, the grading system is developed by scientists, dietitians, and concerned parents for each food.

In this report, we have a goal to give guidelines in developing and upgrading mobile for weight loss mobile applications in terms of user's perspective.

9.2.3 Model

In order to build our model, we used technology acceptance model (TAM) created by Fred Davis as base [16]. According to TAM, one's intention to adopt an information system is determined by two variables: perceived ease of use and perceived usefulness [16]. Perceived ease of use is defined as the degree of effort, which a

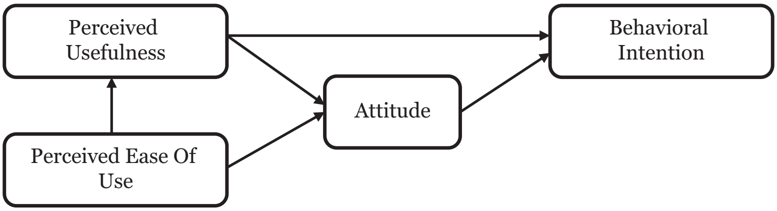


Fig. 9.1 Technology acceptance model

person believes to put in order to use a particular system. Davis indicates that effort is a finite resource that a person may allocate to the various activities for which he or she is responsible, so people would prefer a system free of effort [16]. Perceived usefulness is defined as degree of performance improvement that a person believes to achieve by using a particular system [16]. According to Davis, a system high in perceived usefulness, in turn, is one for which a user believes in the existence of a positive use-performance relationship [16].

In TAM, also, all other external variables are mediated by perceived usefulness and perceived ease of use [16, 17] (Fig 9.1).

Mobile application users would prefer an application that meets their desires and needs. Therefore, to develop the most preferable mobile application requires a research on users' needs, requirements, and preferences. For this purpose, we adopted the Analytic Hierarchy Process (AHP), developed at the Wharton School of Business by Thomas Saaty, allowing decision-makers to model a complex problem in a hierarchical structure showing the relationships of the goal, objectives (criteria), sub-objectives, and alternative [18]. AHP determines individual weights of multiple attributes of a main goal so that they can be compared in a simple way. Then, it simplifies decision-making in the selection process [19]. According to Basoglu and Daim, there are a lot of AHP applications in the healthcare field; for example, AHP is used to develop a human resource planning model for hospital laboratory personnel; also it was used as an approach to select a magnetic resonance imaging vendor by using the criteria like price, service, and technology [19].

The structure of our AHP model contains the main goal, which is "user preferences," at the top level and the main criteria that are easy of use, usefulness, and external factors at the second level. At the bottom level, we have the sub-criteria, which will evaluate the main criteria (Fig. 9.2).

9.2.4 Criteria Selection and Description

After researching several studies about technology adoption factors in online services and healthcare industry, we decided our sub-criteria. Technology adoption factors in online services and healthcare applications are widely explored in the literature. For example, Basoglu et al. [17] looked at product design parameters in nutrition and dietetics as well as endocrinology and metabolism deficiencies, applying technology

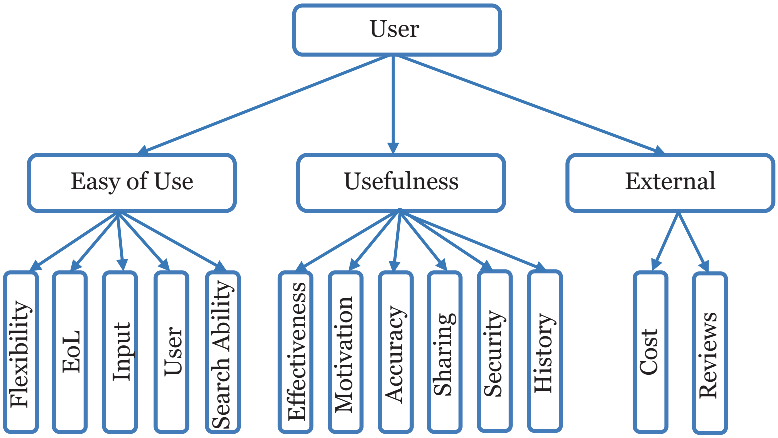


Fig. 9.2 AHP model

acceptance model as a base. In our study, flexibility impacting ease of use and accuracy impacting usefulness were chosen according to their study. Also, in "Determining Patient Preferences for Remote Monitoring" [19], authors look for patient needs for an application in remote health monitoring. Input quantity and type, motivation, security, and cost were selected based on their health information service adoption taxonomy [19]. Davis developed and validates new scales for perceived usefulness and perceived ease of use, in the paper "Perceived usefulness, perceived ease of use, and user acceptance of information technology" [16]. We selected ease of learning and effectiveness according to Davis and Schoeffel's findings [20]; we selected ease of learning and effectiveness impacting, respectively, perceived ease of use and perceived usefulness. Remaining sub-criteria such as sharing, reviews, and user interface were selected according to HIMSS (Healthcare Information and Management System Society)'s report evaluating the usability of medical applications [21].

Explanation of the Criteria

- *Ease of use*: application is easy to learn, the user interface is understandable, search and input are convenient:
  - *Flexibility* means that you can configure the application according to your preferences, e.g., set language, and choose between metric and English units and set targets according to your goals.
  - *Ease of learning* means that you don't have to put much effort while starting to use new application; it also includes availability of manual, help button, hints, etc.
  - *Input quantity and type* means the amount and type of data you are required to input every time you use the application, e.g., food choices and amount, daily activities, etc.
  - *User interface* means that the application is convenient to use; graphs, bottoms, and input fields are appropriate; and the overall feel of the application is satisfactory.

  – *Search ability* means that the application has a database suitable for your needs, for example, contains many products and brands and allows to choose a predefined exercise.

- *Usefulness* means that the application is helpful for your purposes, e.g., it motivates you, makes you eat less/better, makes you exercise more, etc.:

  – *Effectiveness* means that the app is assisting you to eat wisely, to improve your eating habits, to exercise more, and to get results.
  – *Motivation* means that the application encourages you stick to your weight loss plan, e.g., shows motivation pictures, displays reminders, allows you to compare results with friends, etc.
  – *Accuracy* means that the application shows reliable data, e.g., calorie information of food and exercise and correct calculations.
  – *Sharing* means the application allows you to share your activities and weight loss progress with other users via social networks, for example, through Facebook or Twitter.
  – *Security* means that your data is protected and won't be shared with others without your permission.
  – *History* means that the application keeps records to show your progress.

- *External factors* are cost and reviews:

  – *Cost* that application is free to use or required to purchase before installing into your mobile device.
  – *Review* means that the rating and review of application by other users on the app market influence your decision to use weight loss application.

9.3 Analysis

In the hierarchical decision model of our study, the main criteria are compared in pairs; then, contributions to user preferences are calculated. Similarly, all the sub-criteria are compared in pairs and their contribution to the upper level are determined.

To evaluate the criteria, we used pairwise comparison method, which is an expert judgment estimation technique that uses a relative size comparison of multiple entities. For pairwise comparison, experts distribute a total of 100 points between the two elements of each pair to indicate our judgment of the ratio between the relative contributions of each element of the pair to the upper level.

In order to collect data, three surveys were created in a Qualtrics survey tool:

1. Comparing high-level categories (usefulness, ease of use, and external factors) and two external factors (cost and users' reviews)
2. Comparing usefulness sub-criteria
3. Comparing ease of use sub-criteria

The surveys were sent to people who took part in Healthy U Wellness Challenge organized by Portland State University's Recreation Center (PSU REC) in Winter

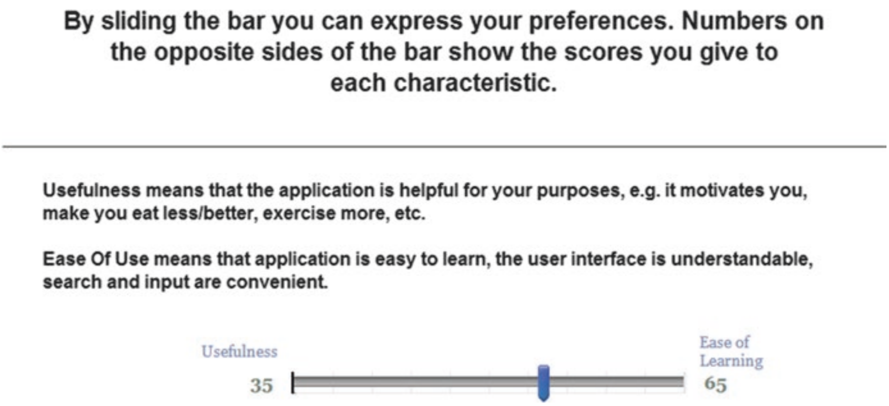


Fig. 9.3 Example of the survey question

2012, as well as members of Russian livejournal community ru_healthlife, and friends and family members (Fig. 9.3).

9.3.1 Respondents Profiles Analysis

Overall more than 200 responses were received. These responses represent 133 unique individuals[1] from 15 countries around the world: Australia, Belarus, Canada, Estonia, Germany, Israel, Latvia, Nepal, Netherlands, Russian Federation (27.8% of total respondents), Spain, Thailand, Turkey, Ukraine, and the USA (41.4% of total respondents).

The results show that the most adopted weight loss mobile applications (WLMA) are those of "calorie trackers" (51% of total respondents) and "activities and workout trackers" (33% of total respondents) types. Appendix C shows the usage of WLMA based on their types. It also shows that there is only an 18% difference between the number of those who used WLMA and those who never did.

- Global respondents' profiles

Surveys also show that there are major similar personal characteristics between those who used a WLMA before and those who did not. More than half of the respondents actually have a body mass index (BMI) between 18.5 and 24.9, which is considered normal weight [1]. The other 43% are overweight (21% of total respondents), obese (15% of total respondents), and underweight (7% of total respondents). This could be interpreted as that the majority of weight loss apps users use them to maintain their weight rather than lose it. Other major similar characteristics were group of age and gender. The majority were females (80% of total respondents) and between ages of 25 and 34 years old (59% of total respondents).

[1] Certain individuals filled out all three surveys, and therefore their responses were counted once in the unique individual count.

Males were only 20% of the total respondents even though our surveys were not targeted toward a specific gender type. There are different hypotheses to explain this result. It could mean that females are more tech-savvy than males when it comes to weight loss and maintaining their weights. This is because the majority of our surveyed audience used a technology-based platform. PSU REC's challenge used an online points tracker, and the Russian health forum is also online. More details about respondents' answers are shown in graphs in Appendix C.

- Global user and nonuser profiles based on WLMA usage

We also examined the responses on a deeper level based on whether they used a WLMA before or not. However, since females were the overwhelming majority of each segment, we excluded males from the following data to be able to give even more accurate analysis. Appendix D shows profiles for each female segment: those who used a WLMA and those who did not. It shows that the previously mentioned major respondents' characteristics still hold in each segment. However, the second largest representation for those who did use a WLMA was obese between the ages of 35 and 44 years, while for those who did not use them, it was also between 35 and 44 years old but overweight instead of obese. This says that 70% of the 17% overweight females of the overall respondents did not use WLMA, whereas 58% of the obese females of the overall respondents used WLMA. This could be mean that WLMA are being used as a last resort to help in losing weight, and users wait until they reach obesity level to start using them.

- US respondents' profiles

We also examined the data in regard to geographic region of respondents, namely, the USA. Interesting enough the major personal characteristics are similar to the global ones with an expected increase in the obesity segment. According to our literature review, obesity is an increasing problem in the USA [4]. Similarly, the difference in percentages between those who use WLMA in the USA and globally is small, yet there is a more diverse distribution in ages between our US surveyees and global ones, shown in Appendix E. More than half of the respondents from the USA have a body mass index (BMI) between 18.5 and 24.9, which is considered normal weight, and are females between the ages of 25 and 34 years old.

- US user and nonuser profiles based on WLMA usage

We did a similar analysis in this section to the one we did for the global WLMA user and nonuser profiles. The only were noticeable differences between our US respondents and global ones are in the exact percentages. However, the major trends are still the same. The majority of respondents are normal-weight females between the ages of 25 and 34 years old.

The second representations of personal characteristics in the US user and nonuser profiles are also very similar to the global ones, shown in Appendix F. Table 9.1 summarizes the highlights of exact percentages differences between US WLMA user and nonuser profiles and global ones. These differences show that our US respondents are older and have higher BMI than global ones.

Table 9.1 Highlighted differences between US WLMA user and nonuser profiles and global ones

	Global BMI	US BMI	Global age	US age
User	17% obese 7% under weight	24% obese 0% under weight	52% 25–34 years old 24% 35–44 years old 7% 45–54 years old	33% 25–34 years old 33% 35–44 years old 14% 45–54 years old
Nonuser	21% under weight 9% obese 62% normal weight	26% overweight 15% obese 56% normal weight	60% 25–34 years old 5% 45–54 years old 33% 35–44 years old	48% 25–34 years old 11% 45–54 years old 19% 35–44 years old

9.3.2 Calculation of Factors' Weights

PCM software was used to calculate the weight of each criterion. Responses with inconsistency levels higher than 0.1 were removed from the analysis [18]. In order to calculate normalized weights of subfactors, their values were multiplied with the weight of a major criterion.

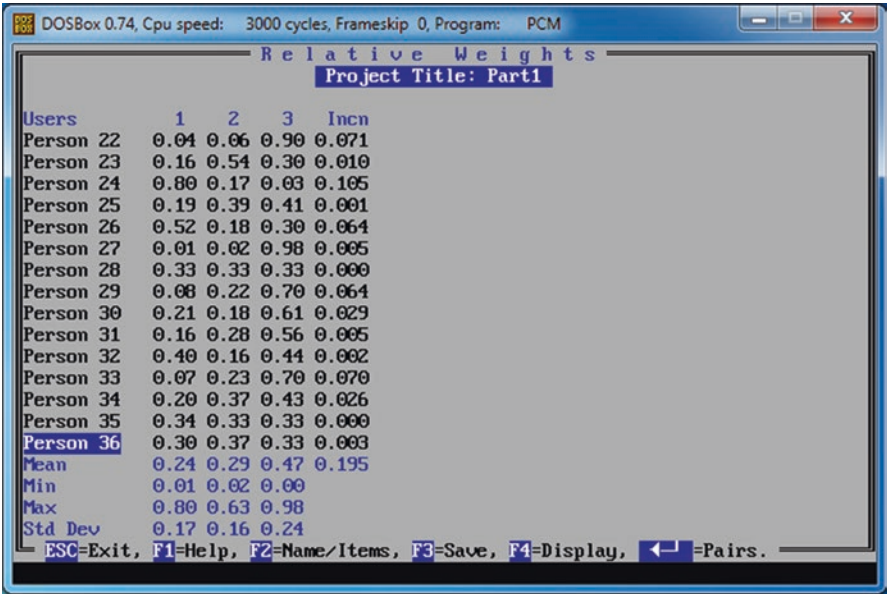
Part 1 Major Criteria and External Factors Sub-criteria
Out from 90 responses, only 42 persons used weight loss software.

1. Usefulness
2. Ease of use
3. External factors (Fig 9.4)

Disagreement among respondents is 0.195. This can be explained by the fact that people from different countries, age, and occupation took part in the survey.

External factors criterion has the biggest loading, 47%, while ease of use and usefulness practically equally share remaining 53% having 29% and 24%, respectively. The possible reason for such weight distribution is that cost and reviews affect initial decision to use the WLMA. If a potential user is neither satisfied with the price nor convinced by the reviews, then he or she most likely will not install an app. Ease of use and usefulness criteria affect the decision whether to continue using the application or not.

External Factors (Table 9.2)
On average both cost and reviews got practically equal values. Interestingly, standard deviation of responses is 0.29 which means that respondents had very different opinions, i.e., for some people, cost is much more important while for others reviews play the major role. This outcome can be explained by the fact that people from different countries, backgrounds, and occupation took part in the survey; thus, their perceptions differed as well.



Users	1	2	3	Incn
Person 22	0.04	0.06	0.90	0.071
Person 23	0.16	0.54	0.30	0.010
Person 24	0.80	0.17	0.03	0.105
Person 25	0.19	0.39	0.41	0.001
Person 26	0.52	0.18	0.30	0.064
Person 27	0.01	0.02	0.98	0.005
Person 28	0.33	0.33	0.33	0.000
Person 29	0.08	0.22	0.70	0.064
Person 30	0.21	0.18	0.61	0.029
Person 31	0.16	0.28	0.56	0.005
Person 32	0.40	0.16	0.44	0.002
Person 33	0.07	0.23	0.70	0.070
Person 34	0.20	0.37	0.43	0.026
Person 35	0.34	0.33	0.33	0.000
Person 36	0.30	0.37	0.33	0.003
Mean	0.24	0.29	0.47	0.195
Min	0.01	0.02	0.00	
Max	0.80	0.63	0.98	
Std Dev	0.17	0.16	0.24	

Fig. 9.4 Major criteria pairwise comparison results

Table 9.2 External factor weights

External factors	Sub-criteria	Results	Name
0.47	0.49	0.23	Cost
0.47	0.51	0.24	Reviews

Part 2 Ease of Use Sub-criteria

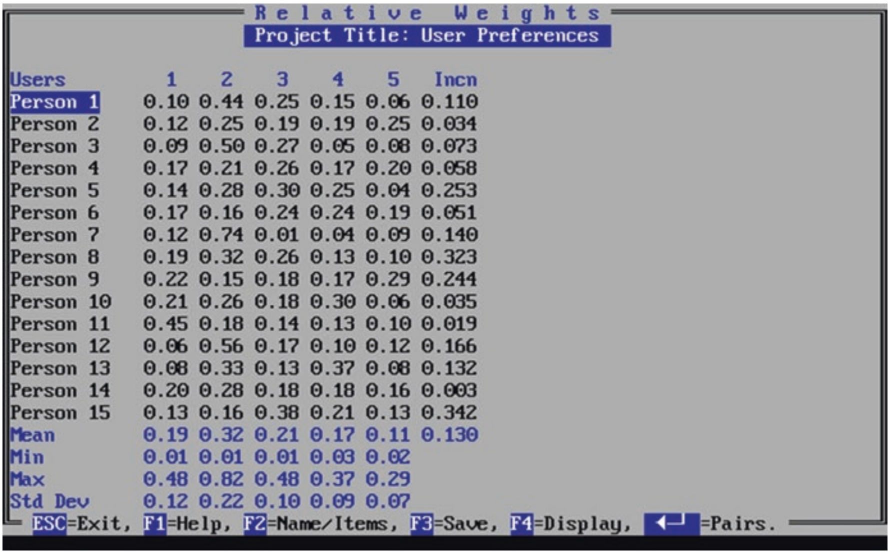
The number of people who took part in the survey was 60, 60% of whom used weight loss software.

Initial Results

1. Flexibility
2. Ease of learning
3. User interface
4. Input
5. Search (Fig. 9.5)

From 23 responses, 11 were inconsistent and were removed (Fig. 9.6 and Table 9.3).

Ease of learning was found to be the most important factor under ease of use criterion, having 32% in this category. After a person has installed an application, he or she starts using it. If a user faces difficulties during the initial phase and doesn't understand how to use the app, it can result in a decision to stop using it or delete it.

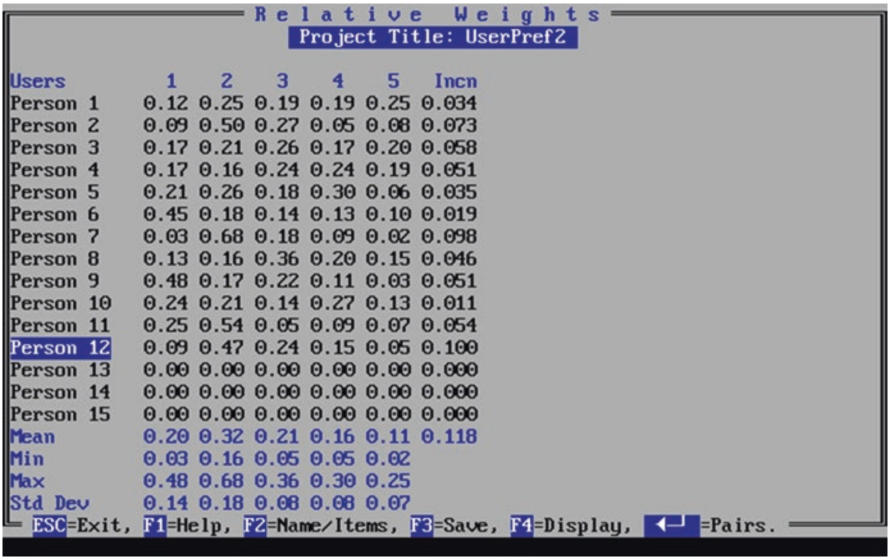


Relative Weights
Project Title: User Preferences

Users	1	2	3	4	5	Incn
Person 1	0.10	0.44	0.25	0.15	0.06	0.110
Person 2	0.12	0.25	0.19	0.19	0.25	0.034
Person 3	0.09	0.50	0.27	0.05	0.08	0.073
Person 4	0.17	0.21	0.26	0.17	0.20	0.058
Person 5	0.14	0.28	0.30	0.25	0.04	0.253
Person 6	0.17	0.16	0.24	0.24	0.19	0.051
Person 7	0.12	0.74	0.01	0.04	0.09	0.140
Person 8	0.19	0.32	0.26	0.13	0.10	0.323
Person 9	0.22	0.15	0.18	0.17	0.29	0.244
Person 10	0.21	0.26	0.18	0.30	0.06	0.035
Person 11	0.45	0.18	0.14	0.13	0.10	0.019
Person 12	0.06	0.56	0.17	0.10	0.12	0.166
Person 13	0.08	0.33	0.13	0.37	0.08	0.132
Person 14	0.20	0.28	0.18	0.18	0.16	0.003
Person 15	0.13	0.16	0.38	0.21	0.13	0.342
Mean	0.19	0.32	0.21	0.17	0.11	0.130
Min	0.01	0.01	0.01	0.03	0.02	
Max	0.48	0.82	0.48	0.37	0.29	
Std Dev	0.12	0.22	0.10	0.09	0.07	

ESC=Exit, F1=Help, F2=Name/Items, F3=Save, F4=Display, ↵=Pairs.

Fig. 9.5 Ease of use sub-criteria pairwise comparison results



Relative Weights
Project Title: UserPref2

Users	1	2	3	4	5	Incn
Person 1	0.12	0.25	0.19	0.19	0.25	0.034
Person 2	0.09	0.50	0.27	0.05	0.08	0.073
Person 3	0.17	0.21	0.26	0.17	0.20	0.058
Person 4	0.17	0.16	0.24	0.24	0.19	0.051
Person 5	0.21	0.26	0.18	0.30	0.06	0.035
Person 6	0.45	0.18	0.14	0.13	0.10	0.019
Person 7	0.03	0.68	0.18	0.09	0.02	0.098
Person 8	0.13	0.16	0.36	0.20	0.15	0.046
Person 9	0.48	0.17	0.22	0.11	0.03	0.051
Person 10	0.24	0.21	0.14	0.27	0.13	0.011
Person 11	0.25	0.54	0.05	0.09	0.07	0.054
Person 12	0.09	0.47	0.24	0.15	0.05	0.100
Person 13	0.00	0.00	0.00	0.00	0.00	0.000
Person 14	0.00	0.00	0.00	0.00	0.00	0.000
Person 15	0.00	0.00	0.00	0.00	0.00	0.000
Mean	0.20	0.32	0.21	0.16	0.11	0.118
Min	0.03	0.16	0.05	0.05	0.02	
Max	0.48	0.68	0.36	0.30	0.25	
Std Dev	0.14	0.18	0.08	0.08	0.07	

ESC=Exit, F1=Help, F2=Name/Items, F3=Save, F4=Display, ↵=Pairs.

Fig. 9.6 Ease of use sub-criteria results after removing inconsistent results

If acquaintance with an app went well, such characteristics as flexibility (20%) and user interface (21%) come into play as a user tries to customize an application and form the attitude toward the interface. And finally a person starts to use an app's functionality, e.g., input meals every day and track activity.

Table 9.3 Ease of use sub-criteria weights

Ease of use	Sub-criteria	Results	Name
0.29	0.20	0.06	Flexibility
0.29	0.32	0.09	Ease of learning
0.29	0.21	0.06	User interface
0.29	0.16	0.05	Input
0.29	0.11	0.03	Search

Part 3 Usefulness Sub-criteria

The number of people who took part in the survey was 55, 60% of whom used weight loss software.

Initial Results

1. Effectiveness
2. Motivation
3. Accuracy
4. Sharing
5. Security
6. History (Fig. 9.7)

After taking out inconsistent responses, nine comparisons were left (Fig. 9.8 and Table 9.4).

The most important factor is sharing (37% in a category). Studies [6, 22] prove that social support is of great benefit during weight loss process. Motivation (18%) is the second important factor. Weight loss apps help users to stay on track, as they provide motivational pictures, quotes, and other people success stories. Effectiveness (13%), security (13%), accuracy (11%), and history (9%) hold the third place. Most respondents do not see weight loss apps as a tool that directly affects their results. Also according to our study, people are not concerned about security issues, e.g., leakage of their data to public access.

Overall results are presented in a chart below (Figs. 9.9 and 9.10).

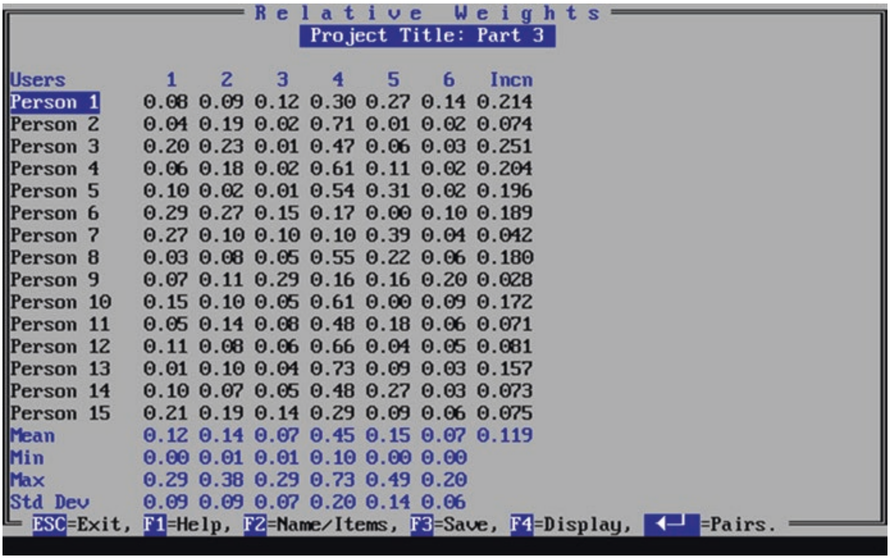
Those who haven't used any weight loss mobile application were asked about the reason.

The following answers were given (Fig. 9.11):

The most common reason is a doubt that an app is helpful. Also people who feel that they do not need to lose weight are not interested in such type of applications. Here there is an opportunity for marketers to attract new users by convincing them in importance of these apps for maintaining healthy weight.

If users have reasons different from proposed, they were asked to input them. Below is a list of the answers:

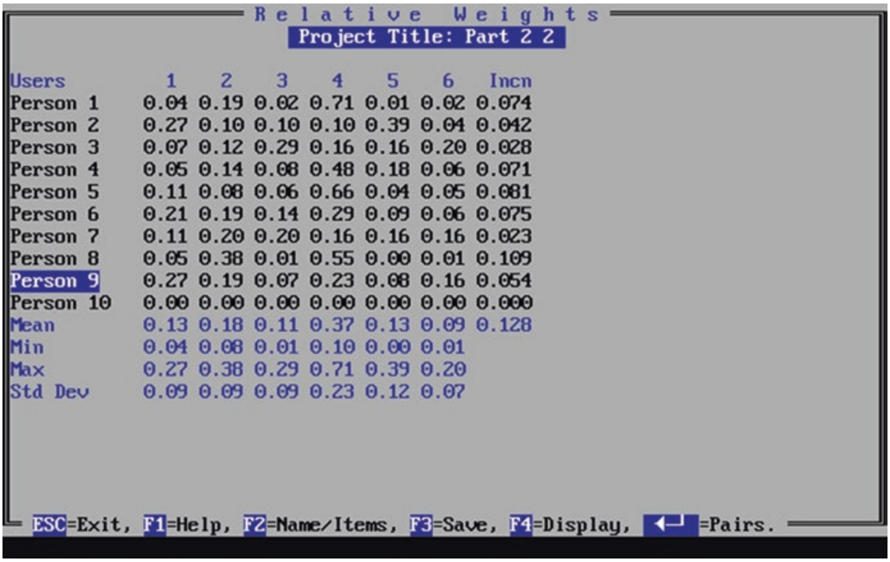
- My smartphone probably doesn't provide this app or at least I don't know they're providing it.
- I'm currently using another mobile application – Gym Book on android.
- Applications are not applicable to my trainings.


Relative Weights
Project Title: Part 3

Users	1	2	3	4	5	6	Incn
Person 1	0.08	0.09	0.12	0.30	0.27	0.14	0.214
Person 2	0.04	0.19	0.02	0.71	0.01	0.02	0.074
Person 3	0.20	0.23	0.01	0.47	0.06	0.03	0.251
Person 4	0.06	0.18	0.02	0.61	0.11	0.02	0.204
Person 5	0.10	0.02	0.01	0.54	0.31	0.02	0.196
Person 6	0.29	0.27	0.15	0.17	0.00	0.10	0.189
Person 7	0.27	0.10	0.10	0.10	0.39	0.04	0.042
Person 8	0.03	0.08	0.05	0.55	0.22	0.06	0.180
Person 9	0.07	0.11	0.29	0.16	0.16	0.20	0.028
Person 10	0.15	0.10	0.05	0.61	0.00	0.09	0.172
Person 11	0.05	0.14	0.08	0.48	0.18	0.06	0.071
Person 12	0.11	0.08	0.06	0.66	0.04	0.05	0.081
Person 13	0.01	0.10	0.04	0.73	0.09	0.03	0.157
Person 14	0.10	0.07	0.05	0.48	0.27	0.03	0.073
Person 15	0.21	0.19	0.14	0.29	0.09	0.06	0.075
Mean	0.12	0.14	0.07	0.45	0.15	0.07	0.119
Min	0.00	0.01	0.01	0.10	0.00	0.00	
Max	0.29	0.38	0.29	0.73	0.49	0.20	
Std Dev	0.09	0.09	0.07	0.20	0.14	0.06	

ESC=Exit, F1=Help, F2=Name/Items, F3=Save, F4=Display, ←┘ =Pairs.

Fig. 9.7 Usefulness sub-criteria pairwise comparison results


Relative Weights
Project Title: Part 2 2

Users	1	2	3	4	5	6	Incn
Person 1	0.04	0.19	0.02	0.71	0.01	0.02	0.074
Person 2	0.27	0.10	0.10	0.10	0.39	0.04	0.042
Person 3	0.07	0.12	0.29	0.16	0.16	0.20	0.028
Person 4	0.05	0.14	0.08	0.48	0.18	0.06	0.071
Person 5	0.11	0.08	0.06	0.66	0.04	0.05	0.081
Person 6	0.21	0.19	0.14	0.29	0.09	0.06	0.075
Person 7	0.11	0.20	0.20	0.16	0.16	0.16	0.023
Person 8	0.05	0.38	0.01	0.55	0.00	0.01	0.109
Person 9	0.27	0.19	0.07	0.23	0.08	0.16	0.054
Person 10	0.00	0.00	0.00	0.00	0.00	0.00	0.000
Mean	0.13	0.18	0.11	0.37	0.13	0.09	0.128
Min	0.04	0.08	0.01	0.10	0.00	0.01	
Max	0.27	0.38	0.29	0.71	0.39	0.20	
Std Dev	0.09	0.09	0.09	0.23	0.12	0.07	

ESC=Exit, F1=Help, F2=Name/Items, F3=Save, F4=Display, ←┘ =Pairs.

Fig. 9.8 Usefulness sub-criteria pairwise comparison consistent results

Table 9.4 Usefulness sub-criteria weights

Ease of use	Sub-criteria	Results	Name
0.24	0.13	0.03	Effectiveness
0.24	0.18	0.04	Motivation
0.24	0.11	0.03	Accuracy
0.24	0.37	0.09	Sharing
0.24	0.13	0.03	Security
0.24	0.09	0.02	History

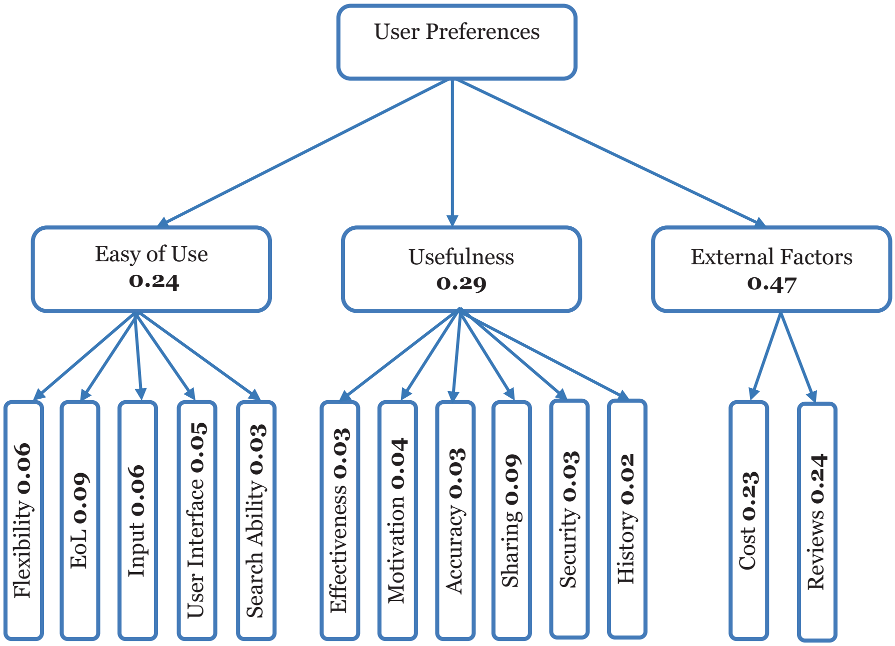


Fig. 9.9 AHP model with factor weights

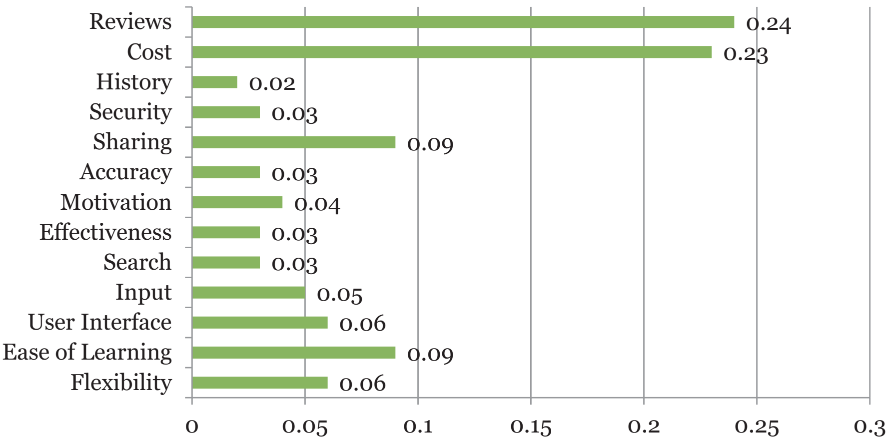


Fig. 9.10 Factor weights

- It takes a bit of time to enter stuff into the phone.
- I haven't really thought to download one. I probably would not use it.
- Ironcare [I don't care], and I am lazy.
- Another application only used to calculate calories for my reference.
- I used calorie tracker on the website and "Runkeeper" mobile app and also their social network on the website to choose and track activities.
- I successfully control my weight.

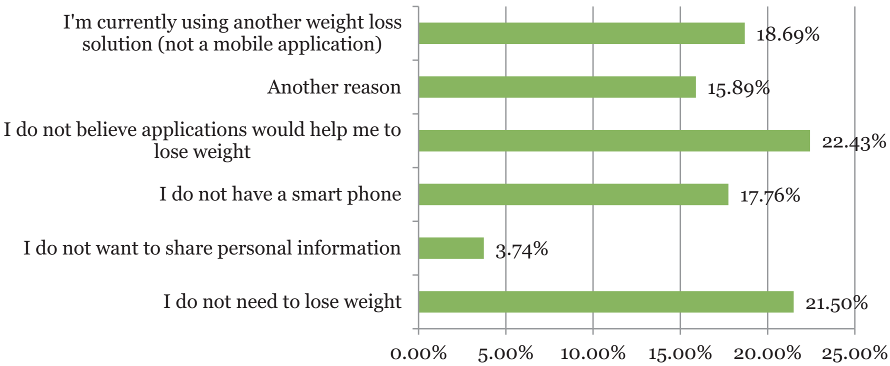


Fig. 9.11 Reasons of not using WLMA

Table 9.5 US responses

Part	Number of responses	Number of consistent responses
Part 1	12	12
Part 2	8	6
Part 3	6	2

- I can control this process by myself.
- Haven't had an interest in using one yet.
- I haven't found an app that meets my needs.
- I do not know about these apps.
- I don't know much about such applications. If someone taught me how to use a free application that would be helpful for me to lose some weight, I would use it. I also want one that calculates sugar and carbohydrate monitoring.
- Want a *free* app and I haven't made time to find one and set it up.

Some of them indicate that there is a lack of awareness about weight loss mobile application among potential users.

- Analysis of US responses (Table 9.5)

The same calculations as for the previous analysis were made. The results are presented in a chart below (Figs. 9.12 and 9.13).

As opposed to the previous analysis, US-only respondents gave nearly equal values to three main criteria: ease of use, usefulness and external factors, 32%, 33%, and 35% accordingly. But distribution in groups is similar:

- Under usefulness criterion, the most important factor is flexibility, 24%, and then ease of learning and user interface, both 21%; input quantity and type has 19%, and the least important is search capability, 15%.
- Under ease of use criterion, sharing has the biggest value as well, 20%; although the difference with the second place is not that big, only 2% as accuracy and his-

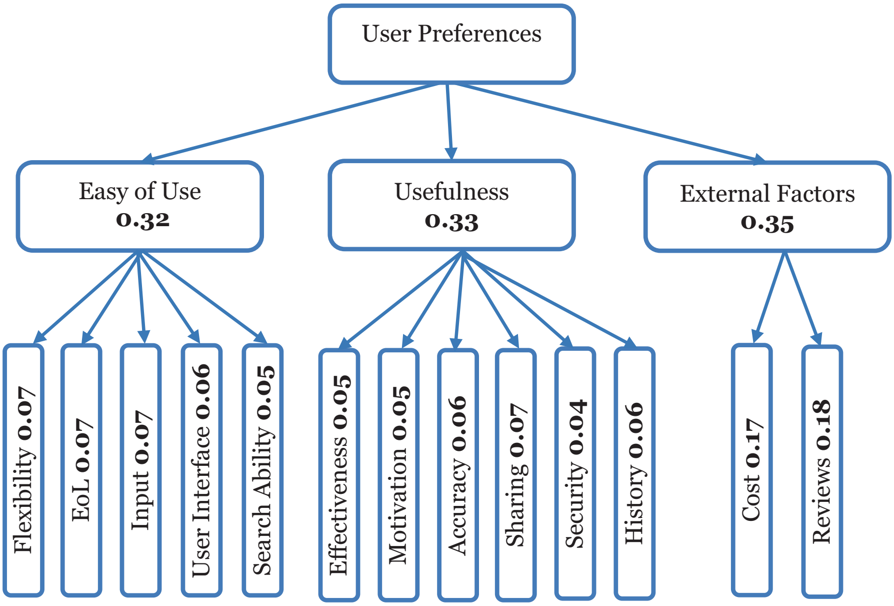


Fig. 9.12 AHP model with weights for US responses

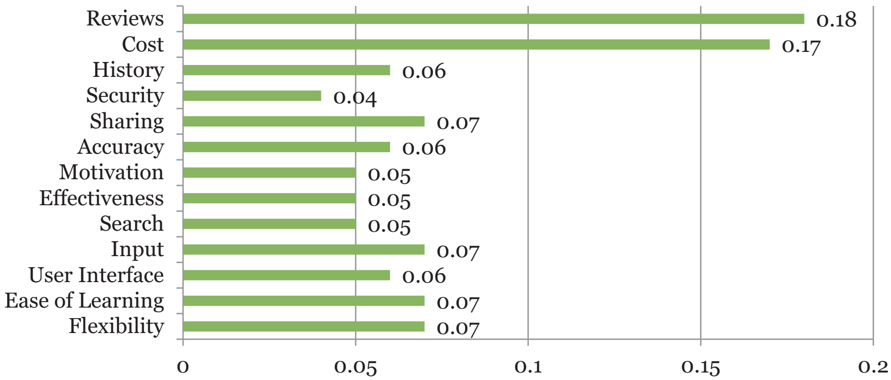


Fig. 9.13 US responses factors weights

tory have both 18%, effectiveness has 17%, and motivation, 15%; the least important factor in this category is security, 12%.

- In the previous analysis, reviews and cost share nearly equal values, 49% and 51% respectively.

9.4 Conclusion

As the advance in mobile technology moves rapidly, the rate of mobile usage and mobile application adoptions are increasing significantly. The adoption of weight loss mobile applications is related to user acceptance which relies on user preference. This study adopted technology acceptance model (TAM) and modified the model with factors that related to the adoption of weight loss mobile application by users in order to create the AHP model that is suitable for this research. The surveys were developed and conducted to collect the data from several sources with the total of more than 200 responses, 133 respondents from 15 different countries. In order to calculate the local weights of the main criteria and the sub-criteria, PCM software was used, and the global weights were identified.

The results show that there are 41% of respondents who have used weight loss mobile applications with the majority of females and 59% of respondents who never use the applications. The types of weight loss mobile application that respondents have used most are calorie tracker and activity and workout tracker as we expected. Respondents who have used weight loss mobile applications have the average age of 24–35-year-olds with 63% of normal-weight people, 13% of overweight people, and 17% of obese people. This shows that people use weight loss mobile applications to maintain their weight rather than loose it. The result shows that price and review in external factor criteria have the most influence effecting user's adoption followed by ease of use and usefulness, respectively. Price and review have practically the same importance since they both have very similar weight values. The possible explanation is that users have a high tendency to adopt the applications if the price is low or free and they tend to avoid the applications that require high purchase. User's decision of adoption also relies mainly on the review according to the result. Review becomes a trend that most users always look first before making decision to download mobile applications. Sharing and ease of learning are the second important criteria that affect user's adoption. The possible explanation is that users prefer to have weight loss mobile applications with integrated sharing function because they would like to share their progress via social networks or the same applications with other people who are also trying to lose weights. Users also prefer weight loss applications that are easy to learn with minimal effort to understand the applications. User interface and flexibility are also major factors that affect user's adoption and long-term using of the applications. Interestingly, the result also shows that most users use weight loss applications for maintaining their weight rather than losing weight. This finding can be justified by the reason that most of the respondents are females with normal weight.

The result of this study also revealed the reasons that negatively affect user's adoption of weight loss mobile application by analyzing the group of respondents who refuse and never used weight loss mobile applications. From the analysis of the result, the possible reasons can be explained as follows. The major reason is most people do not believe the weight loss mobile applications would help them lose weight. The second reason is they prefer not to lose weight since they are normal weight. The third reason is some people find that the weight loss mobile applications are not suitable for their preference and they do not provide the desired features which result in preferring self-weight losing and using other solutions. The fourth reason is there are some people who do not own smart devices which makes it incompatible to install the applications. The final reason is the lack of user's awareness of weight loss mobile applications results in lower user's adoption.

The results of this study give the better insights of user preference to assist mobile application developers to better develop weight loss mobile applications according to user preferences. It is clear that sharing and ease of learning play major roles and application developers need to pay attention. Developers should consider integrating sharing function in the weight loss mobile application since many users utilize social networks and weight loss applications to share their activities and progress to other people. This finding can be supported by the fact that social component indeed helps people to lose weight more effectively and it is also one of the criteria that good weight loss mobile application should be integrated with this component. Developers also need to emphasize on developing weight loss mobile applications that are easy to learn and use by improving user interface and flexibility. Moreover, these results show that cost and review play the most important roles and they are also a barrier for users to adopt the weight loss applications. This finding can assist weight loss mobile application markets to pay special attention on setting the price point according to the user preferences. Indeed, users prefer to use low price and free applications rather than high purchase-required applications. Markets also need to establish an action to increase user's awareness of weight loss applications since the finding shows that the lack of awareness negatively affects the user adoption. Review from other users also needs to be considered since users tend to adopt weight loss applications that have excellent reviews and high ratings if the applications function according to their preferences. Finally, the surveys' analysis identified the target customers of weight loss mobile applications to be 25–34-year-old females of normal weight. It also identified "Calories trackers and Activities and Workout trackers" as the most adopted types of weight loss mobile applications.

9.5 Limitation and Future Research

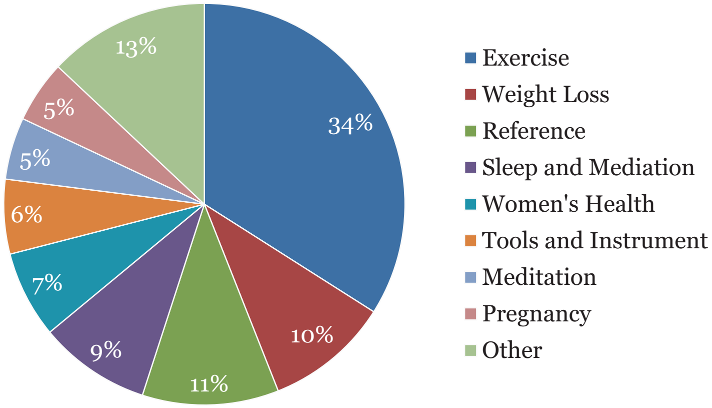
PCM software shows that there were number of respondents who provided responses with high inconsistent. This could be caused by such a reason that some respondents missed understand some of the questions in the surveys. Redesigning the surveys with clear-to-understand questions could potentially solve this problem and could result in achieving higher numbers of data and providing better and more accurate results.

Various data collected from different BMI, genders, and countries in the surveys led to diverse and inconsistent results. Consideration of conducting the same study with specific groups of study by BMI, gender, and country could provide more accurate results and better insights for each specific group.

With the majority of respondents on normal-weight females over males and the results of this study revealed that most of the males were not concerned about their weight as much as females. Conducting new surveys targeting male specifically to test the new hypothesis whether or not males were not actually concerned about their weight is also considered to be interesting for the future work.

Appendices

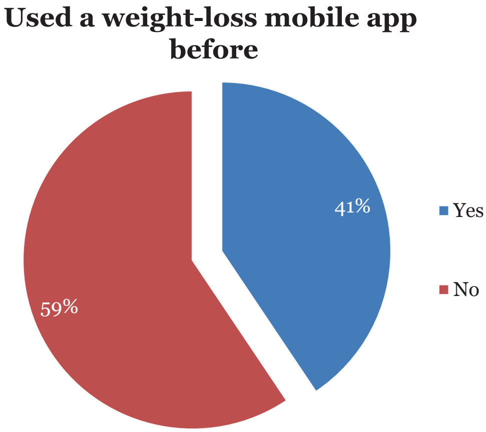
Appendix A: Percentage of Health Mobile Applications by Category: iOS and Android

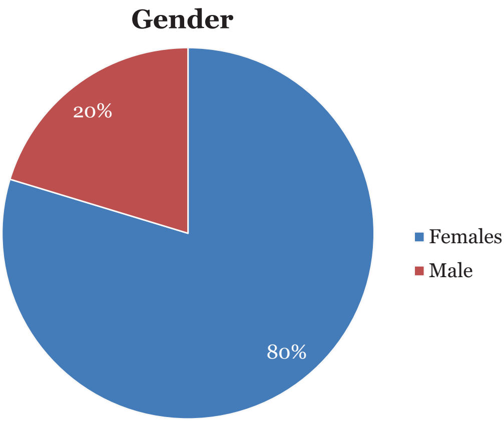


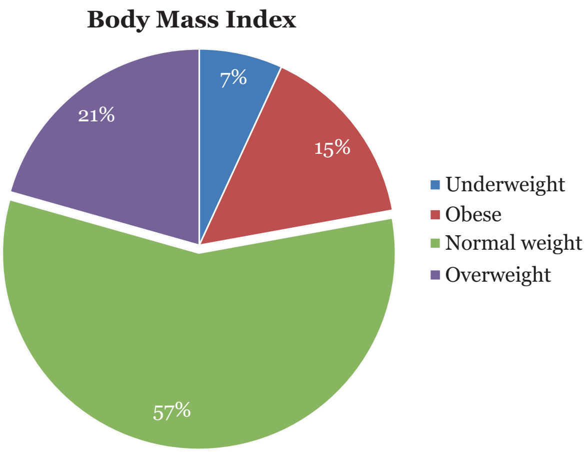
Appendix B: Cost Comparison of Weight Loss Solutions

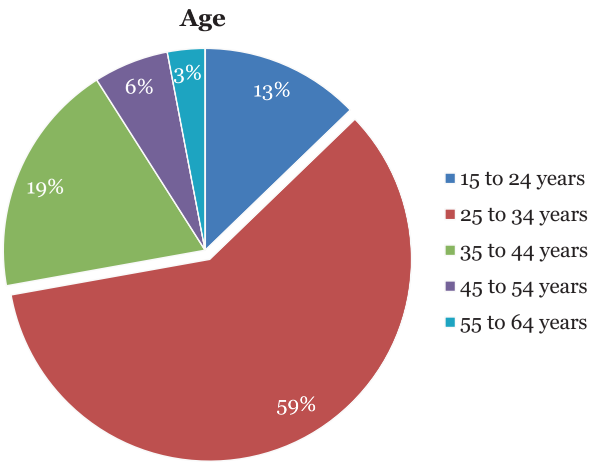
Weight loss solutions	Cost
BistroMD	$179.95/week
eDiets	$169.95/week
Diet-to-Go	$95.99/week
Weight Watcher	Est. $30 to join, plus weekly fees
Loss weight plan	$4/week
Stimulant-free dietary supplement	$51.25/order
Weight loss mobile apps	Free – $9.99/purchase

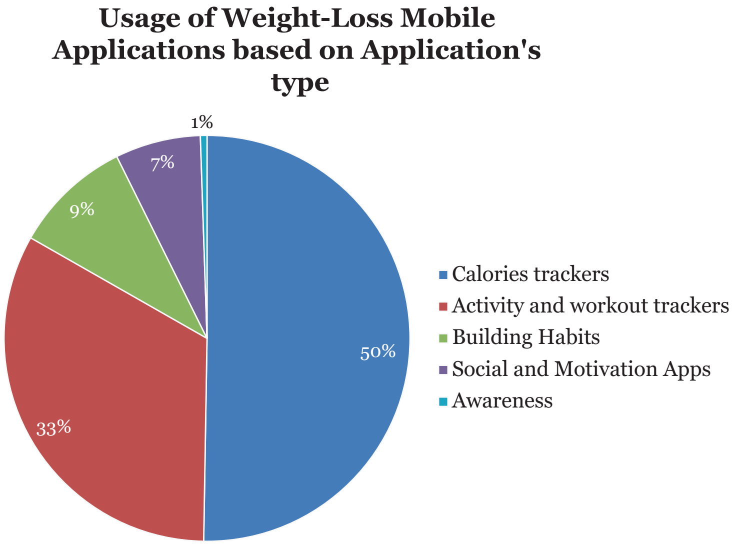
Appendix C: Global Individual Respondent Data Graphs







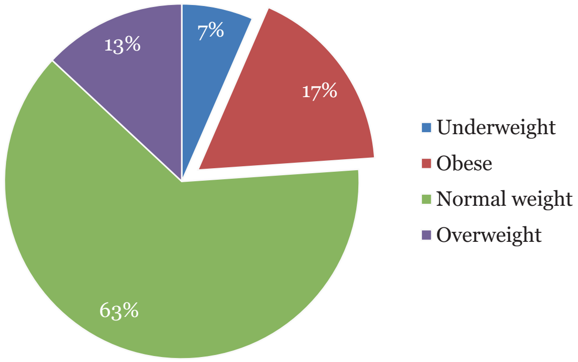

Age
13%
59%
19%
6%
3%
15 to 24 years
25 to 34 years
35 to 44 years
45 to 54 years
55 to 64 years


Usage of Weight-Loss Mobile Applications based on Application's type
1%
7%
9%
50%
33%
Calories trackers
Activity and workout trackers
Building Habits
Social and Motivation Apps
Awareness

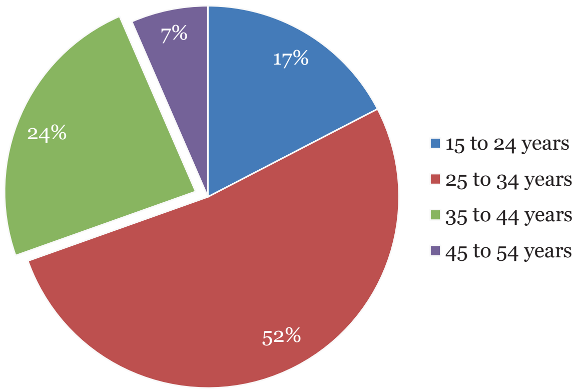
Appendix D: Global User Profiles

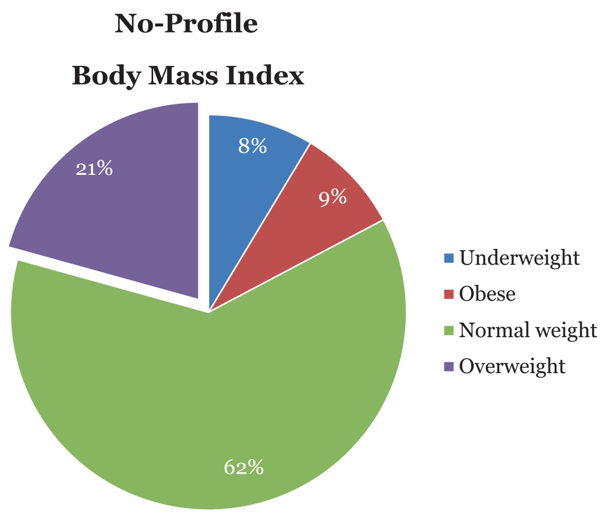
Yes – Profile

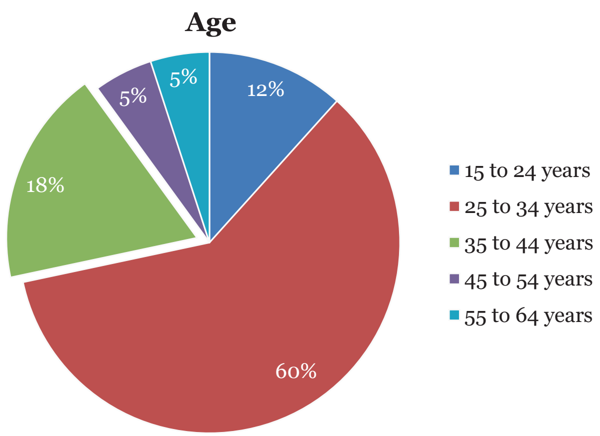
Body Mass Index



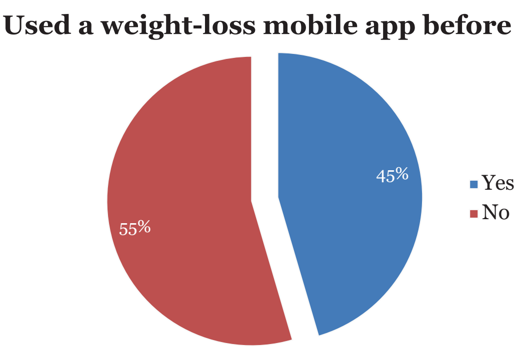
Age

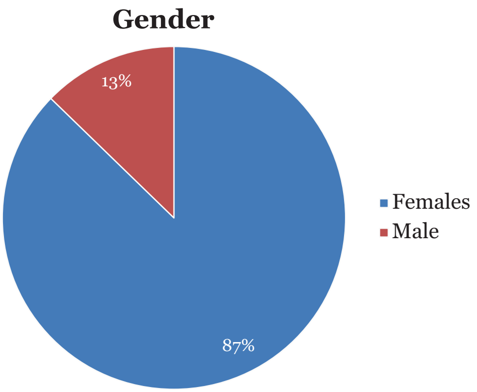


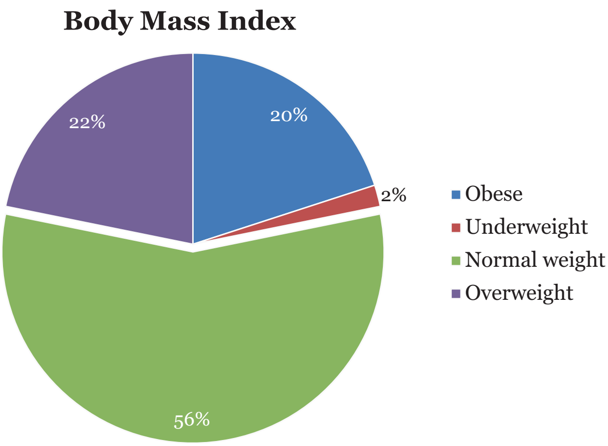


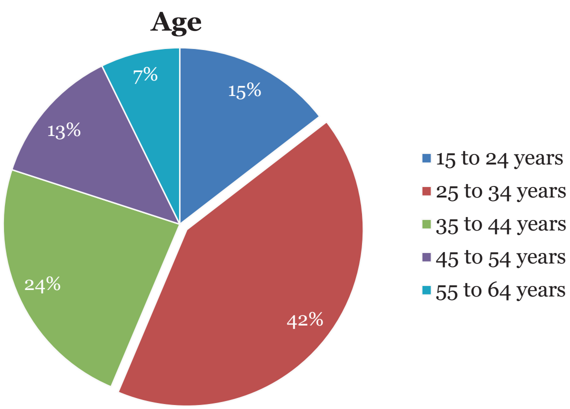


Appendix E: US Individual Respondent Data Graphs



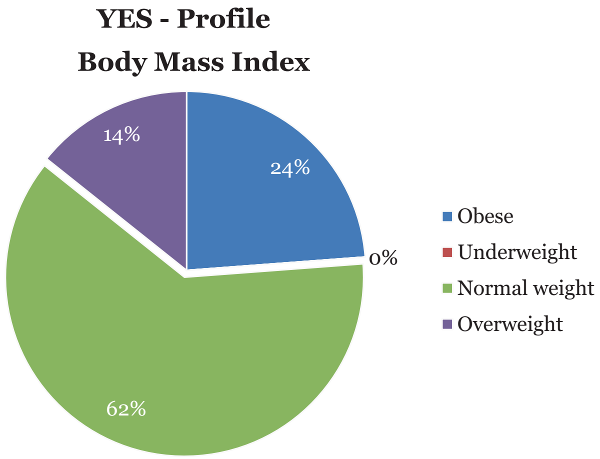

Gender
13%
87%
Females
Male

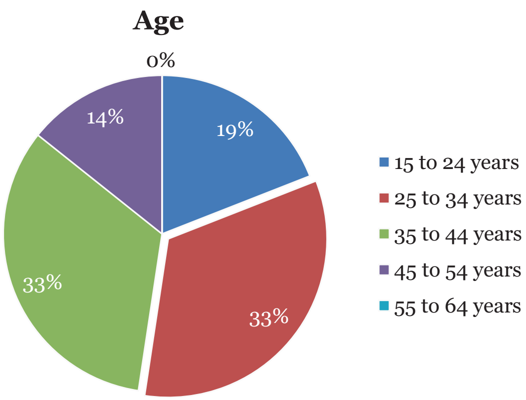

Body Mass Index
22%
20%
2%
56%
Obese
Underweight
Normal weight
Overweight


Age
7%
15%
13%
24%
42%
15 to 24 years
25 to 34 years
35 to 44 years
45 to 54 years
55 to 64 years

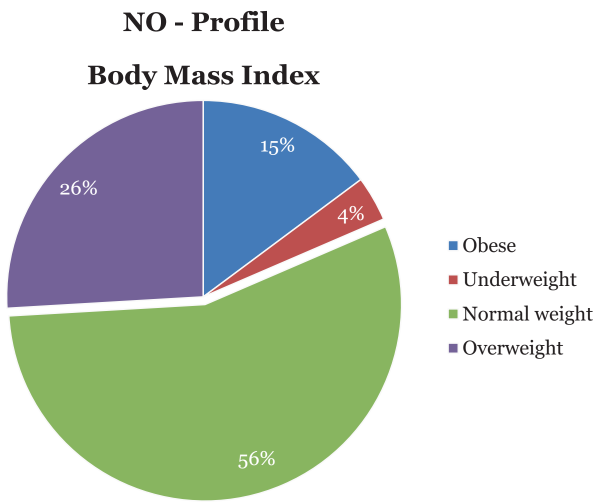
Appendix F: US User Profiles

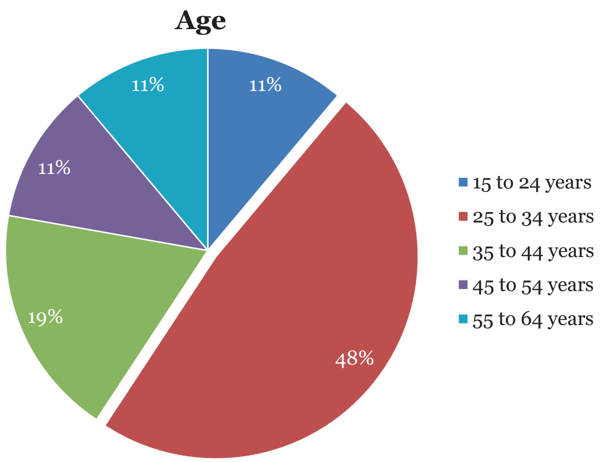
Yes: Profile





No: Profile


NO - Profile
Body Mass Index
15%
4%
56%
26%
Obese
Underweight
Normal weight
Overweight


Age
11%
48%
19%
11%
11%
15 to 24 years
25 to 34 years
35 to 44 years
45 to 54 years
55 to 64 years

References

1. Healthy weight: Assessing your weight: BMI: About adult BMI | DNPAO | CDC. [Online]. Available: http://www.cdc.gov/healthyweight/assessing/bmi/adult_bmi/index.html. Accessed 29 Nov 2012.
2. What are the main causes of obesity in America Today? | LIVESTRONG.COM. [Online]. Available: http://www.livestrong.com/article/354282-what-are-the-main-causes-of-obesity-in-america-today/. Accessed 03 Dec 2012.
3. Martinez, J. A. (2007, February). Body-weight regulation: causes of obesity. *Proceedings of the Nutrition Society, 59*(03), 337–345.
4. Updated adult obesity prevalence figures | The Downey obesity report. [Online]. Available: http://www.downeyobesityreport.com/2012/09/updated-adult-obesity-prevalence-figures/. Accessed 03 Dec 2012.
5. LaRosa, J. (2012). Diet market 2012 forecasts. Available at https://www.marketdataenterprises.com/diet-market-our-specialty/.
6. Wing, R. R. (1999). Benefits of recruiting participants with friends and increasing social support for weight loss and maintenance. *Journal of Consulting and Clinical Psychology, 67*(1), 132–138. Available at https://www.marketdataenterprises.com/diet-market-our-specialty/
7. Top reasons why people want to lose weight | LIVESTRONG.COM." [Online]. Available: http://www.livestrong.com/article/158867-top-reasons-why-people-want-to-lose-weight/. Accessed 03 Dec 2012.
8. Hickey, S. (2012). 2012 prediction: Number of mobile apps increases by factor of 10. *APM Digest*.
9. Mobile health applications marketing & public relations firm – Verasoni Worldwide. [Online]. Available: http://verasoni.com/ahha3/mobile-health-applications-2012-study/. Accessed 03 Dec 2012.
10. What makes a good weight-loss smartphone app? [Online]. Available: http://www.mnn.com/green-tech/gadgets-electronics/stories/what-makes-a-good-weight-loss-smartphone-app. Accessed 03 Dec 2012.
11. Weight loss can be contagious, study suggests | The Miriam Hospital, Providence, RI. [Online]. Available: http://www.miriamhospital.org/wtn/Page.asp?PageID=WTN000161. Accessed 03 Dec 2012.
12. Guillén, S., Sanna, A., Ngo, J., Meneu, T., del Hoyo, E., & Demeester, M. (2009, May). New technologies for promoting a healthy diet and active living. *Nutrition Reviews, 67*(Suppl 1), S107–S110.
13. Six, B. L., Schap, T. E., Zhu, F. M., Mariappan, A., Bosch, M., Delp, E. J., Ebert, D. S., Kerr, D. A., & Boushey, C. J. (2010, January). Evidence-based development of a mobile telephone food record. *Journal of the American Dietetic Association, 110*(1), 74–79.
14. Why weight loss mobile apps aren't really changing the game | Psychology Today. [Online]. Available: http://www.psychologytoday.com/blog/shrink/201207/why-weight-loss-mobile-apps-aren-t-really-changing-the-game. Accessed 03 Dec 2012.
15. iPhone, iPod Touch, iPad Application List » Apps » Health & Fitness » Top apps. [Online]. Available: http://iphoneapplicationlist.com/apps/health-fitness/. Accessed 03 Dec 2012.
16. Davis, F. D. (1989, September). Computer and information systems graduate school of business administration University of Michigan.
17. Basoglu, N., Daim, T., Işkın, İ., Aydınoglu, B., & Öztürk, M. (2012 Jun). New product development for the healthcare industry: A case study of diet software. *Health Policy and Technology, 1*(2), 93–104.
18. Saaty, R. W. (1987). The analytic hierarchy process—What it is and how it is used. *Mathematical Modelling, 9*(3–5), 161–176.
19. Basoglu, N., Daim, T. U., & Topacan, U. (Jun. 2012). Determining patient preferences for remote monitoring. *Journal of Medical Systems, 36*(3), 1389–1401.
20. Schoeffel, R. (2003, March). The concept of product usability. pp. 5–7.
21. mHIMSS App Usability Work Group. (2012, July). Selecting a mobile app : Evaluating the usability of medical applications.
22. 7 ways technology helps you lose weight – Prevention.com. [Online]. Available: http://www.prevention.com/weight-loss/weight-loss-tips/7-ways-technology-helps-you-lose-weight. Accessed 01 Dec 2012.

Part III
Transportation

Chapter 10
Landscape Analysis: The Electric Car (Is It a Viable Alternative?)

Henry Janzen, Deepak Yasaswi Kancherla, Sridhar Paneerselvam, Shiva Ram Reddy, and Tugrul U. Daim

10.1 Introduction

Cleaner air, renewable energy, and domestic energy use are the primary reasons to drive electric cars.

This report evaluates the battery electric vehicle (BEV) as an alternative to the internal combustion engine (ICE) vehicle to achieve cleaner air, renewable energy sources, and domestic energy. Although these are the main initial drivers for changing to BEVs, there is the realization that products don't become mainstream viable alternative unless there is a cost, performance, or utilitarian benefit. This report focuses on the cost, performance, and utilitarian benefit to drive BEVs.

10.1.1 Electric Car History

The electric car has been proposed as an alternative to the internal combustion engine for some time. In fact in the early years of the automobile industry, 1830s–1900s, electric cars were a substantial percentage of the market. Internal combustion cars then became the dominant power train, for good reason. The model "T" was introduced in 1908 by Ford which reduced the price of gasoline cars significantly. The introduction of the electric starter in 1912 eliminated a major safety

H. Janzen (✉)
Daimler, Stuttgart, Germany
e-mail: henry.janzen@daimler.com

D.Y. Kancherla • S. Paneerselvam • S.R. Reddy • T.U. Daim
Portland State University, Portland, OR, USA
e-mail: kancher2@pdx.edu; sridhar2@pdx.edu; shiv2@pdx.edu; tugrul.u.daim@pdx.edu

T.U. Daim et al. (eds.), *Infrastructure and Technology Management*, Innovation, Technology, and Knowledge Management,
https://doi.org/10.1007/978-3-319-68987-6_10

concern of the hand engine cranking. These and the inherent energy density of gasoline moved the ICE to become the dominant power train by 1930. The 1970s brought an electric car renaissance. The Environmental Protection Agency was created in December of 1970. The oil embargo of 1973 caused US oil shortages and gasoline price spikes. These events drove the reintroduction of BEVs. Hybrid cars are established as high-volume mainstream cars. But hybrids have two power trains, and it is questionable how much reduction in fossil fuels will be achieved with hybrids. Hybrids do reduce the amount of fuel consumed, but plug-in battery electric cars have a greater potential to achieve the goals outlined. For this reason this report focuses on BEV automobiles.

With IC engines being successful for 100 years, the switch to electric cars, if at all, will have some hurdles. First of all, there is an inherent love for internal combustion cars, especially in the North American culture. The raw power developed from combustion has a visceral connection with North Americans. The familiarity with the internal combustion car compared to the unfamiliarity with the electric car is also a deterrent to purchase BEVs. Finally the performance and cost need to be comparable. The cost and performance do not need to be a one to one equal or better, since electric cars in some cases will be better than ICE and vice versa, but combination of total cost of ownership, performance, and convenience needs to be such that an individual will prefer to purchase an electric car.

10.1.2 Current Electric Car Market

With the increased interest of consumers in electric vehicles, most of the automobile manufacturers are focusing on developing electric vehicles. After Nissan released the first LEAF in 2010, there has been significant improvement in the market share of battery electric vehicles. The LEAF has brought considerable awareness among the consumers. In the current BEV market, there are around 12 models from major manufacturers like Ford, GM, Nissan, BMW, and Tesla. The number of electric vehicles has increased in the recent years, and this is likely to continue. Considering the Nissan LEAF, after its release in 2010, the 2014 LEAF has improved range, torque, top speed and power. This proves that organizations are not just trying to increase the number of vehicles but also improving the vehicle performance to make them more efficient. The image below shows the current battery electric vehicle models, their acquisition price, range, and the charging duration.

The zero-emission vehicle (ZEV) program was initiated with an objective to achieve the US long-term emission reduction goals by mandating states to offer specific numbers of the cleanest technologies available. ZEV regulation was first adopted in 1990 as a part of Low Emission Vehicles I standards and has undergone many significant modifications since then. ZEV regulation was that 2% of vehicles sold in California in 1998 and 10% of vehicles for sale in California in 2003 must be zero-emission vehicles. The early version of the ZEV program was the LEV (light emission vehicles) which had regulations for the emission levels of the vehicles.

The ZEV program accounted for 98% more cleaner environment compared to the average new 2003 model year vehicle. The states including Connecticut, California, Maryland, Massachusetts, New York, Oregon, Rhode Island, and Vermont signed a memorandum of understanding (MOU) to support the zero-emission vehicle program by involving in the implementation task force [1]. In May 2014, the task force published a ZEV action plan identifying some priority actions that help in accomplishing the goals of MOU, including deployment of at least 3.3 million ZEVs and adequate EVSE infrastructure within the member states by 2025. Research [1] shows the forecast of the ZEVs from 2015 to 2025. It shows the total number of ZEVs in 2015 is just above 60,000 and will be able to reach above 550,000 by 2025. This program has spurred and enabled the auto manufacturers to focus on the improvement and development of the BEVs. In addition the ZEV program has increased consumer awareness, helping ZEV market growth.

10.2 Methodology

We performed an in-depth literature review and shortlisted key drivers that play a prominent role in the development and market growth of electric vehicles. Deloitte identified the following key factors for electric vehicle adoption [3]:

- Range
- Charge time
- Acquisition price
- Total cost of ownership (TCO)

These requirements are also reflected as key factors in a number of other reports [4]. We have also added emissions as the fifth key factor since environmentally conscious consumers would also switch to electric vehicles. To this end we identified whether emissions from electric vehicles were really lower compared to gasoline-powered vehicles. Based on literature review, the following factors were considered as key consumer drivers for widespread adoption of electric vehicles:

- Range
- Acquisition price
- Charging
- Total cost of ownership
- Emissions

We have analyzed the key drivers from the perspective of a customer to find out the real needs of the market. The current status for each of the drivers was reviewed to determine the gap between market need and current status. Technologies that affect the drivers were also identified. For example, the range of electric vehicles is mainly dependent on battery technology. We studied these technologies that impact the key customer drivers to identify factors (e.g., battery cost, size, and density). We looked at the journals, industry reports, and news websites to learn about any new

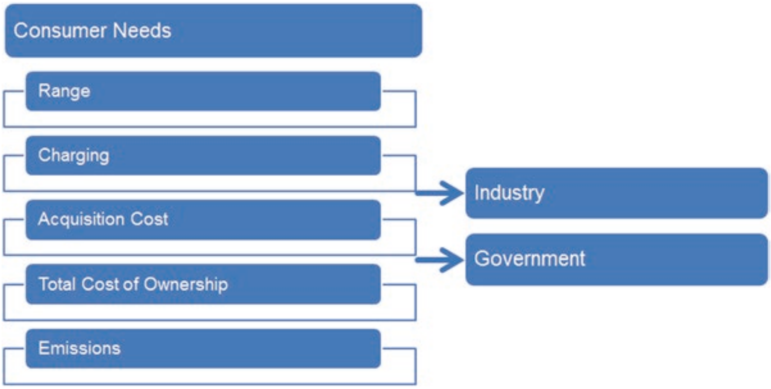


Fig. 10.1 Methodology

improvements on current technologies or any future innovations that could help the companies overcome the gap identified for each of the factors. We have identified the minimum requirement for each of the drivers and also whether they have already exceeded those requirements. Finally Sect. 10.7 summarizes the key drivers and recommendations that are made for industry and government to improve or close the gap between market need and current status (Fig. 10.1).

10.3 Analysis

The analysis reviews four key customer requirements, range, total cost of ownership, charging, and acquisition price. The social and soft consumer driver of emission reduction is also analyzed.

10.3.1 Range

10.3.1.1 Customer Needs

Required range is reviewed based on average vehicle miles traveled per day, vehicles per household, battery capacity reduction through life of the battery, and charging.

10.3.1.1.1 Vehicle Daily Miles Traveled

Key to the required range is the average daily vehicle miles traveled per day. Two sources were reviewed to determine this value: the National Household Transportation Survey (NHTS) [5] and the Ecotality journal [6]. See appendix B for more information on the NHTS. The NHTS 2009 US survey found that average vehicle distance traveled is 29 miles. The Ecotality journal reported on a survey conducted by ODOT in 2000 that 50% of Oregonians in metropolitan regions traveled 50 miles or less per day.

10.3.1.1.2 Vehicles Per Household

The number of vehicles a household has also factors into the required range. As reported in [6] 80% of US households have two or more vehicles. Having more than one household vehicle allows one vehicle to be an ICE that can be used for longer trips.

10.3.1.1.3 Charging Capacity Reduction

The battery capacity reduces as the battery charges and discharges. The Idaho National Laboratory conducted battery capacity reduction testing [7] on four 2012 Nissan LEAFs. Two were tested using a level 2 charger, and two used DC fast charging with results as per [7]. The level 2 charging had an average 25% battery reduction after 50,000 miles. The DC fast charging had an average 27% battery capacity reduction after 50,000 miles. This is a very small sample size; further testing with increased the sample size is required to improve statistical confidence.

10.3.1.1.4 Charging Method

Finally the method of charging is considered. It is assumed that BEV owners will install a home level 2 charger. This is an assumption made by a number of the reports, [8] being one of them. This allows the vehicle to be charged every night. Typical charge time for 100 miles using a level 2, 30A charger is 6–7 h. Typically the average miles traveled will be less than the maximum. A 75 mile charge time would be approximately 4–5 h. This makes home overnight charging for a daily vehicle miles traveled of 75 very convenient.

10.3.1.2 Current Status

The typical battery range for the current market is shown in Table 10.1

Table 10.1 Typical battery range for 2014 models

Model (2014)	Range (miles)
Nissan LEAF	84
Ford Focus	75
Chevrolet Spark	80
Tesla S	208

10.3.1.3 Future Development

There is currently extensive battery development being carried out. Most of the battery developments are focused on lithium ion, looking at different compositions of the metal oxide lithium cathode, high capacity anode, and new electrolyte with high oxidation potential [29, p. 35]. One promising technology uses a solid-state interface between the cathode and the anode. Near-term goals to achieve $150kWh battery are thought to be achievable with the current lithium-ion battery developments [29, p. 30].

10.3.2 Charging

10.3.2.1 Customer Need for Charging

A survey was conducted by Deloitte [30] among 17 countries on global electric vehicle study, and it shows that around 41% of US residents want their electric car to get fully charged within 4 h or less.

10.3.2.2 Current Status

Charging stations can be classified into three levels:

(a) *Level 1 chargers*: These chargers run on 120 Volts and are mostly included with the car. They are portable, but they take around 11–20 h of charging time. Usually, these are not preferred on a regular basis because of the charging time. If the charger is not included with the car, the basic price for this car starts from as low as $99 and ranges up to $850, depending on the functions of the charger.

(b) *Level 2 charging station*: These charging stations run on 240 volts and need to be installed by an electrician. They are not portable and they need to be installed in places such as garage. They take around 3–8 h for charging and hence these are commonly preferred. These are commonly used for home, parking garage, and curbside parking.

   (i) *Home charging stations*: The basic price starts from as low as $450 and can range up to $1000, depending on the functions of the charging station. Apart from the charger, electrical materials cost around $50–$150. Installation of the charging station may cost around $50–$200. Calculating the above work, an electrician may charge around $100–$350. Sometimes, depending on the state, permitting charges may also be levied which range from $0 to $100. The total cost for home charging station, including installation, is $650–$1800. State tax rebates may be available depending on the state.

(ii) *Public charging stations*: Unlike home charging stations, public charging stations require additional costs for wire, conduit, and breaker points. Around 60–80% of the total cost include only these materials. Charging station installation at garage costs less than that of charging stations at curbside because of the extra labor for drilling, boring, etc. These charging stations are further classified into single as well as multi-port depending on the demand. Multi-port charging stations are usually economical because of the reduction in conduit as well as the wire.

(i) *Parking garage charging stations*: The basic price for parking garage charging stations starts from $1500 and may range up to $2500 depending on the various functionality like alerts, LED screen, etc. Apart from the charging station, electrical materials cost around $210–$510, and installation of the charging station may cost around $250–$500. Calculating the above work, an electrician may charge around $1240–$2940. Unlike home charging stations, parking garage charging stations also include other labor costs for boring, trenching, etc. Sometimes, depending upon the state, permitting charges may also be levied which range from $50 to $200. The total parking garage charging station installation cost ranges from $3550 to $7500. State tax rebates may be available depending on the state.

(ii) *Curbside charging stations*: The basic price for curbside charging stations starts from $1500 and may range up to $3000 depending on the various functionalities. Apart from the charging station, electrical materials cost around $150–$300, and installation costs around $250–$500. Unlike parking garage charging stations, curbside charging stations charge less for electrical materials because of the ease of breaker box location which in turn helps in the reduction of wire and conduit materials. But other charges such as directional boring and trenching are quite high. Permitting charges may also be levied from $50–$200 depending upon the state. The total curbside charging station installation cost ranges from $5300 to $13,150. State tax rebates may be available depending on the state.

(c) *Public DC fast charging stations* (*level 3*): These charging stations run on 480 volts. They may in the future successfully replace the usage of level 2 charging stations. They are not portable and need to be installed by an electrician. The current cost for these chargers ranges from $12,000 to $35,000. These charging stations require an additional transformer which range in cost from $10,000 to $25,000. Electrical materials range in cost from $300 to $600, installation charges from $600 to $1200, and electrician labor from $1600 to $3000. Other materials required for boring, trenching, etc., may be required, costing from $100 to $400. Permitting charges may also vary from $50 to $200 depending upon the state. The total cost that takes for a DC fast charging is $29,650–$80,400 [31]. State tax rebates may be available depending on the state.

10.3.2.3 Future Development

1. *Home charging*: Upcoming technologies like solar panel charging are further more encouraging the use of clean energy at home. These solar panels are installed on the top of each garage at home; by doing so a part of electricity used for charging electric cars is made of clean solar energy. Companies like Tesla have formed an alliance with SolarCity for the installation of solar panels. Also, for encouraging this purpose, SolarCity has even come up with $1000 rebate option for Tesla customers. [http://solar.solarcity.com/promotions/tesla/]
2. *Public charging*: Upcoming technologies like superchargers, battery swap [32], and changes in battery such ultrafast charging technologies [31] are helping in the charge time reduction. Superchargers can charge an 85 KWh battery in 40 min. Electric vehicles with a minimum of 60 KWh can be charged at these stations. Battery swap is another technology that is introduced by Tesla. For this technology various swapping stations need to be located similar to gas stations. It is an alternative for charging. Instead of charging the battery, it is replaced with a fully charged battery in 90 s. Apart from changes in charging stations, there are also technologies that are upcoming in battery for reduction in charging time such as ultrafast charging technology invented by Nanyang Technological University. They replaced the use of graphite with a new titanium dioxide material which charges an average electric vehicle battery to 70% in 2 min. These studies suggest that there are potential technologies for charging stations and batteries to significantly reduce charging time.

10.3.3 Acquisition Price

We have compared the acquisition price of different electric vehicles in the market with that of a IC vehicle to analyze the price difference. The MSRP prices of the vehicles are used since the net final price which a customer pays varies among different states. Section 10.3.4 analyzes the total cost of ownership using acquisition price of the Nissan LEAF and Honda Civic LX because these two vehicles can be classified into the same "small car segment" and the Honda Civic is a popular compact car [9, 10].

10.3.3.1 Consumer Need

The acquisition price of electric vehicles (excluding Tesla, which is in the luxury segment) ranges from $23,800 to $50,700. The high sticker price is a main purchase deterrent for potential electric vehicles buyers [11]. Consumers are not willing to pay a premium on purchase price for electric cars [3].

10.3.3.2 Current Status

The main driver of the incremental cost increase between an ICE and a BEV is the cost of the lithium-ion battery [12]. Cost of a lithium-ion battery kilowatt hour ranges between $500 and $650, making up a large portion of an electric vehicle's cost [13]. For example, the Nissan LEAF, which has a 24 kWh battery, costs approximately $12,000–$15,000 [14]. The MSRP price of Nissan LEAF is $29,800; thus the battery pack would alone represent about 40–50% of the acquisition price. Thus, the cost of battery is very likely to be reduced in the future, resulting in the acquisition price of electric vehicle to be comparable to gasoline-powered vehicles.

10.3.3.3 Future Development

There are different forecasts of battery cost per kWh from various agencies. For example, the Department of Energy has a battery cost target of $150/kWh by 2020 [15]. In the 2009 Electrification Roadmap and the 2010 Fleet Electrification Roadmap articles, the Electrification Coalition forecasted battery cost per kWh would decline to $325–$350 per kWh by 2020 [12]. As per these predictions, the battery cost would halve by 2020, which could reduce cost of battery pack which was similar to ones used in Nissan LEAF to $6000–$7000. This reduction in cost of battery pack would significantly reduce the acquisition price, which is one of the key requirements for a consumer to purchase an electric vehicle.

10.3.4 Total Cost of Ownership

We have calculated the total cost of ownership for Nissan LEAF S and Honda Civic LX to determine if the Nissan LEAF is cost competitive when compared to a Honda Civic LX.

10.3.4.1 Consumer Need

We have already seen under acquisition price that consumers are not willing to pay a premium price for electric cars [8]. TCO will become an important consumer driver in the near future [3]. Expectations from average consumer would be to have a lower or comparable TCO for BEVs [16].

10.3.4.2 Current Status

Below are the assumptions used to calculate TCO for both Nissan LEAF S and Honda Civic (Table 10.2).

Table 10.2 Assumptions for TCO calculation

Category	Value
Electricity price	12.94c/kWh [17]
Gasoline price	$2.821/gallon [18]
Miles traveled	120,000
EVSE price	$1500

The most recent electricity rates (Sep 2014) and gas prices (Nov 2014) were considered for the calculation of TCO. There are different models of electric vehicle support equipment (EVSE) available in the market, with prices ranging from $500 to 6000. A charging infrastructure model (level 2), which costs around $1500, which was recommended by major automakers Ford and Toyota was included in the analysis [13 sr19]. The MSRP prices were included for both Honda Civic LX and Nissan LEAF S, which were $18,490 and $28,650, respectively [10, 19]. The $7500 federal tax incentive was deducted from the LEAF purchase price [20]. Maintenance costs for Honda Civic LX were obtained from a Portland dealer. Nissan LEAF S costs were sourced from Edmunds.com [21]. To calculate fuel cost, mpg for Honda Civic is taken as 32mpg. For BEVs, companies publish kWh required for their cars to travel 100 miles. Published energy required for the Nissan LEAF S to travel 100 miles is 30 kWh [19]. Based on kWh required for 100 miles, electricity cost per kWh, and the number of miles traveled, energy cost has been calculated. The below chart represents the total cost of ownership calculated based on these assumptions (Fig. 10.2).

The total cost of ownership for Nissan LEAF S and Honda Civic LX were $28,491 and $31,168, respectively. TCO over 120,000 miles for Nissan LEAF S is lower or comparable to that of Honda Civic LX. When higher electricity prices (18c/kWh in California) are used, the TCO increases to $30,313. However, it is still comparable with Honda Civic LX. Research done by EPRI also shows that the financial factors should not be a deterrent to a BEV purchase for most buyers due to current incentives and prices [22]

10.3.4.3 Future Development

With the improvements in battery technology, the purchase price is anticipated to become significantly lower in the future. Hence, TCO for electric vehicle would become considerably lower compared to gasoline-powered engines.

10.3.5 Emissions

The transportation sector currently accounts for nearly 30% of the US energy usage, and motor gasoline accounts for 20% of the US greenhouse gas emissions [23].

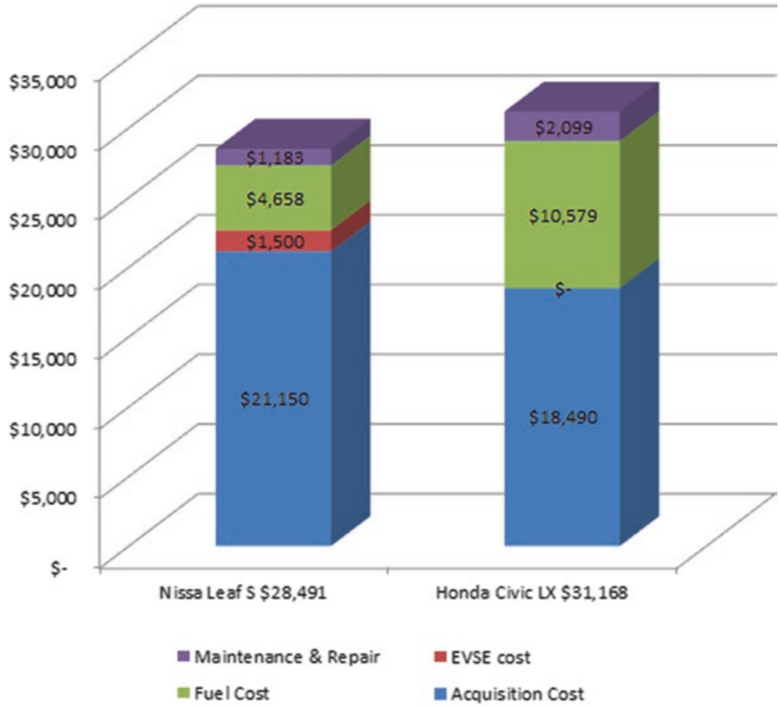


Fig. 10.2 Total cost of ownership for Nissan LEAF S and Honda Civic LX

10.3.5.1 Consumer Need

Electric vehicles emit zero tailpipe emissions, but the electricity they use would have contributed to greenhouse contributions due to some electricity utilities using fossil fuels to generate electricity. Thus, it is necessary to find out whether the electric vehicles have lower emissions compared to gasoline-powered vehicles. Consumers require electric vehicles to lower emissions, which would reduce global warming.

10.3.5.2 Current Status

Anair and Mahmassani have developed a method to compare emissions from electric vehicles and gasoline vehicles. They determined how many miles per gallon a gasoline-powered vehicle would need to achieve in order to match the emissions of an BEV due to utility electric energy generation [24]. Global warming emissions that would result at the power plant from charging an electric vehicle with a specific amount of electricity are calculated. Then the estimate is converted into a gasoline mile-per-gallon equivalent known as MPGghg, where ghg stands for greenhouse

Table 10.3 Well-to-wheel EV miles per gallon (MPGghg) [24, p. 5]

Coal	30
Oil	32
Natural gas	54
Solar	500
Nuclear	2000
Wind	3900
Hydro	5800
Geothermal	7600

gases. When the electric vehicle MPGghg value is equal to that of a gasoline-powered vehicle mpg, then both vehicles would emit equivalent amounts of greenhouse gases for every mile they travel (Table 10.3).

Authors have assumed Nissan LEAF's efficiency to calculate the MPGghg value. From the table, the MPGghg value for coal-generated electricity would be 30. Thus, the gasoline-powered vehicle should have 30 mpg to emit the same amount of greenhouse pollutants as an electric vehicle. However, the mpg value rises considerably when using electricity from renewable sources such as hydropower. For example, gasoline-powered vehicles would need to have mpg of 5800 to have same emissions of an electric vehicles that use electricity from an electrical utility using hydroelectric generation. Based on the electricity mix in different regions [24], authors have calculated MPGghg value for those regions.

The mpg value shown for different region is the combined city/highway fuel economy rating of a gasoline-powered vehicle that would have emissions equivalent to an electric vehicle. For example, if we consider northwest (NWPP) region, the mpg for internal combustion vehicle would need to be 73 to match the emissions from an electric vehicles, which in that region is primarily hydro-generated electricity. Based on these values, it can be concluded there are no regions in the country where a gasoline-powered vehicle could emit lower global warming pollutants compared to an electric vehicle.

10.3.5.3 Future Development

EIA's forecast indicates that the emissions intensity of the country's electricity grid would decline by 11% by 2020 versus 2010 [23]. Thus, the government is committed to decreasing global warming pollutants through implementation of renewable energy electric power generation. The industry is also creating innovative ideas such as rooftop charging for electric vehicles to reduce emissions. Thus, global warming pollutants would decrease in the future even further with the changes in electric generation mix.

Research from Becker, Sidhu, and Tenderich also supports this fact that when powered by nonpolluting sources of electricity, electric vehicle deployment results in a 20–69% decline in 2030 greenhouse gas emissions from US light vehicles over 2005 levels [21].

10.4 Government Support

Government support from all three levels, federal, state, and local, provides support for the BEV market growth through enabling efforts and financial incentives.

One example of enabling is the Oregon Public Utility Commission # 12–13 which allows the reselling of electricity for the purposes of providing energy to electric cars. All other applications do not allow companies to resell electricity in Oregon.

Below are examples of Oregon state and federal incentives to grow the BEV market.

10.4.1 Oregon Tax Credit for Residents

Residents of Oregon can receive a 25% tax credit of up to $750 for installing residential charging infrastructure. Fuels, such as gasoline blends, electricity, natural gas, etc., are eligible for this program. According to oregonlaws.org, this act will be employed until late 2017.

10.4.2 Oregon Tax Credit for Businesses

Companies and other organizations are eligible for a 35% of tax credit for the installation of alternative fuel infrastructure. These include facilities for vehicles which operate on renewable sources such as electricity, gasoline blends with a minimum of 85% ethanol, hydrogen cells, and other fuels as agreed upon by the Department of Energy. According to the oregonlaws.org, this act will be employed until late 2018.

10.4.3 Zero-Emission Vehicle Program

There are various states across the USA which have adopted the implementation of ZEV (zero-emission vehicle) program such as Oregon, New York, Vermont, etc. The main mission of this program is to deploy around 3 million of ZEVs and provide sufficient renewable sources by 2025. This program supports all states by providing data helpful for ZEV program such as number of ZEVs and number of charging stations.

10.4.4 American Clean Energy and Security Act

This bill was originally introduced in 2009. Its main mission is to reduce greenhouse gases by setting a maximum level allowed per year. These allowances are then converted into credits and sold to the companies. If a company's automobile emits more greenhouse gases, the company needs to buy credits at a higher price. This bill will simultaneously decrease gas prices as well as increase the market growth of electric vehicles.

10.5 Market Adoption and Forecast

In order for a new disruptive product to become mainstream, especially to disrupt the huge entrenched ICE automotive market, three main items are required:

1. The superseding product needs to have equivalent or better performance and utility.
2. The superseding product needs to have a lower total cost of ownership with near acquisition cost.
3. Product awareness and product knowledge.

A tool to analyze new technology adoption is the Rogers diffusion of innovation as described in [25]. It is a time-proven model. This model will be used to assist the timeline prediction for BEVs to achieve 5% market share. Once 5% market share is reached, it is very likely that there will be further advancements in BEV technology and infrastructure that may well allow this classic S curve to be reapplied for further BEV market share growth.

Using Roger's model and setting the target market share at 5%, below shows the market share at the end of each of the phases.

Innovators:	5% × 0.025 = 0.125%
Early adopters:	5% × 0.15 = 0.75%
Early majority:	5% × 0.50 = 2.5%
Late majority:	5% × 0.84 = 4.2%
Laggards:	5% × 1.0 = 5%

The start of commercially available BEVs occurred in 1996 through to 2010. Battery electric vehicles introduced in this phase were the GM EV1, Ford Ranger EV, and Toyota RAV4 EV. The period from 1996 to 2010 can be considered the "innovators" phase. The launch of the Nissan LEAF to the US market in December 2010 and proliferation of more than 13 other BEVs in recent years have grown the market share. With the market share at 0.5%, the market growth is somewhere in the "early adopters" phase.

With the TCO, initial acquisition price (with tax rebates), charging, and range being acceptable for many of the consumer needs, the third component "product awareness and product knowledge" becomes an important factor for market share growth. The means to which customers gain product awareness is identified in paper [26] in which three main mechanisms are identified.

Many consumers also do research on the internet finding valuable information from blogs, technical papers, and information from BEV interest groups [8].

Most of the literature forecast that BEVs will become more popular and grow in market share. Only three reports were found to make a forecast. One forecast (done in 2010), has 2.5% BEVs by 2015, 18% by 2020, and 63% by 2030 [8].

A second forecast (done in 2011) of the West Coast region [27] predicts a US BEV market share of 2.5% by 2018. The third forecast (done in 2011) has forecasted US BEV adoption [6].

10.6 Results and Discussions

10.6.1 Range

Taking into consideration the US average vehicle daily driving distance of 29 miles, double that to account for when more than average is driven, add an additional 25 miles for battery capacity reduction, and add 20% reserve; the total comes to a 100 mile range. Navigant Research survey [28] and a number of other surveys and journals have also identified that 100 miles is the threshold for BEVs to advance market share.

10.6.2 Charging

Keeping customer's expectation in view, the minimum charging time acceptable by 41% of the customers is 4 h or less in the USA [30]. Even though current charging stations take 4–8 h of time for charging, there are upcoming future technologies such as superchargers, battery swap, ultra-charging batteries, etc. that can significantly reduce the time of charging.

10.6.3 Acquisition Cost

Considering the fact that consumers are not willing to pay a premium for electric vehicles, the price of electric vehicles needs to be at a comparable level to those of gasoline-powered vehicles available in the segment. Our analysis shows that electric vehicles were priced higher due to the high cost of the battery pack. With the future developments in battery technology, the cost of battery would at least come down by 40–50% in the future (different forecast ranging $150–300/kWh versus $500/kWh in 2012–2013). This would lower the acquisition cost of electric vehicles significantly in the future.

10.6.4 Total Cost of Ownership

The total cost of ownership is already lower for electric vehicles than internal combustion vehicles. TCO is lower due to current incentives, lower maintenance, and electricity price. For widespread adoption of electric vehicles, the government should continue its financial incentives. Industry could also provide some benefits like free charging to lower TCO of electric vehicles further.

10.6.5 Emissions

Electric vehicles already have lower emissions compared to gasoline vehicles based on the current electricity generation mix. The government is taking steps to lower the dependence on electricity generated from nonrenewable sources. The change in electricity mix toward renewable sources would further widen the gap of emission level between electric and internal combustion vehicles.

10.6.6 Market and Adoption

All of the papers and journals predict that the BEV will continue to be an option in the current automotive market. There is considerable variation in the volume forecasts, as would be expected for new technology. There is a consistent conclusion that the BEV market will grow, and by our estimate, 5% of the car and light truck would be a conservative estimate. More research would need to be done to make a scientific prediction of when the 5% would be reached, but understanding that the BEV market is in a growth mode, a conservative estimate would be a doubling of market share every 5 years. The market share is currently at 0.5%. A doubling every 5 years would have 1% market share in 2019, 2% in 2024, and 4% in 2029, with a final 5% market share in 2030 (Table 10.4).

10.7 Key Findings and Recommendations

There are five key drivers that we identified in this study and three of the five met the current requirement of the consumers.The two key drivers that need further development to meet the requirement of the consumers are:

Table 10.4 Key conclusions and recommendations

Key drivers	Requirement	Status	Industry	Government
Range	100 mile		Li-ion improvements	
			Evolve li-ion technology – solid state, lithium air	$ 2.48 – American Recovery and Reinvestment Act
	Minimum		Create charging infrastructure	
			Provide low-cost rental car for long trips	Provide incentives for charging infrastructure development
Charging time	Home charging		Home charging technology development	
	3–4 h level 2		Investigate alternative battery swap technology	Continued tax rebate for charging infrastructure installation
	for 100 mile			
Acquisition cost	Comparable to ICE		Battery improvement will translate into lower cost	Continued and expanded tax rebate for new BEV purchases
				Provide grants for battery development
Total cost of ownership	BEV to have lower TCO		Free charging	Provide discounts for off-peak electricity
			Battery improvement will translate into lower cost	Collaborate with industry to provide free charging
Emissions	Lower emissions compared to ICE		Pursue renewable energy sources	
			Battery OEMs to invest in battery technology development	Provide monetary incentives to grow renewable energy

Range: The present range of the midsized electric Nissan LEAF is 84 miles. But the 2015 version of LEAF has higher range (125 miles) which means that the range is also going to meet the consumer needs by 2015. Range can also be improved if the solid-state and lithium-air batteries will be able to reach the market soon as they are already under study.

Acquisition cost: The acquisition cost of the Nissan LEAF is higher than the Honda Civic by $2660 after applying the $7500 federal tax credit. It is a fact that batteries constitute the majority of the vehicle total cost, and as discussed earlier, new battery technologies will result in further reductions of BEV's acquisition cost.

10.8 Conclusion

The increasing interest in battery electric vehicles and consumer adoption has enabled the manufacturers to invest in the BEV industry. Through this study, we are able to conclude that:

- The Nissan LEAF has a total cost of ownership that is lower than a Honda Civic over 120,000 miles.
- Current available range for a typical battery electric vehicle, such as the Nissan LEAF with 84 miles, is suitable for a small percentage of the market. A range of 100 miles would be suitable for a considerably larger portion of the market.
- Anticipate that battery electric vehicles will become a mainstream viable alternative with at least 5% of the car and light truck market share by 2030.
- Market adoption will be significantly impacted by battery technology improvements and gasoline price fluctuations.

Acknowledgments We would like to thank John MacArthur, Research Associate at Portland State University, for answering our questions on battery electric vehicles and giving guidance for next steps in the early stage of the research project.

Appendix A

Comparison of acquisition cost of electric vehicles and Honda Civic LX

Vehicle name	Price ($)
EMW i3	42,300
Chevrolet Spark EV	27,500
Ford Focus Electric	36,000
Mitsubishi i-MiEV	23,800
Smart Electric Drive	25,700
Tesla Model S	81,000
Toyota RAV4 EV	50,700
Mercedes B-Class Electric Drive	42,400
Fiat 500e	32,600
Kia Soul EV	34,500
Tesla Model X	80,000
Volkswagen e-Golf	36,300
Nissan LEAF	29,800
Average EV cost (ex Tesla)	38,467
Honda Civic LX	18,490

Appendix B

The NHTS was originally the National Personal Transportation Survey (NPTS), which conducted its first survey of US transportation behavior in 1969. In 2000 the NPTS combined its survey efforts with American Travel Survey and changed the name to National Household Travel Survey. The 2009 NHTS included 150,000 households and 300,000 people representing a cross section of the USA.

References

1. Davis, A. (2013, August 13). Here's How Tesla's model S compares to other top electric cars. Business insider [online]. Available: http://www.businessinsider.com/electric-car-comparison-chart-2013-8. Accessed 17 Nov 2014.
2. ADFC energy. ZEV deployment support [online]. Available: http://www.afdc.energy.gov/laws/11081. Accessed 23 Nov 2014.
3. Giffi, C., Vitale, J., Drew, M., Kuboshima, Y., & Sase, M. (2011). Unplugged: Electric vehicle realities versus consumer expectations, Deloitte.
4. Kodjak, D. (2012). Consumer acceptance of electric vehicles in the US. The International council on clean transportation, Dec.
5. National Household Travel Survey. (2009). [Online]. Available: http://nhts.ornl.gov/2009/pub/stt.pdf. Accessed 22 Nov 2014.
6. EV Charging Infrastructure Plan for Western Oregon. (2010, August). [Online]. Available http://www.theevproject.com/downloads/documents/Long%20Range%20EV%20Charging%20Infrastructure%20Plan%20for%20Western%20Oregon%20Ver%203.3.pdf. Accessed 22 Nov 2014.
7. DC Fast charge effects on battery life and performance study – 50,000 Mile Update. (2014), *2*, 29877.[Online] Idaho National Laboratory. Available http://energy.gov/sites/prod/files/2014/07/f18/vss131_francfort_2014_o.pdf. Accessed 15 Nov 2014.
8. Cet, T., Becker, T. A., Pi, I. S., & Tenderich, B. (2009). Electric vehicles in the United States a new model with forecasts to 2030.
9. Plugincars. Cars, plugincars.com, [Online]. Available: http://www.plugincars.com/cars. Accessed 28 Nov 2014.
10. Honda. Pricing Options, automobiles.honda.com, [Online]. Available: http://automobiles.honda.com/civic-sedan/price.aspx?Model=FB2E5FEW. Accessed 28 Nov 2014.
11. Thorstensen, L., & Libby, T. (2013). Creating the clean energy economy: Analysis of the electric vehicle. International Economic Development Council.
12. Electrification Coalition. (2013, July). EV market outlook: State of the plug-in electric vehicle market: EV market outlook.
13. US Department of Energy. (2012, May). Vehicle technologies program annual merit review.
14. Bullis, K. (2012, November). How improved batteries will make electric vehicles competitive. MIT Technology Review.
15. US Department of Energy. (2011). 2011 annual progress report: Energy storage R&D.
16. Trigg, T., & Telleen, P. (2013, April). Global EV outlook: Understanding the electric vehicle landscape to 2020. International Energy Agency.
17. EIA. Gasoline and diesel fuel update. eia.gov. [Online]. Available: http://www.eia.gov/petroleum/gasdiesel/. Accessed 29 Nov 2014.
18. EIA. Electric Power Monthly. eia.gov. [Online]. Available: http://www.eia.gov/electricity/monthly/epm_table_grapher.cfm?t=epmt_5_6_a. Accessed 29 Nov 2014.

19. Nissan. 2015 Nissan Leaf. [Online]. Available: http://www.nissanusa.com/electric-cars/leaf/. Accessed 28 Nov 2014.
20. Egbue, O. N. (2012). *A socio-technical analysis of widespread electric vehicle adoption*. Ph.D. dissertation, Missouri Univ. Of Science And Tech., Rolla, MO.
21. Edmunds.com. 2014 Nissan Leaf Hatchback Pricing. [Online]. Available: http://www.edmunds.com/nissan/leaf/2014/. Accessed 28 Nov 2014.
22. Alexander, M., & Davis, M. (2013, June). Total cost of ownership model for current plug-in electric vehicles. EPRI.
23. Becker, T. A., Sidhu, I., & Tenderich, B.. (2009, August). *Electric vehicles in the United States: A new model with forecasts to 2030*. Berkeley: Center for Entrepreneurship & Technology, University of California.
24. Anair, D., & Mahmassani, A. (2012, June). State of charge: Electric vehicles' global warming emissions and fuel-cost savings across the United States. Union of Concerned Scientists.
25. Sahin, I., Rogers, F., Rogers, F., & Rogers, F. (2006). Detailed review of rogers' diffusion of innovations theory and educational technology-related studies based on Rogers'. *Turkish Online Journal of Educational Technology, 5*(2), 14–23.
26. Shafiei, E., Thorkelsson, H., Ásgeirsson, E. I., Davidsdottir, B., Raberto, M., & Stefansson, H. (2012). An agent-based modeling approach to predict the evolution of market share of electric vehicles: A case study from Iceland. *Technological Forecasting and Social Change, 79*(9), 1638–1653. https://doi.org/10.1016/j.techfore.2012.05.011.
27. Schellenberg, J. A., & Member, M. J. S. (2011). *Electric vehicle forecast for a large west coast utility* (pp. 1–6), published in Power and Energy Society General Meeting, 2011 IEEE.
28. Vyas, C., & Hurst, D. (2012). Electric vehicle consumer survey consumer attitudes, opinions, and preferences for electric vehicles and EV charging stations. Available at http://www.navigantresearch.com/wp-content/uploads/2012/10/EVCS-12-Executive-Summary.pdf.
29. Garcia-Valle, R., & Pecas Lopes J. A. (Eds.). (2013). Electric vehicle integration into modern power networks. http://www.springer.com/978-1-4614-0133-9
30. Deloitte. Unplugged: Electric vehicle realities versus consumer expectations. [Online] Available: http://www.deloitte.com/assets/Dcom-China/Local%20Assets/Documents/Industries/Manufacturing/cn_mfg_GlobalEVStudy_091011.pdf
31. Cleantechnica. EV: Charging station infrastructure costs [Online]. Available: http://cleantechnica.com/2014/05/03/ev-charging-station-infrastructure-costs/
32. Tesla motors, [Online]. Available: http://www.teslamotors.com
33. National Research Foundation. Ultra-fast charging batteries that can be recharged in two minutes [Online]. Available http://www.nrf.gov.sg/scientific-advances/ultra-fast-charging-batteries-that-can-be-recharged-in-two-minutes-Public Utility Commission of Oregon, Order No. 12–013, 2012.

Chapter 11
Technology Roadmap: A Roadmap for Tesla

Yasaswi Deepak Kancherla and Tugrul U. Daim

11.1 Introduction

By the increased use of fossil fuels on day-to-day life, there is a huge impact on the environment because of the carbon emissions emitted from these vehicles. Hence, there increased a need for alternate energy for vehicles. To help the cause of adopting the electric vehicle in the market, this report helps in enlightening the need for replacing the conventional vehicles by electric cars in the current world of technology and also extends it by constructing the roadmap for the pioneer of electric vehicles – Tesla motors. The competitors for Tesla are not just electric vehicles but they are bigger firms such as Audi, Mercedes, etc. which manufacture a higher range of comfort cars which run on conventional energy. One of the biggest hurdles faced by the electric vehicle market is the lack of running the EV vehicle for a long range on a single charge and replacement of conventional vehicles in the market by electric cars. The goal is to analyze the current situation of electric car adoption, to analyze the current status of the EV technology, and to prepare a roadmap on how they are going to reach their goal of successfully being a pioneer in automobile industry.

The most prominent motive of driving an alternative vehicle like electric car is to make use of clean, eco-friendly, and renewable energy. For the electric vehicles to become a mainstream alternative, there are certain milestones that they have to cross such as performance, cost, and benefits for driving an electric vehicle. This report helps in assessing the current technology of battery electric vehicle, and it also extends by developing a roadmap plan for the batteries used by Tesla motors for the coming 10 years.

Y.D. Kancherla • T.U. Daim (✉)
Portland State University, Portland, OR, USA
e-mail: kancher2@pdx.edu; tugrul.u.daim@pdx.edu

T.U. Daim et al. (eds.), *Infrastructure and Technology Management*,
Innovation, Technology, and Knowledge Management,
https://doi.org/10.1007/978-3-319-68987-6_11

11.2 History of Electric Vehicles

Electric cars were quite focused in the market in the early years of the 1800s. Soon, a small-scale electric car was developed after the concept of developing the electric motor from an electric battery. An early electric carriage was developed in this same time by a British inventor named Robert Anderson. In the late nineteenth century, few practical electric cars were released in the market by French and English inventors. In the United States, an inventor named William Morrison released a six-seater electric car with speed of 14 mph which helped in growing interest among people for electric cars [1].

Gasoline engine was also introduced along with the electric cars which had quite few of defects such as smelly residue, manual crank starter, and too noisy. Electric cars on the other hand never had these issues, so they became quite popular with urban residents and people who wanted to travel less number of miles. At that particular time, lot of entrepreneurs observed this increasing technology and scope in electric cars and started to release their own such as Ferdinand Porsche released a car called as P1. At the same time, Henry ford along with Edison developed an electric car. But later, the mass production of Henry Ford's internal combustion car called as Model-T gave a serious blow to electric car. The car which was released had less deficiencies and was affordable compared to all the IC cars that were released previously. New routes were discovered in the United States, and by 1920 there were better roads connecting cities. People wanted to explore and travel to new cities. Further, crude oil was discovered in Texas which made gas cheap. In the end IC engines outgrew electric vehicles, and slowly electric vehicles started to decline and entirely disappeared by 1935.

11.3 Current Electric Market

With the increasing trend and advanced technology, various automobile entrepreneurs have started to focus on manufacturing electric vehicles. Nissan has launched its first battery electric vehicle called as leaf in 2010 which accounted for the increase in the market share of electric vehicles. There are currently 24 prominent electric cars in the world from manufacturers like Nissan, Chevrolet, Hyundai, Mercedes Benz, Tesla, etc. All of these electric vehicles face a unified problem which is the range. The range of the electric car depends upon the battery that has and the consumption of electric vehicle. However, Tesla motors have the most advanced battery technology which helped in increasing the range of Model S and Model X by 240 miles on an average. By looking at the Tesla release of Model S in 2005 with an updated model in 2006, we can say that there are even advancements in technology apart from just considering the number of electric cars in the market [2]. The current challenges that the electric vehicle industry faces are the lack of range on running an electric vehicle on single charge and the cost of making the battery as it is the most expensive part of an electric vehicle.

11.4 Literature Review

According to the union of concerned scientist organization, 30% of all the US global warming emissions are produced by the transportation through conventional vehicles [3]. Plug-in electric vehicles help in reducing the emissions by 70% if conventional fuels are used for the production of electricity and lower all the fuel costs by 80% [4].

In any given sector, always an electric energy has efficient use of energy than conventional energy. Specifically in electric vehicles, it is around 80% efficient compared to the conventional engine which is 20% efficient [5].

The US Environmental Agency has plans to reduce the carbon emissions drastically by 2025 which also includes encouraging alternative clean energy vehicle usage. It also includes offering benefits for the deployment of advanced technology in the transportation sector. Over the period of the lifetime of vehicles sold in years from 2012 to 2025, it plans to cut 6 billion metric tons of GHG [6].

According to the US Energy Information Administration in 2015, the United States imported 9.4 million barrels per day of petroleum from 82 countries, and 27% of the oil is imported from other countries [7].

Government also started providing funding, tax relief, and incentives to encourage the use of clean energy in automotive industry. It offers consumers a tax rebate of $7500 for electric vehicles in rebate. It also plans to invest in further R&D of electric cars and reward communities that invest in the electric vehicle technology [8].

According to the Roland Berger Strategy Consultants, their value chain reveals that cathodes are the most expensive part in Li-ion batteries, but it is predicted that from new developments the cost of the batteries goes down from $650 USD/kWh to $270 USD/kWh in 2020 [9].

The average cost of electricity in the United States is $1.22 per gallon in E, while the average cost of gasoline in the United States is around $2.78 per gallon [10].

Even if we neglect the value of money, the contribution to the environment in terms of emissions is prominent [11].

11.5 Technology Roadmapping

Technology roadmap is a strategic plan for an organization which is used to meet the short- and long-term goals [30]. It was first introduced in the 1970s to support the alignment between technology and product development [31].

Technology roadmapping can be used in several industries; Hilary Martin and Dr. Tugrul Daim represented a new approach in a nanocentric system rather than being in macrocentric system. This project represents and provides a great production support of one trillion dollars along with providing employment opportunities in the next 10 to 15 years. Dr. Timothy, R. Anderson, and Rinne helped in creating a roadmap for virtual innovations and factories and how knowledge of these patterns helps in the detection of employment opportunities in innovation [32]. Allen et al. [33] provided a roadmap technology for semiconductors to confront the changes in Moore's law and its R&D needs over a span of 15-year horizon. McDowall and Eames constructed a roadmap for the energy sector of the hydrogen and help in researching into the future of hydrogen energy [34]. I.J. Petrick and A.E. Echols constructed a roadmap which helps the firms for product development based on concentrating on technological trajectories by combining technology roadmapping, information technology (IT), and supply chain management [35].

From the above literature review, it can be suggested that:

1. Technology roadmap can be used for short-term or long-term planning.
2. It can be used in either national level or corporate level technology planning.
3. It can be used for having strategic priorities across the timeline.
4. It can be used to help in effective communication and strategic planning.

The following steps have been taken in this project to successfully implement the technology roadmap:

1. Identification of needs and market drivers
2. Identification of corresponding products and services for satisfying these drivers and needs
3. Identification of corresponding technologies for these products
4. Formation of linkages among the three steps described above and providing proper color coding for linkages among them to form a roadmap.

11.6 Market Drivers

After performing a literature review and analysis of the various reports, the areas that need to be concentrated are the technology currently used in the electric vehicle battery technology industries including Tesla motors, universities which play a significant role in breakthrough technologies, and independent researchers. From the literature review and by the PEST Analysis, various drivers were deduced which are:

1. Business Needs

   According to the "eco watch," the price of solar PV cells and wind energy project capital cost have gone down, whereas the price of coal, crude oil, and natural gas has gone up in an increasing trend by 2015. This opens up an opportunity for several entrepreneurs. Initially investing on the solar PV cells or wind energy would cost a fortune with minimal profit, but according to the statistics, the price of the alternative energy is getting reduced, whereas conventional fuels are increasing gradually so there is huge scope for the business in alternative energy in the future [12].

According to the recent findings from the Rocky Mountain Institute Organization, if there is a significant change of conventional vehicle to electric vehicle, the United States will have an additional of 1.9 million jobs by 2030. Considering the present time, even companies like EnerDel started hiring 1400 additional jobs for lithium ion battery plant [13]. Furthermore, business needs can be split into various subdrivers such as:

(a) Market position: Maintaining top market position/brand name is quite important. According to the Forbes, Tesla has a unique market position as it concentrates not only selling automobiles but it also sells technologies. Right now it is in a position where it dominates all other electric vehicles in the market and produces electric vehicles which dominate other electric vehicles in luxury, high capacity, and range [14]. There might be competitors in the electric vehicle business once any revolution in the technology is released. Hence, being a pioneer in electric vehicle business is quite important for Tesla for its future success.
(b) High capacity: The biggest challenge according to the Forbes for Tesla is not electric cars in the market but the conventional vehicles. To overcome the competition and become the pioneer in automobile industry, Tesla EV vehicles should have higher power and get more market share by designing family-friendly vehicles [14].
(c) Greater performance: Electric motors should be developed parallelly to sustain the high-capacity batteries while giving its maximum performance such as higher speed, longer range, and faster acceleration.
(d) Longer range: Range is one of the biggest challenges that EV industry faces. At present, Tesla vehicles have the longest range among all the other electric vehicles in the industry. It should be constantly concentrated and needs to be increased further such that they overcome the range gap between internal combustion vehicles and electric vehicles.
(e) Low production cost: According to *International Business Times*, Tesla has plans to build a $5 billion factory called as “Gigafactory” which will help in lowering the costs of battery production. By doing this, it will not only be able to manufacture vehicles in lesser time but it will fetch in gaining profits [15].
(f) Less charging time: According to the survey done by Deloitte, the need for 2 hours or less charging time is required by the people. Tesla has already reached this stage of full charge with the help of super chargers, but for attracting more consumers in the future, Tesla should also concentrate on reducing the charging time eventually.
(g) Lower charging service cost: Even though tesla’s battery swap program is pretty much dead, it needs to find alternatives for replacing the higher charging service cost for making it affordable.
(h) Appealing automobile: Along with all other technical features, appeal should also be considered for attracting “Everyday Joe” which leads to higher market share in EV.

2. Technology Advancements

   (a) Research assistance: Universities such as Nanyang Technology University are developing new technology batteries which are far more superior to the usual Li-ion batteries [16]. These universities and private researchers need monetary assistance for developing revolutionary technologies.
   (b) Lithium replacement: Lithium batteries are very costly to dispose, and there is a need for replacing these lithium-based batteries with other batteries which are less harmful to the environment, give higher performance, and have low manufacturing cost.
   (c) Battery charge by renewable sources [4]: Electric vehicles release about 70% lesser carbon emissions than conventional vehicles when charged with the help of conventional fuels, but if renewable sources are used for charging the electric vehicle, there won't be any carbon emissions.
   (d) Pioneering in inventions: Tesla has not only the luxurious class of vehicles in electric vehicles but also contributes a lot to new innovations in electric vehicle industry. A constant timely innovation would help it to prevail as a pioneer in electric vehicle industry.

3. Social Trends

   (a) Low carbon footprint: Emerging markets and consumers are becoming more aware of the carbon footprint. Tesla should keep reducing its sources which cause emissions and find alternative sources.
   (b) Greener everything: Electric vehicle contributes to a cleaner environment, but not all parts of manufacturing or recycling are in favor of a cleaner environment. So, parts like Li-ion should be properly manufactured in an eco-friendly way and so should the recycling be eco-friendly.

4. Regulations

   (a) Stringent regulations: There are certain stringent regulations in each state that need to be followed either on manufacturing or recycling of batteries.

11.7 Products and Corresponding Technologies

The products were categorized into four main classes which are:

1. Comfort
2. Convenience
3. Safety
4. Technology innovation

Furthermore, various technologies have been mapped to these to form a technological structure as follows:

1. Comfort
   (a) Health monitoring: By the increasing healthcare costs and medications, people are concentrating on taking care of their health on regular basis. This can be a future scope of adding such kind of devices with the automobile.
   (b) Family friendly: Tesla manufactures just comfort cars as of now, but for being more family friendly, it can further concentrate on wagons, vans, SUVs, etc.
   (c) Wi-Fi hotspot: Cellular data transfer has become quite deficit in the recent times. Demand is outweighing the supply and the allocation of electromagnetic spectrum is reducing. Hence, there is a scope for a Wi-Fi hotspot which allows multiple devices to connect to a Wi-Fi network to reduce the usage of cellular data [17].
   (d) Reconfigurable body panels: According to recent advancements and concept cars, fewer automobile industries have begun to concentrate on reconfigurable body panels such as converting a full size into a pickup truck, etc. Instead of owning multiple of such cars having a convertible car would be an advantage and provide quite an appeal to the consumers. Companies such as Toyota have already started to build such kind of concept car to their electric car to attract more consumers [18].
2. Convenience
   (a) Wireless charging stations: Humans have always found ways to make life simpler from the early man making wheels to the wireless charging technology currently to reduce the hassle of wired components. Just by parking a car in a parking space without any hassle, the electric car gets charged. A firm called as plugless has started producing wireless level 2 charging for limited cars. As of now, it only supports fewer cars such as Tesla models, etc., but there can be a huge scope in the future to construct wireless superchargers by tesla.
   (b) Portable charging equipment: One of the challenges that electric car industry faces is being unable to reach as many miles as an IC vehicle and having the same convenience as an IC vehicle for fuel. According to current technologies, there are portable charging equipment which can be used at any time in a 240-volt socket plug to charge an electric car. Tesla should manufacture or should have tie-ups with firms like TurboCord which will help the vehicles to conveniently charge [19].
   (c) Service network expansion: Since there is a minimal need of service stations for electric cars, there are not as many around which can even help in road side assistance. Having an ample amount may satisfy the consumer to feel secured which can be started by Tesla as an initiative.
   (d) Faster-charging batteries: According to tesla's chief technology officer, J B Straubel, Tesla started to work on batteries which could charge in 5–10 min in the coming year, but there will be several other advancements in the future

to reduce this charging time. According to the MIT Technology Forum, for achieving this 5 min charging time, entire battery system such as electric grid, cooling system, etc. should also be changed which would certainly take couple of years for advancements in technology [20].

3. Safety

   (a) Facial recognition: According to the Insurance Information Institute Organization, around 689,527 vehicles were reported stolen in 2014 [21]. To avoid further more auto theft, security enhancements must be made such as facial recognition. Automobile firms such as Ford and Volvo have already started to test facial recognition systems in automobiles which will help in increasing security as well as taking an intruder's photo and sending it to the smartphone of the driver if in case of auto theft [22].
   (b) Anti-hack technology: Apart from the pros with a wide variety of computer-operated and technology-related advancements in vehicles, there are cons to it as well. According to the article in the *International Business Times* by various cybersecurity firms, a car with higher technology can be prone to a hack, and with it a hacker can even control the steering, engine, brakes, and headlights which can be a potential threat. So, these technologies should be completely made with antivirus and anti-hack technologies which should be prominent in Tesla as well because of high technology adoption rate in Tesla.
   (c) Night vision: Automobile firms like Audi embed such night vision technologies into the automobiles for avoiding accidents especially when it is dark. Tesla should implement such kind of technologies in the future to provide the safety for the driver and to attract more consumers.
   (d) Remote vehicle control: Remote vehicle control is operated either by smartphones or by a simple remote to navigate the automobile easily out of complicated parking spaces, and instead of having faith in another driver, one can simply control the vehicle from hundreds of miles. Firms such as Ford started to exploit such kind of technology [23]. Tesla should also try to implement such kind of technology in the future.

4. Technology Innovation

   (a) Solar charging panels: Solar charging panels should also be adopted with electric chargers and cars to be energy efficient and also to avoid any production of electricity by nonrenewable energy sources.
   (b) Batteries: By recent innovations and changes in the battery science, a low-cost yet high-capacity battery is expected to be introduced every year with an increase of 5% in capacity. Tesla should aim for this benchmark every year for being a successful pioneer in the automobile market.
   (c) Hybrid with clean fuel: Tesla currently aims at just electric vehicle market, but there are much more clean fuels when combining with electric power

which makes a hybrid car. Automobile firms such as Mercedes Benz aim to introduce such a hybrid car with electric and hydrogen as fuel [24]. To gain more market share, Tesla should expand their electric fleet into other hybrid vehicle markets.

(d) Lithium-free batteries: Lithium is highly flammable, and according to recent advancements, materials such as aluminum graphite can be used as cathode in the batteries which are not flammable [25]. Also, lithium is considered to be toxic, flammable, and explosive material. For future safety, Tesla should consider lithium-free batteries.

(e) High-efficiency motors: Rather than having two inverter and two motor configurations in electric car, a single-stator, dual-rotor induction motor drive by single power inverter can be used for having simple drive train of the electric car and a low cost for manufacturing can be obtained [26]. Tesla should concentrate on manufacturing and embedding such motors in electric cars to reduce the overall cost of vehicle.

(f) Low-cost battery: One of the main drawbacks of an electric vehicle is that its price is higher than that of an internal combustion engine because of the battery. In 2007, the battery price was $1000/kwh, but in 2014 it reached to $300/kwh and is expected to go further down by 2020 according to the study made by *Nature Climate Change* [27].

(g) Recyclable batteries: According to Tesla's closed-loop battery recycle program, it has partnered with Umicore for a battery recycling process which recycles about 70% of the battery [28]. Lithium is considered to be one of the dangerous and flammable components which even causes environmental pollution; if lithium is not replaced with a different cathode, then Tesla should aim at a recycling process which can make the battery 100% recyclable and environmentally safe.

Thus, 15 drivers and 19 product technologies were identified and are mapped together to form a driver and product analysis grid. Thus, technologies that are yet to be adopted in the future were identified, and a detailed product gap analysis was developed in three phases that are 2016–2017, 2018–2020, and 2021–2025.

11.8 Methodology

11.8.1 SWOT Analysis

A detailed SWOT Analysis was performed in order to understand the factors which affect Tesla motor's performance in the future. Drivers were analyzed from the perspective of a consumer to find out the real needs in the market, and also an extensive literature review helped in deducing these drivers along with the future products that needed to be added to the electric cars.

11.8.2 *Defining Market Drivers and Products*

The main drivers for the market were identified and weightage was given to each of them. The weightage was given on a scale of 1–10. The market drivers and products were defined and labeled. Drivers were divided in four categories, namely, business needs, technology advancements, social trends, and regulations. For ease of use, these different drivers were named from D1 through D15. A roadmap was formulated by segmenting these categories across three timelines, i.e., 2016–2017, 2018–2020, and 2021–2025 (Fig. 11.1).

11.9 Product Gap Analysis

Products that were related to the drivers were mapped and analysis grid was formed. The mapped drives and product were given the weightage that was initially given to the drivers. The weights for each of these product-driver unions were added. The top

DRIVER AND PRODUCTS ANALYSIS GRID

Product Features		Health Monitoring	Family Friendly	Wifi Enabled	Reconfigurable Body Panels	Wireless Charging Stations	Portable Charging Equipment	Expanded Service Network	Faster Charging Batteries	Facial Recognition	Hack Proof Technology	Night Vision	Remote Vehicle Control	Solar Charging Panels	High Capacity Batteries	Hybrid With Clean Fuel	Lithium Free Batteries	High Efficiency Motors	Low Cost Battery	Refurbish-able Batteries
Drivers		P16	P8	P17	P18	P12	P3	P10	P1	P13	P14	P15	P19	P4	P5	P9	P2	P7	P11	P6
Market Position	D1		×			×	×	×	×		×				×			×	×	
Higher Capacity	D2	×	×	×	×				×			×	×				×		×	
Higher Performance	D3					×	×		×				×		×			×		
Longer Range	D4		×			×	×	×	×					×	×	×		×		×
Low Carbon Footprint	D5		×			×	×		×					×	×	×	×	×		×
Research Assistance	D6				×	×	×		×	×	×	×	×	×	×	×	×	×	×	×
Move Away From Lithium	D7		×													×	×			×
Charge By Renewable Sources	D8													×						
Pioneer In Innovations	D9				×	×	×		×	×	×	×		×	×	×	×	×	×	×
Lower Production Cost	D10		×					×											×	×
Less Charge Time	D11					×	×		×						×		×	×		
Lower Charging Service Cost	D12							×												×
Attractive to "Everyday Joe"	D13	×	×	×	×	×	×	×	×	×	×	×	×	×	×		×	×	×	×
Greener Everything	D14													×		×	×			
Stringent Regulations	D15							×						×	×	×	×			×

Fig. 11.1 Driver and product mapping [29]

2016-2017 PRODUCT GAP ANALYSIS

	Products		Active Health Monitoring	family friendly models (wagons, vans, suvs)	wifi	reconfigurable body panels (transformer)	wireless charging stations	portable charging devices	expanded service network	faster charging batteries	Facial recognition (theft protection)	Hack Proof Technology	Night Vision	remote vehicle control	solar charging panels	high capacity batteries	electric hybrid vehicle	lithium free batteries	high efficency motors	low cost battery	refurbishable batteries
Lable	Drivers	WT	P16	P8	P17	P18	P12	P3	P10	P1	P13	P14	P15	P19	P4	P5	P9	P2	P7	P11	P6
D1	Maintain top market position in electric car market	10		10			10	10	10	10		10				10			10	10	
D2	Target families	8	8	8	8	8				8			8	8				8		8	
D3	Maintain the high performance appeal	7					7	7		7				7		7			7		
D4	Reduce range anxiety	8		8			8	8	8	8					8	8	8		8		8
D6	University research in need of monetary assistance and real life	6				6	6	6		6	6	6	6	6	6	6	6	6	6	6	6
D9	first to go away from bulky cube batteries, need to continue the	9				9	9	9		9	9	9	9		9	9	9	9	9	9	9
D10	increase profit margin	7		7					7											7	7
D11	decrease charge time	9					9	9		9						9		9	9		
D12	low cost charging service (battery swap program)	5							5												5
D14	Green living (lithiom ion battery production are environmentally	6													6		6	6			
D15	Stringent regulations on the manufacture and recycling of batteries	7							7						7	7	7	7			7
Total			8	33	8	23	49	49	37	57	15	25	23	21	36	56	36	45	49	40	42
Rank							2	2		1						1		3	2	3	3

Fig. 11.2 Product gap for 2016–2017 [29]

eight unions with the highest weightage were chosen and given a ranking. This procedure was done for all three timelines. The highest-ranked products were color coded with red being the highest and white being the lowest. A driver-product roadmap was generated considering the rankings of the products across every timeline (Figs. 11.2, 11.3, and 11.4).

11.10 Technology Gap Analysis

Each of the products that was identified was analyzed if supporting technologies were available in the market. In places where gaps were identified, new technologies were recommended (Figs. 11.5, 11.6, and 11.7).

2018-2020 PRODUCT GAP ANALYSIS

Products			Active Health Monitoring	family friendly models (wagons, vans, suvs)	wifi	reconfigurable body panels (transformer)	wireless charging stations	portable charging stations	expanded service network	faster charging batteries	Facial recognition (theft protection)	Hack Proof Technology	Night Vision	remote vehicle control	solar charging panels	high capacity batteries	electric hybrid vehicle	lithium free batteries	high efficency motors	low cost battery	refurbishable batteries
Lable	Drivers	WT	P16	P8	P17	P18	P12	P3	P10	P1	P13	P14	P15	P19	P4	P5	P9	P2	P7	P11	P6
D1	Maintain top market position in electric car market	10		10			10	10	10	10		10				10			10	10	
D3	Maintain the high performance appeal	7					7	7		7				7		7			7		
D4	Reduce range anxiety	8		8			8	8	8	8					8	8	8		8		8
D5	Emerging market/customers are becoming more aware of their carbon footprint	6		6			6	6		6					6	6	6	6	6		6
D6	University research in need of monetary assistance and real life applications	6				6	6	6		6	6	6	6	6	6	6	6	6	6	6	6
D7	move away from Lithium which can be costly to dispose of	6		6													6	6			6
D8	charge by renewable sources (solar)	6													6						0
D9	first to go away from bulky cube batteries, need to continue the innovations	9				9	9	9		9	9	9	9		9	9	9	9	9	9	9
D10	increase profit margin	7		7					7											7	7
D11	decrease charge time	9					9	9		9						9		9	9		0
D13	make EVs more attractive to "everyday joe"	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6		6	6	6	6
D14	Green living (lithiom ion battery production are environmentally	6													6		6	6			0
D15	Stringent regulations on the manufacture and recycling of batteries	7							7						7	7	7	7			7
Total			6	43	6	21	61	61	38	61	21	31	21	19	54	68	48	55	61	38	55
Rank							2	2		2					3	1		3	2		3

Fig. 11.3 Product gap analysis 2018–2020 [29]

11.11 Technology Roadmap

The technologies were categorized into three subcategories, namely, battery technology, charger technology, and motor technology. The technologies needed to implement were found out using gap analysis. Based on the ranking in the product gap analysis, the technologies were prioritized. These are depicted in the roadmap using different color schemes. The roadmap has been developed

2020-2025 PRODUCT GAP ANALYSIS

Products			Active Health Monitoring	family friendly models (wagons, vans, suvs)	wifi	reconfigurable body panels (transformer)	wireless charging stations	portable charging stations	expanded service network	faster charging batteries	Facial recognition (theft protection)	Hack Proof Technology	Night Vision	remote vehicle control	solar charging panels	high capacity batteries	electric hybrid vehicle	lithium free batteries	high efficency motors	low cost battery	refurbishable batteries
Lable	Drivers	WT	P16	P8	P17	P18	P12	P3	P10	P1	P13	P14	P15	P19	P4	P5	P9	P2	P7	P11	P6
D1	Maintain top market position in electric car market	10		10			10	10	10	10		10				10			10	10	
D3	Maintain the high performance appeal	7					7	7		7				7		7			7		
D5	Emerging market/customers are becoming more aware of their carbon footprint	6		6			6	6		6					6	6	6	6	6		6
D6	University research in need of monetary assistance and real life applications	6				6	6	6		6	6	6	6	6	6	6	6	6	6	6	6
D7	move away from Lithium which can be costly to dispose of	6		6													6	6			6
D8	charge by renewable sources (solar)	6													6						
D9	first to go away from bulky cube batteries, need to continue the innovations	9				9	9	9		9	9	9	9		9	9	9	9	9	9	9
D13	make EVs more attractive to “everyday joe”	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6		6	6	6	6
D14	Green living (lithiom ion battery production are environmentally desctructive)	6													6		6	6			
D15	Stringent regulations on the manufacture and recycling of batteries	7							7						7	7	7	7			7
Total			6	28	6	21	44	44	23	44	21	31	21	19	46	51	40	46	44	31	40
Rank							3	3		3					2	1	3	2	3		

Fig. 11.4 Product gap 2021–2025 [29]

combining the driver, product, and technologies. The gap analysis was used to determine which technologies would create the right avenues to keep the product viable in the market. The roadmap below has three levels, and each of these levels has multiple sublevels. Each sublevel describes the roadmaps for the product timelines. The driver, product, and technology levels are connected to illustrate a roadmap on a 9-year timeline. For ease of use and to make the roadmap easier to understand, different color schemes were used to indicate the relation between product and the technology categories. Drivers, products, and technologies were labeled and sublabeled which made it easier to interpret the relation between them (Fig. 11.8) [29].

Product Features		ID	Technologies Needed	Gaps
P1.1	1 hour to fully charge	T1a.1 T1b.1 T1c.1	Fast charging electronics Battery charging controller Charger protection	Currently Available Currently Available Currently Available
P2.1	Lithium Disposition	T2a.1 T2b.1	Chemical disposal Waste management	Currently Available Currently Available
P3.1	Portable Charger Ver. 1.0	T3a.1 T3b.1	Portable Charger Portable charger protection	Currently Available Currently Available
P5.1	100 kWh batteries	T5a.1 T5b.1	Battery storage capacity Battery protection	High power density technology Currently Available
P6.1	Refurbish-able Batteries Ver. 1.0	T6a.1 T6b.1	Chemical recycling Refurbish process	Currently Available Reuse of recycled lithium
P7.1	90% Efficiency Motors	T7a.1 T7b.1 T7c.1	Electronic motor design Motor control electronics Motor overheating protection	Currently Available Currently Available Currently Available
P11	$250/kWh Batteries	T11a T11.b	Battery manufacturing Battery material cost	Battery assembly process improvement Currently Available
P12.1	1st Wireless Charging Station	T12a.1 T12b.1	Wireless charging Charging station design	High power wireless charging High Efficiency/low noise charging station design

Fig. 11.5 Technology gap 2016–2017 [29]

Product Features		ID	Technologies Needed	Gaps
P1.2	30 minutes to Fully Charge	T1a.2 T1b.2 T1c.2	Fast charging electronics Battery charging controller Charger protection	Lithium battery has a limit in charging rate. Unless change battery material to be lithium free, 30 minute to fully charge is not possible.
P2.2	Lithium Free Batteries	T2c.2	Aluminum battery	In research phase, not in production yet
P3.2	Portable Charger Ver. 2.0	T3a.2	Fast Portable charger	Increased charging capacity
P4.2	PV Panel on Vehicle	T4a.2	Integrated PV panel	Light-weight, durable PV material
P5.2	130 kWh Batteries	T5a.2 T5b.2	Battery storage capacity Battery protection	High power density technology Overheating and overcharging protection
P6.2	Refurbish-able Batteries Ver. 2.0	T6a.2 T6b.2	Chemical recycling Refurbish process	Currently Available Cost efficient refurbish process
P7.2	95% Efficiency Motors	T7a.2 T7b.2 T7c.2	Electronic motor design Motor control electronics Motor overheating protection	High performance magnet Currently Available Currently Available
P12.2	1000 Wireless Stations	T12a.2 T12b.2	Wireless charging Wireless charging station design	High power wireless charging High Efficiency/low noise charging station design

Fig. 11.6 Technology gap 2018–2020 [29]

11.12 Conclusion

With the increase of human population, there is also an increasing demand in the need of energy. This is the area where our supply is not being able to meet the demand, and by the usage of fossil fuels, we are deteriorating the environment and thereby our living. Since, 30% of the environmental pollution is caused by the usage of transportation from conventional energy, there is an immediate need of replacement of these vehicles with a cleaner fuel energy such as electric vehicles. This is

Product Features		ID	Technologies Needed	Gaps
P1.3	1 minute to Fully Charge	T1a.3	Fast charging electronics	This is possible only with aluminum battery. It is a gap for lithium ion battery.
P2.3	Lithium Free Batteries	T2c.3	Aluminum battery	We anticipate the aluminum battery technology will be available in production by then
P3.3	Portable Charger Ver. 3.0	T3a.3	High Capacity portable charger	Higher power storage
P4.3	PV Stations Nationwide	T4a.3 T4b.3	High-production PV panel Efficient energy storage	High efficiency power conversion Currently available
P5.3	160 kWh Batteries	T5a.3 T5b.3	Battery storage capacity Battery protection	High power density technology Overheating and overcharging protection
P7.3	98% Efficiency Motor	T7a.3	Electronic motor design	High performance magnet
P9.3	Battery/Hydrogen Hybrid	T9a.3 T9b.3 T9c.3	Hydrogen process Hydrogen storage Hydrogen fueled engine	Hydrogen fuel cell technology might not be possible to be used on Electric Vehicles
P12.3	5000 Wireless Stations	T12a.3 T12b.3	Wireless charging Wireless charging station design	High power wireless charging High Efficiency/low noise charging station design

Fig. 11.7 Technology gap 2020–2025 [29]

possible with firms such as Tesla which are not only the pioneer of their electric vehicle industry but encourage adoption of new technology to make electric cars more sustainable in the market. Not only the electricity is cheaper when compared to the gasoline but they are efficient. With upcoming inventions and technologies in the coming years, there would be electric cars which will be better than compared to the conventional vehicles. With this achievement, not only it would help the environment; it also would make the country energy independent.

The main objective of this report is to develop a roadmap for the Tesla motors and to assess the current state of electric cars in the market. This research report considers all factors and integrates drivers, products, and relevant technology together to form into a roadmap.

This report helps in assessing the current state of battery electric vehicles and where the industry is at. It also provides a roadmap for Tesla motors for a span of 10 years and helps in forecasting the technologies that need to be adopted in the future for satisfying the consumers and to overcome the hurdle between conventional vehicles and electric vehicles. The gaps were also included in this report for products and what level of technology is needed to reach that particular product for adoption with the help of SWOT Analysis. However, the Porter's Five Force Analysis helped to identify the current threat level of the electric industry.

This roadmap is usually constructed by considering all the present factors and forecasting technology for the future. However this particular roadmap was made free of arrows which are used for linkage rather it is constructed based on the color code and the sublabels attached to it. This would make the roadmap easier for adding or deleting any technology. With new challenges in the market, new technologies also should be added to the roadmap to overcome these and to make Tesla a pioneer in the entire automobile industry.

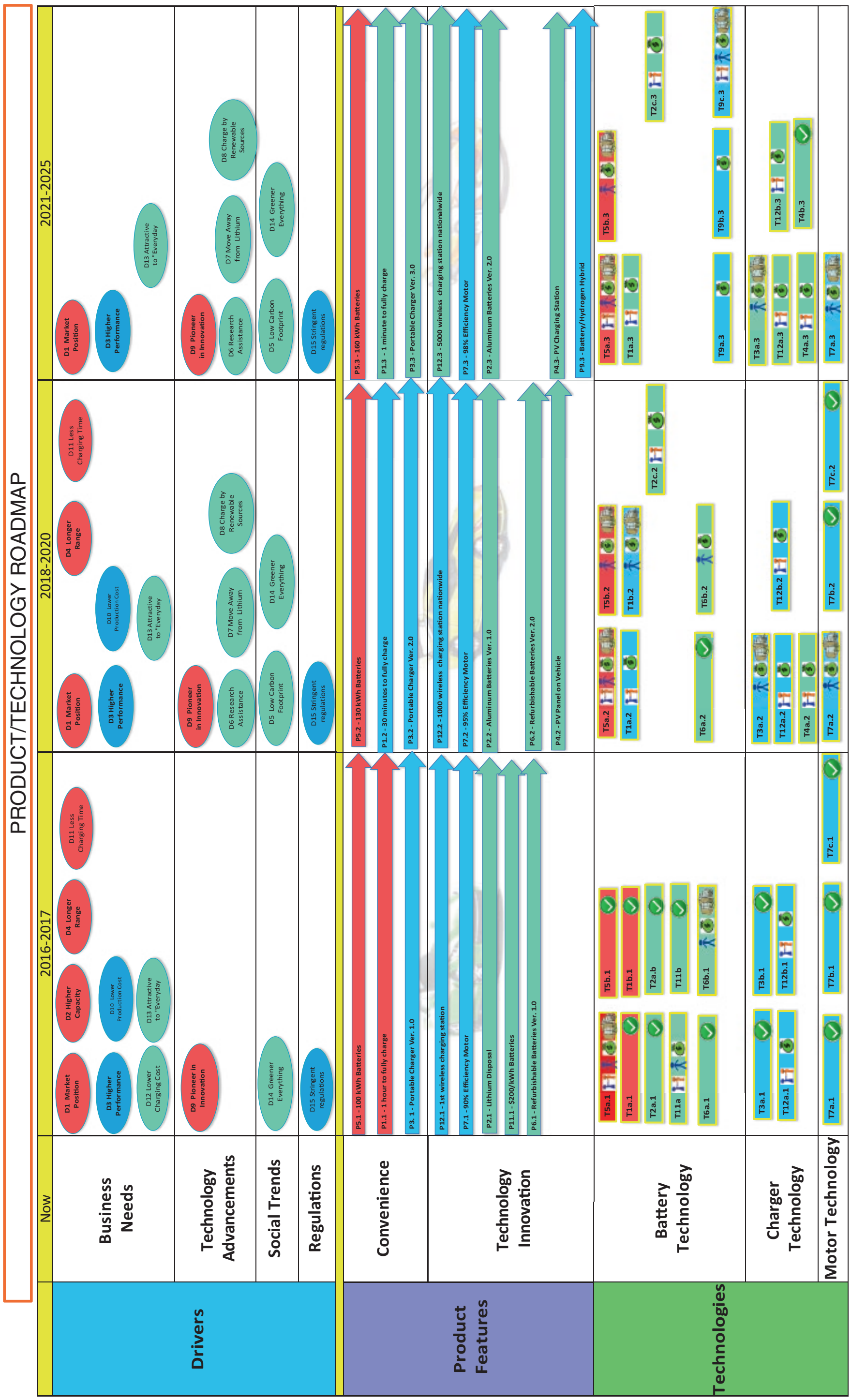


Fig. 11.8 Final roadmap [30]

Acknowledgment Colette Marthaller, Liyan Xiao, Yasaswi Deepak Kancherla, Stephen Jordan, Ahlam Alsuwaida, and Tanzila Akhter collected and analyzed initial data for this project.

Appendices

Appendix A

Basic Working Principle of an Induction Motor

It has two main components which are rotor and stator mainly. The rotor is a shaft with copper rods running through it, whereas the stator is attached primarily to the car and the rotor rotates in it (Fig. 11.9).

Appendix B

Three analyses have been used to understand the electric cars as well as Tesla motors' position in the current market and future market. These are, namely, SWOT Analysis, PEST Analysis, and Porter's Five Force Analysis.

B.1 SWOT Analysis (Fig. 11.10)

B.2 Porter's Five Force Analysis (Fig. 11.11)

B.3 PEST Analysis

Based on the PEST (Political, Economic, Social, and Technological) Analysis, several market drivers were deduced which affect the market condition of electric cars. It is a part of analysis which helped in extensive market research and which helped to deduce these factors which affect the company status.

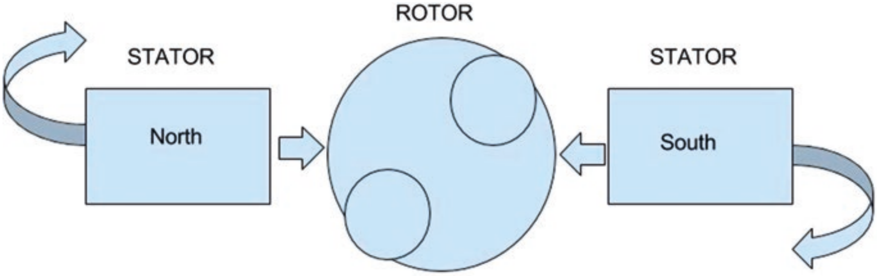


Fig. 11.9 Basic working principle of an induction motor

Strengths	Weaknesses
• Brand Recognition • Higher Performance • Advanced Battery Technology • Environmental Friendly	• Expensive Vehicles • Low profit • Longer Charging Time • Lower Range • Lesser Charging Stations and supercharging stations
Opportunities	**Threats**
• More research in EV technology • Increasing prices of conventional fuels • Greater benefits and tax breaks from government • Increasing concern about global warming causing to increase the opportunity	• Introduction of new startups in the EV industry • Other renewable source of energy and hybrid energy technology

Fig. 11.10 SWOT analysis

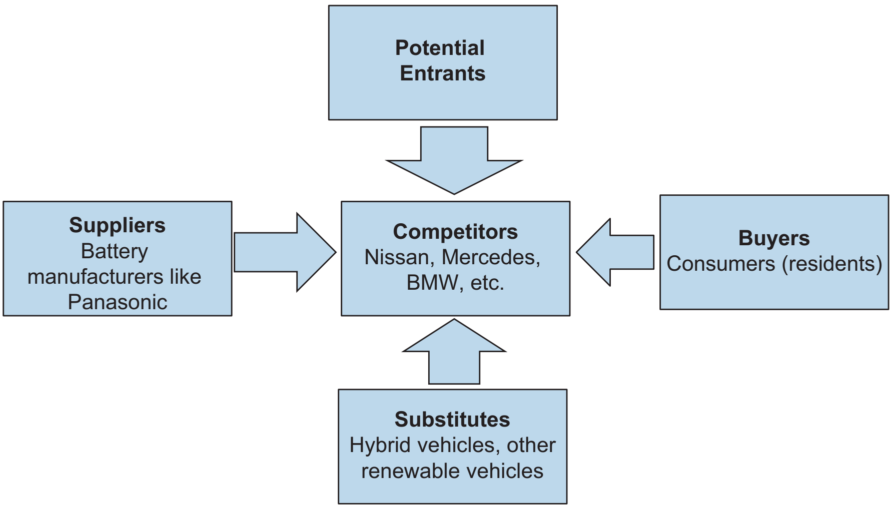


Fig. 11.11 Porter's five force analysis

References

1. URL, http://energy.gov/articles/history-electric-car
2. URL, http://evobsession.com/tesla-chevy-volt-ford-energi/
3. URL,http://www.ucsusa.org/our-work/clean-vehicles/car-emissions-and-global-warming
4. URL, http://www.nexteraenergy.com/news/contents/2009/092409.shtml
5. Sachen, R., (2015) EV vs. gas cars – Part 1 efficiency. *Electrical Vehicles.* Availabe at http://sunspeedenterprises.com/ev-vs-gas-cars-part-1-efficiency/
6. URL, http://www.epa.gov/otaq/climate/regs-light-duty.htm
7. URL, http://www.eia.gov/tools/faqs/faq.cfm?id=727&t=6
8. URL, https://www.whitehouse.gov/sites/default/files/other/fact-sheet-one-million-advanced-technology-vehicles.pdf
9. URL, http://www.rechargebatteries.org/wp-content/uploads/2013/04/Batteries-2012-Roland-Berger-Report1.pdf
10. URL, http://energy.gov/articles/egallon-how-much-cheaper-it-drive-electricity
11. URL, http://www.vacleancities.org/wp-content/uploads/Clean-Car-Charging.pdf
12. URL, http://ecowatch.com/2013/11/26/renewable-energy-biggest-business-opportunity/
13. URL, http://www.rmi.org/DoEVsCreateJobsImproveEconomy
14. URL,http://www.forbes.com/sites/greatspeculations/2015/07/02/teslas-unique-position-in-the-car-market-is-one-of-its-biggest-strengths/#62779abc22ec
15. URL, http://www.ibtimes.com/why-tesla-model-s-so-expensive-how-can-price-go-down-model-3-1655338
16. URL,http://media.ntu.edu.sg/NewsReleases/Pages/newsdetail.aspx?news=809fbb2f-95f0-4995-b5c0-10ae4c50c934
17. URL,http://www.wballiance.com/industryinsights/importance-of-wi-fi-in-a-connected-society/
18. URL, http://firsttoknow.com/me-we-toyotas-green-concept-car-features-fully-reconfigurable-body/
19. URL, http://www.evsolutions.com/turbocord
20. URL,https://www.technologyreview.com/s/516876/forget-battery-swapping-tesla-aims-to-charge-electric-cars-in-five-minutes/
21. URL, http://www.iii.org/issue-update/auto-theft
22. URL, http://www.foxnews.com/leisure/2014/09/02/gm-reportedly-ready-to-introduce-facial-recognition-tech-in-cars/
23. URL, https://www.wired.com/2015/01/fords-working-remote-control-car/
24. URL, http://www.extremetech.com/extreme/191336-mercedes-hydrogen-electric-hybrid-harvests-solar-wind-energy-with-its-paint-job
25. URL, http://www.rsc.org/chemistryworld/2015/04/super-fast-charging-aluminium-batteries-aluminum-ready-take-lithium
26. Patrick M. K., & Lorenz R. D. (1995). Control methodology for single stator, dual-rotor induction motor drives for electric vehicles In *Power electronics specialists conference*. PESC '95 Record, 26th Annual IEEE.
27. URL, http://cleantechnica.com/2015/03/26/ev-battery-costs-already-probably-cheaper-than-2020-projections/
28. URL, https://www.teslamotors.com/blog/teslas-closed-loop-battery-recycling-program
29. Marthaller C., Xiao L., Kancherla Y. D., Jordan S., Alsuwaida A., & Akhter T. (2015). Electric vehicle technology roadmap for Tesla. Portland State University, Department of Engineering and Technology Management.
30. URL, http://www.iea.org/publications/freepublications/publication/TechnologyRoadmapAguidetodevelopmentandimplementation.pdf
31. Willyard, C. H., & McClees, C. W. (1987). Motorola's technology roadmap process. *Research Management, 30*, 13–19.

32. Rinne, M. (2004). Technology roadmaps: Infrastructure for innovation. *Technology Forecasting and Social Change, 71*, 67–80.
33. Allan, A., Edenfeld, D., Joyner, W. H., Kahng, A. B., Rodgers, M., & Zorian, Y. (2002). 2001 technology roadmap for semiconductors. *Computer, 35*(1), 42–53.
34. McDowall, W., & Eames, M. (2006). Forecasts, scenarios, visions, backcasts and roadmaps to the hydrogen economy: A review of the hydrogen futures literature. *Energy Policy, 34*, 1236–1250.
35. Petrick, I. J., & Echols, A. E. (2004). Technology roadmapping in review: A tool for making sustainable new product development decisions. *Technology Forecasting and Social Change, 71*, 81–100.

Chapter 12
Technology Assessment: Emerging Automotive Technologies for the Future

Aurobindh Kalathil Puthanpura, Rafaa Khalifa, Leong Chan, and Husam Barham

12.1 Introduction

The continuous increase in human population is accompanied with more transportation demand. As a result, the pressure on transportation infrastructure has increased beyond the ability of infrastructure to catch up, leading to increased number of traffic incidents and road congestions [1, 2]. In the USA, there are more than 6 million traffic accidents, including fatality accidents that kill more than 30 thousand people every year [3]. Also, road congestion leads to a cost of about 4.8 billion hours of time, 1.9 billion gallons of wasted fuel (equivalent to 2 months operation of the Alaska Pipeline), and $101 billion in combined delay and fuel costs, aside from cost associated with travel time and dependability [3–5].

In the past 125 years since the first automobile was invented around 1885 [6], people have never stopped seeking new means to improve vehicles, traffic, transportation systems for efficiency, safety, environmental sustainability, and comfort. The advancements in information and communication technologies have been utilized as part of those efforts, leading to the rise of the intelligent transportation systems (ITS) [7].

Using information and communication technologies, vehicles have increasingly effective driver assistance and protection mechanisms. Various onboard controls and information sources allow the driver to customize her driving experience and remain up to date on the vehicle status. Recent technological developments, wireless communication, notably in mobile computing and remote sensing, are now

A prior version of this paper was presented at Portland International Conference on Management of Engineering and Technology, 2015.

A.K. Puthanpura • R. Khalifa (✉) • L. Chan • H. Barham
Department of Engineering and Technology Management, Portland State University, Portland, OR, USA
e-mail: rkhalifa@pdx.edu; chanla@plu.edu

T.U. Daim et al. (eds.), *Infrastructure and Technology Management*, Innovation, Technology, and Knowledge Management,
https://doi.org/10.1007/978-3-319-68987-6_12

pushing intelligent transportation systems (ITS) toward a major leap forward. Vehicles are already integrated with sophisticated computing systems and onboard sensors each dedicated to one part of the car's operation. The new elements include addition of new wireless communication, computing and sensing capabilities. Interconnected vehicles not only collect information about themselves and their environment, but they also exchange information in real time with other nearby (in principle) vehicles [8].

Considering the problems and development in the automotive industry, this research developed and applied scenario-based multi-attribute decision-making (MADM) methodology for the selection of automotive technology. This would be the main focus of the paper and reminder of this paper is organized in six sections. Section 12.2 reviews the literature. Section 12.3 describes the methodology that was used to conduct the study, candidate technology, data collection, and scenario analysis explanations. Section 12.4 details the empirical results of the analysis and followed by discussion of the results; conclusion and future research are outlined.

12.2 Literature Review

In this section, a summary of literature review including the current challenges facing the automotive industry related to the automotive technologies is offered. A description of the technologies that emerged in response to those challenges, and the current status of those technologies are also provided.

12.2.1 Current Automotive Challenges

The ever-increasing number of people and vehicles on the roads is causing several societal challenges related to safety, pollution, and economy [3, 9–13]:

– Safety: As described earlier in the introduction, in the USA alone, there are more than 6 million traffic accidents, including fatality accidents that kill more than 30 thousand people every year [3]. Accidents are caused by vehicle collisions and vehicles hitting road elements or hitting pedestrians. Statistics indicates that human error is the dominant reason for accidents.
– Environment and health pollution: The fossil-fueled vehicle's engine is a main source of environment and health hazards; it emits nitrogen oxides, particulate matters, carbon monoxide, CO2, and other green gases which contribute to climate change and have health impacts on humans and all living beings. So, vehicles have environment and health impact just by being on the road, not to mention the extra time vehicles spent on the road due to traffic congestions.
– Economy: The ever-increasing number of vehicles on the roads has major economical costs. The US Department of Transportation estimates that the average

American spends a week of commuting every year [5]. Extra driving time due to traffic congestions and parking search results in more fuel cost and time wastage for businesses and people. Furthermore, adding more infrastructure capacity to handle the increased traffic is very expensive.

– Government regulations: In many countries, including the USA, regulations are being enacted to enforce better fuel efficiency. For example, the Energy Policy and Conservation Act (EPCA) which established mandatory fuel economy standards for all new automobiles sold in the USA [10] along with the Corporate Average Fuel Economy (CAFE) was designed to increase the incentive for automotive producers to improve fuel efficiency beyond that dictated by market forces.

12.2.2 Intelligent Transportation Systems (ITS)

According to the US Department of Transportation (DOT), intelligent transportation systems (ITS) are the application of advanced information and communications technology to surface transportation in order to achieve enhanced safety and mobility while reducing the environmental impact of transportation [14]. So, the idea behind ITS is to create management mechanisms with learning capabilities, based on cognitive networking principles, to offer insights and analytics that can be actively used to manage the traffic and influence driving decisions and behaviors [15, 16].

This will lead to several benefits including [15–18]:

– Reduction of traffic congestions and commute time wastage by effectively managing the traffic and guiding cars to optimal routes from source to destination based on real-time feedback on traffic and road element conditions
– Minimizing the risk of accidents or at least reducing the severity of accidents using technologies like incident management and collision avoidance
– Increasing safety for pedestrians, by adding smart capabilities to vehicles to identify and avoid pedestrians
– Reduce environment pollution by reducing average traffic time and applying complex analysis to in order to create better environment traffic patterns, for example, by spreading the traffic around the city and making sure diesel-based vehicles are not condensed in certain areas and so on
– Achieve cost savings, since reducing commute time means more work time and less fuel consumption
– More efficient use of infrastructure, which means less need to add more, expensive, traffic capacities

To effectively create the needed analytics, ITS leverage on technology and communication-based infrastructure to acquire comprehensive traffic data. This data would be generated using sensors and computing capabilities embedded in cars and road elements, as well as data generated from communication and interactions between cars and between cars and transportation infrastructure [11, 16, 18, 19]. The addition of wireless communication systems offers a powerful and transformative opportunity to establish transportation connectivity that further enables cooperative systems and dynamic data exchange using a broad range of advanced systems and technologies [20].

12.2.3 Automotive Technologies Under ITS

As explained earlier, ITS benefits include offering mechanisms to make driving more safe and efficient (less traffic congestions and better use of traffic infrastructure), as well as reducing environmental pollution and cost. Moreover, offering needed capabilities to enable autonomous cars. However, to effectively achieve such benefits, cars need to have the ability, not just to harness information within the vehicle only but also to connect and communicate with each other and the infrastructure, using a ubiquitous communication system [21].

Such system relies on several technologies that can be grouped into three categories: within the vehicle, between vehicles, and between vehicle and infrastructure [15, 18, 19].

First, technologies within the car itself: Technologies and controls offer protection and driving assistance to drivers, by enabling the driver to be informed about the status of the car, provide passive safety against road adversaries, and assist in driving the car. Such technologies aim to reduce traffic incidents and increase driving efficiency. Technologies within the car are paving the way for autonomous driving. Examples of technologies within the car, that are already available commercially, include GPS-based navigation, anti-lock braking, collision avoidance, object detections and auto braking, rear cross-traffic alerts, blind spot monitoring, adaptive headlights, drowsiness detection, park assist (automatic, rear cameras, back sensors), and so on [9, 22–25].

Second, vehicle-to-vehicle (V2V) communication technologies: A driver typically relies on other driver's reaction to know about and respond to emergency situations. For example, drivers typically rely on the tail brake light of the car immediately ahead to decide on braking actions. However, this is not always the best collision avoidance strategy [26]. Furthermore, as noticed and reported in some previous research, in many cases, the ability to detect emergency event occurring at some distance ahead is limited by the inability of drivers to see past the vehicle in front of them.

So, V2V technologies have emerged to help drivers respond to road conditions by allowing cars to share safety messages. It depends on vehicular ad hoc networks (VANETs) that disseminate safety messages for nearby cars [27, 28].

Third, vehicle-to-infrastructure (V2I) communication technologies: These provide information and suggestions about vehicles and drivers related to safety and infrastructure, to impose certain behaviors on the road as a whole. These information and suggestions are provided in real time; it is personalized, more accurate, and reliable than that currently provided on VMS, radio, etc. V2I depends on vehicle and road elements' sensors reporting information to a central location, as well as preexisting information about the road that can then be used together as a source for traffic control measurement [21, 29]. V2I technologies are being developed now to not just address safety and current traffic conditions but also to offer suggestions and controls on the roads that help the environment as well [30]. Appendix A Table 12.1 lists several technology advances under ITS.

12.2.4 Autonomous Cars

Autonomous technologies have been developed over several decades to support human drivers. Some of these technologies include anti-lock brake system, traction and cruise control, warning systems, and parking assist – to provide some level of autonomy. The RAND Corporation report on autonomous vehicle research indicates that these systems have indeed helped to reduce road crashes to a great extent. However, all these advancements still require the driver to provide a level of control and monitoring while on the road in order to stay safe – which means regardless of the kind of new features, which are added to assist the driver – driver decision is very much required during driving [31].

Even with some of the advances made in developing safety technologies in cars, public records from the USA show that in 2011, 39% of road fatalities had something to do with alcohol [31, 32]. This trend shows that the existing advancements still essentially are not close to fixing the road crash fatality issues due to alcohol.

With today's automotive intelligence technologies, the driver is the one at helm, including which road to travel, where to park, and at what speed to accelerate on a highway. Since the driver might be wrong in his judgment in all these decisions, it is apparent that fuel usage is not efficient since the driver might not know which roads are busy or which parking spot is available. Research shows that several gallons of fuel are wasted everyday looking for parking spot [32]. Again, there is evidence suggesting that driving practices of uniform acceleration help to efficiently burn fuel; the question to answer is "Does the current level of vehicle automation ensure the optimal consumption of fuel?" [31]. Thirdly, the past and present vehicles are made with heavy metals to keep them stable for safety reasons. If we can develop automobiles, which can ensure enhanced safety using intelligent sensors or other connected communication technologies, 20% of weight decrease corresponds to 20% fuel efficiency [32]. The inefficient use of fuel leads to greenhouse gases which have a tremendous cost implications in terms of threat of this planet and associated cost to decrease emissions; for instance, the Environmental Protection Agency (EPA) estimates the annual cost of greenhouse gases for the USA alone is about $41 billion [31].

The tasks associated with operating a vehicle that requires effortful processing can drain a driver's cognitive resources, leading to the stress of the driver. In fact, considering all aspects of the driving task, one might argue that the complexity of operating a modern automobile has outstripped the capability of the human nervous system. But as long as there is still the action of the driver and sometimes for long distances, it is still stressful and is a contributing factor to several road accidents [33].

It is estimated that at least one out of four North American and European citizen will be over 65 by 2020 and might have some kind of disability which can impact their driving capabilities. The existing autonomous car technologies do not take into consideration the aging population and the disabled [34].

As can be seen from this discussion, autonomous cars held the promise of answering many automotive challenges. And in recent years, there was a great deal of progress to introduce autonomous cars, fueled by the advancement in ITS technologies [35]. For example, autonomous cars by Google hit the roads in 2009 and by March 2016 reached 1.5 million miles of autonomous driving [36]. Furthermore, most major car manufacturers are now conducting research on autonomous cars and expect to have it on the streets by the early 2020s [37].

12.2.5 Current Situation

The development of vehicle communications is more active in Europe, the USA, and Japan. For example, in Europe E-safety research program from EU Intelligent Car Initiative and industry-driven project V2V Communication Consortium are some of the lead actors; in the USA, the V2I technology and the California Partners for Advanced Transit and Highways (PATH), and in Japan, the Advanced Safety Vehicle (ASV) program, are notable, and some testing has been conducted in this regard. Among the ASV technologies, adaptive cruise control (ACC), lane keeping support system, automatic braking system for reducing injury, curve overshooting preventing support system, and nighttime forward pedestrian advisory system are now available in market. While some new technology ideas are under research, others are at driving test stage [38].

12.3 Methodology

Multiple-attribute decision-making methodology is the process of finding the best option from all of the possible alternatives. In almost all such complications, the multiplicity of criteria for judging the alternatives is pervasive. That is, for many such problems, the decision-maker wants to solve multiple criteria decision-making (MCDM) problem [39]. One such methodology is Technique for Order Preference by Similarity to Ideal Solution (TOPSIS). TOPSIS is used to rank the best alternative from three different alternatives. The methodology is extended to include scenario analysis to mimic real-life situations. Since information available to decision-makers may vary in quality and scale, it becomes challenging to make real-life decisions.

TOPSIS is a simple ranking method in conception and application developed by Hwang and Yoon in 1981. It is an extension of the theory of ideal solutions developed by Zeleny [40] in 1974. The basic principle governs that the chosen alternative should have the shortest distance from the ideal solution and the farthest distance from the negative ideal solution [41]. The positive ideal solution maximizes the benefit criteria and minimizes the cost criteria, whereas the negative ideal solution maximizes the cost criteria and minimizes the benefit criteria. TOPSIS is a technique that combines quantitative attribute (such as price, distance, time, and so on) and qualitative attributes (such as quality of relationship, quality of assurance, and reliability) and compares all alternatives together based on these attributes [42]. TOPSIS also provides cardinal ranking of alternatives, making apt use of attribute information, and does not require attribute preferences to be independent.

12.3.1 Technique for Order Preference by Similarity to Ideal Solution (TOPSIS)

TOPSIS methodology is created using a series of steps described below [43].

Step 1 Calculate the normalized ratings

Normalizing the attribute value information as it is available in different scales. The normalization converts dimension attributes to non-dimension attributes allowing comparison across attributes.

$$r_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} x_{ij}^2}}$$

where r_{ij} is the normalized score matrix and x_{ij} is the score of the jth indicator for ith alternative and there are n attributes and m alternatives.

Step 2 Calculate the weighted normalized ratings

The weighted normalized matrix is calculated as

$$a_{ij=} w_j r_{ij}$$

where w_j is the weight of the jth attribute.

Step 3 Identification of positive ideal and negative ideal solution

Positive ideal solution (PIS) is found by finding the maximum a_{ij} value for each set of benefit attribute and minimum a_{ij} value for each set of cost attribute whereas negative ideal solution (NIS) is found by finding the minimum a_{ij} value for each set of benefit attribute and maximum a_{ij} value for each set of cost attribute.

$$\text{PIS} = \{(\max a_{ij} | j \in j_1), (\min a_{ij} | j \in j_2) | i = 1, \ldots, m\}$$

$$\text{NIS} = \{(\min a_{ij} | j \in j_1), (\max a_{ij} | j \in j_2) | i = 1, \ldots, m\}$$

where j_1 is set of benefit attributes, j_2 is set of cost attributes, and $j_1 + j_2 = n$ (total number of attributes).

Step 4 Calculate separation measures

The separation measure between attributes is measured by the n-dimensional Euclidean distance. The separation of each alternative from the positive ideal solutions, D^+, is given by the formula:

$$D_{\mathrm{i}}^{+} = \sqrt{\sum_{j=1}^{n} \left(a_{ij} - a_j^{+}\right)^2}, i = 1, \ldots, m$$

The separation from the negative ideal solutions, D^- is given by the formula:

$$D_{\mathrm{i}}^{-} = \sqrt{\sum_{j=1}^{n} \left(a_{ij} - a_j^{-}\right)^2}, i = 1, \ldots, m$$

Step 5 Calculate similarities to positive ideal solution

Similarities to positive ideal solution are calculated using the formula:

$$R_i^* = \frac{D_i^-}{\left(D_i^+ + D_i^-\right)}, i = 1, \ldots, m$$

Note $0 \le R_i^* \le 1$, where $R_i^* = 0$ when $D_i = D^-$ and $R_i^* = 1$ when $D_i = D^+$.

12.3.2 Candidate Technology

12.3.2.1 Vehicle to Vehicle (V2V)

Vehicle to vehicle (V2V) is an automotive technology that is designed to allow automobiles to communicate with each other. The V2V system uses dedicated short-range communication (DSRC) which is in the 5.9 GHz frequency. This frequency is also used by U-NII devices (Unlicensed National Information Infrastructure).

Federal Communications Commission (FCC) has allocated spectrum for use by DSRC technologies that are part of DOT's ITS research program. Allocation involves segmenting spectrum used for wireless communication into bands of frequencies that are allocated for use by particular types of services. FCC manages spectrum use for non-federal users, including private, commercial, and state and local government users; the Department of Commerce's National

Telecommunications and Information Administration manages spectrum for federal users (47 U.S.C. §§ 303, 305) [44]. Specifically, in 1999, FCC allocated 75 megahertz (MHz) of spectrum[1] – the 5.850–5.925 gigahertz (GHz) band (5.9 GHz band) – for the primary purpose of improving transportation safety and adopted basic technical rules for DSRC operations.[2] In 2003, FCC established licensing and service rules for the 5.9 GHz band to provide short-range, wireless link for transferring information between vehicles and roadside systems.[3] However, the president and Congress have responded to the growing demand for wireless broadband services by making changes in the law to promote efficient use of spectrum, including the bands previously set aside for use by DSRC-based technologies.

The communication technology will enable vehicles to exchange vital information ten times per second, about location, acceleration, speed, and braking. Cars will be able to calculate the hazard risks within about 300 meters and alert their drivers or even take automatic collision-avoidance action [45].

12.3.2.2 Vehicle to Infrastructure (V2I)

V2I is defined as a communication and cooperative exchange of data between vehicles via wireless technologies, within a range that can vary from a few meters to a few hundred meters. In order to improve road safety, quality, efficiency, and when necessary increase the capacity of the road, this technology has been conceived to deal with a small time interval: even through an accident has occurred at a distance which would make it difficult for the driver to react promptly, the information is rapidly transmitted to the vehicle, and if required an automatic system intervenes, possibly without the driver's involvement, to prevent the accident or other consequential accidents [46].

The V2I computing, communication, and sensing equipment and user interfaces will be, in most cases, new with respect to the current onboard equipment. In terms of sensing and user interface hardware and software, V2I technology and its systems will leverage the array of equipment vehicles currently carry; for example, data concerning the vehicle operation will be obtained via the corresponding or

[1] In the Matter of Amendment of Parts 2 and 90 of the Commission's Rules to Allocate the 5.850–5.925 GHz Band to the Mobile Service for Dedicated Short-Range Communications of Intelligent Transportation Services, Report and Order, 14 FCC Rcd 18,221 (1999).

[2] Radio frequencies are grouped into bands and are measured in units of hertz, or cycles per second. The term megahertz (MHz) refers to millions of hertz and gigahertz (GHz) to billions of hertz. The hertz unit of measurement is used to refer to both the quantity of spectrum (such as 75 MHz of spectrum) and the frequency bands (such as the 5.850–5.925 GHz band).

[3] Amendment of the Commission's Rules Regarding Dedicated Short-Range Communication Services in the 5.850–5.925 GHz Band (5.9 GHz Band); Amendment of Parts 2 and 90 of the Commission's Rules to Allocate the 5.850–5.925 GHz Band to Mobile Service for Dedicated Short Range Communications of Intelligent Transportation Services; WT Docket No. 01–90, ET Docket No. 98–95, Report and Order, 19 FCC Rcd 2458 (2004) (FCC 03–324).

upgraded onboard interfaces. In general, V2I technology will not be developed from scratch; rather, as ongoing projects show, mature and well-understood components and their variants will be the basis [9].

The new objectives of transport systems and mobility concerns are quality, efficiency, safety, and security. One of the most interesting tools related to safety refers to a set of applications that involve interaction and cooperation between an infrastructure and in-vehicle systems.

12.3.2.3 Autonomous Vehicles

Over the past 50 years, there have been several innovations in the automotive industry to create autonomous technologies that provide some level of assistance to human drivers [47]. Examples of such technologies include advanced cruise control, anti-lock brake systems, collision avoidance systems, and several others which companies have incorporated on incremental basis to provide some level of control and support to drivers. Our definition of autonomous cars is beyond the incorporation of some level of autonomous behavior in a car. Autonomous cars for our purpose represent a leap from providing support systems to human drivers to developing self-driving cars, which require no human control to move from point A to B [31, 47].

Autonomous cars offer the possibility of fundamentally changing transportation and promise to do away with several kinds of interactions with cars which required human cognition, control, and monitoring [32]. Levels of autonomy as illustrated in Appendix Table 12.2 are regarded as the highest level of classification established by the National Highway Traffic Safety Administration. The benefits which can be derived depend largely on the level of autonomy provided, for example, a car with anti-lock brake system will only provide the safety associated with such a technology whereas one with full autonomy as defined above has all conceivable safety and other kinds of benefits.

Unlike existing cars (level 0 through 3) where the level of autonomy still requires the human driver to be aware of his environment and driving conditions in order to make accurate decisions, the autonomous car will be capable of sensing its environment and navigating without human input [47].

12.3.3 Data Collection

Data collection was done though survey with an expert in the field. The attributes were rated on a 7 point Likert scale 1 being the lowest and 7 being the highest. The attributes that were rated were grouped into two categories: benefit attributes and cost attributes. Safety, fuel efficiency, compatibility, and availability were grouped as benefit attributes, and cost is grouped as cost attributes. The attributes were selected based on literature review as illustrated in Appendix Table 12.3. The values for the data collected are illustrated in Appendix Table 12.4. Availability attribute is calculated based on differences between current year (2014) and when the technology will be available. V2V technology is expected to be in the market by 2018 so the value is (2014–2018) -4. V2I technology is expected to be in the market soon after that as that is an extension of V2V technology, so the value is (2014–2021) -7. Autonomous vehicle technology is expected by 2025 so the value is (2014–2025) -11.

12.3.4 Scenarios

In order to mimic the real-world situation, nine scenarios and no scenario were created, and based on the scenarios, each attribute was assigned weights. In Appendix Table 12.5, the scenarios and the weights are elaborated upon. This is performed to create the scenarios' push-pull framework to policy decisions and influence the supply of new knowledge directly. There are two ways governments can encourage innovation: technology push implements measures to reduce the public measures, and demand pull implements measures that increase the private payoff to successful innovation [48]. Three different policy instruments were used to create the six different scenarios in three different time frames. The three policy instruments are government sponsored R&D, tax credit for companies to invest in R&D, and tax credit and rebates for consumers for adoption of new technology. The three time frames used for the study are short term, medium term, and long term.

No scenario depicts a non-real solution. Scenario 1, scenario 2, and scenario 3 assess the impact of the government-sponsored R&D in the three different time frames. Scenario 1 depicts the situation where the initial government-sponsored R&D is assessed in the short-term time frame. Even with the policy in place, the cost of the technology is high as it is a new technology, and as the technology evolves, the cost of the technology will lower. Scenario 2 and scenario 3 depict the situation in medium and long term with the cost of the technology decreasing. Scenario 4, scenario 5, and scenario 6 assess the impact of the tax credit for companies to invest in R&D in the three different time frames. Scenario 4 depicts the situation where the companies are given tax credit to invest in R&D in the short term that lowers the cost of innovation in the initial stages. However, as the tax credit policy diminishes, the cost of the investment will increase in the scenario 5 and 6 as the time frames increase. But the knowledge gained in the initial stages will reduce the cost in the long run as they have knowledge of the technology. Scenario 7, scenario 8, and scenario 9 assess the impact of the tax credit and rebates for consumers in the three different time frames. Scenario 7 depicts the situation where the consumers are given a rebate for the adoption of this technology in the short term where the cost of the technology will be higher. However, as time progresses, as depicted in scenario 8 and 9, and with improvement of the technology, the cost to the technology will gradually decrease and will be competitive with other traditional vehicles in the market.

12.4 Results and Discussions

Table 12.6 provides detailed results of all the scenarios and time frame discussed above. For the no scenario case, all the attributes are given equal weights. Even in this case, V2V (with a score of 0.883) is ranked as the most preferred alternative since the attribute rated for V2V is higher. V2V is ranked as the most preferred alternative (with a score of 0.883), while V2I holds the second rank (with a score of 0.576) for scenario 1. This outcome is reasonable for scenario 1 as it depicts a situation in which alternatives are evaluated in the short term and with government-sponsored R&D. V2V has a lower cost than the other alternatives and satisfactory performance in terms of safety and compatibility. Scenario 2 and scenario 3 are similar to scenario 1 with the only difference being the time frame which would help consumers with more options as there are more competitors in the market that would drive the price.

Scenario 4, scenario 5, and scenario 6 depict the situation in which the alternatives are evaluated where companies are provided tax credit to invest in R&D. V2V is ranked as the most preferred alternative (with a score of 0.923) followed by V2I (with a score of 0.573) in scenario 4. Scenario 5 and scenario 6 are similar to scenario 4, the only difference being the time frame; still V2V is the most preferred alternative (with a score of 0.915, 0.900) followed by V2I (with a score of 0.552, 0.522). This is expected since in the medium-term and long-term technologies are in use and the cost of the alternatives is lower than their initial price.

Scenario 7, scenario 8, and scenario 9 depict the situation in which the alternatives are evaluated in which tax credit and rebates for consumers are given for technology adopters. V2V is ranked as the most preferred alternative (with a score 0.920) followed by V2I (with a score of 0.563). Scenario 8 and scenario 9 are similar to scenario 7, the only difference being the time frame. Still V2V is the most preferred alternative (with a score of 0.912, 0.899) followed by V2I (with a score of 0.540, 0.499). This is expected since autonomous vehicles are still more expensive than other technologies.

The result shows that V2V will most likely fit the safety needs of road transport in the short, medium, and long terms while still balancing all the other criteria (compatibility, cost, fuel efficiency) and could be available sooner than the other candidates, whether or not there is policy to push it. More R&D to speed up V2V implementation will help provide more safety features for existing cars and that same technology can further speed up the development of full autonomous cars.

The weight assignment for each of the scenarios is given based on cardinal scale of 0–100 (0 as the worst and 100 as the best for benefit criteria and vice versa for cost criteria). This is used to transform qualitative criteria to quantitative one. The safety attribute was given a weight of 80 for all the scenarios, since for successful adoption of these vehicular technologies it is mandatory for it to have the highest safety rating and any small error in the technology could lead to a devastating outcome. Fuel efficiency was given a weight of 50 for all the scenarios, because it would be dependent on the consumer to choose appropriate vehicles. Some consumers may weigh this attribute higher if they prefer green vehicles, and some would prefer vehicles with higher horse power, such as a truck, for their towing capacity. Compatibility criteria were given weight of 80 for scenarios 1, 4, and 7 as they are related to short term. In the short term, it is important to know if these technologies are compatible with the existing ecosystem. With the increasing adoption rate of these technologies, the consumer would be aware that these technologies are already compatible with the ecosystem as more new automobiles replace older automobiles. The weight for medium term (scenarios 2, 5, and 8) and long term (scenarios 3, 6, and 9) are given in decreasing scale 70–50, as more adoption compatibility will not be of major concern for consumers. Availability criteria depict the same condition as compatibility since as the time progresses the availability of the technology increases and improvement is also made due to additional knowledge gained through experience. Cost criteria for scenarios 3, 6, and 9 are given lower score (70–50) than other scenarios, since in the long term, with improved adoption, the cost of the technology will be lower as the manufacturing process will improve. In the short term (1, 4, and 7) and medium term (2, 5, and 8), the cost would be initially high. However, with time and improvement in the manufacturing process, acquired through the knowledge gained, the cost would go down.

12.5 Conclusion

The problem of selecting appropriate vehicular technology alternatives is addressed in this study with a scenario-based MDM method. Nine scenarios are articulated, depicting the most commonly encountered decision situations and addressing the technology options. The methodology developed in this work effectively captures different policy options and time frames in terms of weights for criteria for each scenario and translates them into the mathematical algorithms of the MDMA methodology. Five attributes are used for evaluating alternatives that represent the characteristics of appropriate technologies for each scenario. The methodology developed efficiently identifies the appropriate technology for each scenario.

For the scenario case where equal weights were assigned for the attributes, it is difficult to identify the most appropriate vehicular technology alternative. For the scenarios considered in the study, the alternatives are ranked according to the policy and the time frames. It should also be noted that it is not possible to achieve the optimal solution for each scenario because there are a finite number of alternatives available. Therefore, the best available solution has to be selected. TOPSIS mimics the nature of this type of decision-making problem and is found to the efficient in identifying the best alternative for each of the scenarios.

12.6 Future Research

The present study uses TOPSIS method to identify the best alternative. Future research would include Delphi method that would include a panel of experts to provide score for the attributes. We would also expand the attributes used for the TOPSIS method by surveying the population in order to get a better understating of the requirement for these technologies that users value the most.

Acknowledgment We are grateful for the help we received from Felix Sie during the initial research phase of this project.

Appendix A

Table 12.1 Attribute and research

Attribute	VII engineering research	ITS program focused toward deployment
Communications technologies	DSRC only	Best technology for intended application (DSRC for safety)
In-vehicle devices	OEM production units only	Aftermarket and retrofit opportunities
Vehicle focus	Light vehicles	All vehicle types
Stakeholder involvement	Limited	Broad engagement
International focus	Limited	Significant international harmonization effort
Program cohesion	Loosely coupled research programs	Strong, collective USDOT support, coordination, and leadership
Deployment focus	Limited – oriented toward prototyping and proof of concept – see more	Strong deployment focus

Source: U.S. Department of Transportation

Table 12.2 Level of automation

Level of automation	Description
Level 0	Human driver completely in control of all functions
Level 1	One function is automated
Level 2	More than one function automated at the same time
Level 3	The driving functions are sufficient. Driver can safely do other things
Level 4	The car drives itself without human input

Table 12.3 Attributes

	Safety	Fuel efficiency	Cost	Availability	Compatibility
K. Dar, M. Bakhouya, J. Gaber, M. Wack. 2010 [17]	x	x			
S. Biswas, R. Tatchikou, F. Dion, 2006 [26]	x				
R. Crandall, J. Graham. 1989 [10]		x			
L. Morgan, R. Daniels, 2001 [49]			x		
I. Hsu, M. Wódczak, R. White, 2010	x				
U. m. O. Zgu¨ner, C. Stiller and K. Redmill, 2007 [47]	X				
J. M. Anderson, N. Kalra, K. D. Stanley, P. Sorensen, C. Samaras and O. A. Oluwatola, 2014 [31]	X	X	X	X	
KPMG, "self-driving cars: The next revolution," 2012 [32]			X		X
S. Kraus, M. Althoff, B. HeiBing and M. Buss, 2009 [50]			X		
"Autonomous cars – Not if, but when," automotive technology research, 2014					X
W. J. Mitchell, 2007 [51]					X
Volvo cars, 2014 [52]	X				
Boston, MA, Artech house, 1999 [53]					X
Lindsay Wilson, 2013 [54]		X			

Table 12.4 Value assignments for attributes

	Benefit attribute				Cost attribute
	Safety	Fuel efficiency	Compatibility	Availability	Cost
V2V	7	5	7	−4	3
V2I	4	6	7	−7	4
Autonomous vehicle	5	5	4	−11	7

Table 12.5 Scenarios and weights

	Benefit attributes				Cost attributes
	Safety	Fuel efficiency	Compatibility	Availability	Cost
No scenario	0.2	0.2	0.2	0.2	0.2
Scenario 1	80	50	80	70	90
Scenario 2	80	50	70	60	80
Scenario 3	80	50	60	40	70
Scenario 4	80	50	80	80	80
Scenario 5	80	50	70	70	70
Scenario 6	80	50	60	50	60
Scenario 7	80	50	80	80	70
Scenario 8	80	50	70	70	60
Scenario 9	80	50	50	60	50

Table 12.6 Relative distance matrix for each scenario and rank for each alternative

		Candidate technologies					
		V2V	V2I			Autonomous vehicle	
		Score	Rank	Score	Rank	Score	Rank
No scenario		0.883	1	0.576	2	0.119	3
Scenario 1	Government-sponsored R&D\short term	0.923	1	0.584	2	0.119	3
Scenario 2	Government-sponsored R&D\medium term	0.915	1	0.564	2	0.133	3
Scenario 3	Government-sponsored R&D\long term	0.901	1	0.536	2	0.156	3
Scenario 4	Tax credit for companies to invest in R&D\short term	0.923	1	0.573	2	0.119	3
Scenario 5	Tax credit for companies to invest in R&D\medium term	0.915	1	0.552	2	0.132	3
Scenario 6	Tax credit for companies to invest in R&D\long term	0.900	1	0.522	2	0.158	3
Scenario 7	Tax credit and rebates for consumers\short term	0.920	1	0.563	2	0.124	3
Scenario 8	Tax credit and rebates for consumers\medium term	0.912	1	0.540	2	0.138	3
Scenario 9	Tax credit and rebates for consumers\long term	0.899	1	0.499	2	0.159	3

References

1. Available: http://www.census.gov/popest/data/national/totals/2014/index.html
2. Available: http://traveltips.usatoday.com/effects-traffic-congestion-61043.html
3. Available: https://crashstats.nhtsa.dot.gov/Api/Public/ViewPublication/812384
4. Hallenbeck, M. E., Ishimaru, J. M., & Nee, J. *Measurement of recurring versus non-recurring congestion*. [Online]. Available: http://www.wsdot.wa.gov/research/reports/fullreports/568.2.pdf. Accessed 2014.

5. AutoInsurance Center. (2016). *Jammed: The cost of traffic congestion*. [Online]. Available: http://www.autoinsurancecenter.com/traffic-jammed.htm. Accessed 25 May 2017.
6. *Traffic safety facts.* (2005). Washington, DC: National Center for Statistics and Analysis.
7. Qu, F., Wang, F., & Yang, L. (2010). Intelligent transportation spaces: Vehicles, traffic, communications, and beyond. *Communications Magazine, IEEE*. [Online]. Available: ieeexplore.ieee.org
8. Papadimitratos, P., La Fortelle, A., Evenssen, K., Brignolo, R., & Cosenza, S. (2009). Vehicular communication systems: Enabling technologies, applications, and future outlook on intelligent transportation. *Communications Magazine, IEEE, 47*, 84–95.
9. Papadimitratos, P., La Fortelle, A., Evenssen, K., Brignolo, R., & Cosenza, S (2009). Vehicular communication systems: Enabling technologies, applications, and future outlook on intelligent transportation, *IEEE Communications Magazine, 47*(11), 84–95.
10. Crandall, R. W., & Graham, J. D. (1989). The effect of fuel economy standards on automobile safety. *Journal of Law and Economics, 32*, 97–118.
11. Joseph, A. D., et al. (2006). Intelligent transportation systems. *IEEE Pervasive Computing, 5*(4), 63–67.
12. Zeyu, J., Shuiping, Y., Mingduan, Z., Yongqiang, C., & Yi, L. (2017). Model study for intelligent transportation system with big data. *Procedia Computer Science, 107*, 418–426.
13. Janssen, N. A. H., et al. (2011). Black carbon as an additional indicator of the adverse health effects of airborne particles compared with PM10 and PM2.5. *Environmental Health Perspectives, 119*(12), 1691–1699.
14. DOT. (2017). *Intelligent transportation systems – About ITS*. [Online]. Available: https://www.its.dot.gov/about.htm. Accessed 04 May 2017.
15. Dimitrakopoulos, G., & Demestichas, P. (2010). Intelligent transportation systems. *IEEE Vehicular Technology Magazine, 5*(1), 77–84.
16. Chowdhury, M., & Dey, K. (2016). Intelligent transportation systems-a frontier for breaking boundaries of traditional academic engineering disciplines education. *IEEE Intelligent Transportation Systems Magazine, 8*(1), 4–8.
17. Dar, K., Bakhouya, M., Gaber, J., Wack, M., & Lorenz, P. (2010). Wireless communication technologies for ITS applications [Topics in Automotive Networking]. *Communications, IEEE, 48*, 156–162.
18. United States Government Accountability Office. (2015). *Intelligent transportation systems: Vehicle-to-infrastructure technologies expected to offer benefits, but deployment challenges exist*. [Online]. Available: http://www.gao.gov/assets/680/672548.pdf. Accessed 04 May 2017.
19. Weiland, R. J., & Purser, L. B. (2000). *Intelligent transportation systems*. Washington, DC: Transportation in the New Millennium.
20. Sill, S., Christie, B., Diephaus, A., Garretson, D., Sullivan, K., & Sloan, S. (2011). *Intelligent transportation systems (ITS) standards program strategic plan for, April 2011*. [Online]. Available: http://www.its.dot.gov/standards_strategic_plan/stds_strat_plan.pdf
21. Cheng, X., Yang, L., & Shen, X. (2015). D2D for intelligent transportation systems: A feasibility study. *IEEE Transactions on Intelligent Transportation Systems, 16*(4), 1784–1793.
22. Martinez, F. J., Manzoni, P., Garrido, P., & Fogue, M. (2012, September). Assistance through communication technologies and vehicles. *IEEE.*
23. Coelho, M., & Rouphail, N. (2010). *Assessing the impact of V2V/V2I communication systems on traffic congestion and emissions.* Human Centred Design for Intelligent. Presentation at the European Conference on Human Centered Design for Intelligent Transportation. Systems, Berlin, Germany, April 29–30, 2010
24. Available: http://www.consumerreports.org/car-safety/collision-avoidance-systems-are-changing-the-look-of-car-safety/
25. Thomopoulos, N., & Givoni, M. (2015). The autonomous car–A blessing or a curse for the future of low carbon mobility? An exploration of likely vs. desirable outcomes. *European Journal of Futures Research, 3*(1), 14.
26. Biswas, S., Tatchikou, R., & Dion, F. (2006). Vehicle-to-vehicle wireless communication protocols for enhancing highway traffic safety. *Communications Magazine, IEEE, 44*, 74–82.
27. Jeong, Y., Chong, J. W., Shin, H., & Win, M. Z. (2013). Intervehicle communication: Cox-fox modeling. *IEEE Journal on Selected Areas in Communications, 31*(9), 418–433.

28. van Rooyen, G.-J., Zeadally, S., & Booysen, M. J. (2011). Survey of media access control protocols for vehicular ad hoc networks. *IET Communications, 5*(11), 1619–1631.
29. Toulminet, G., & Boussuge, J. & Laurgeau, C. (2008). *Comparative synthesis of the 3 main European projects dealing with cooperative systems (CVIS, SAFESPOT and COOPERS) and description of COOPERS.* Demonstration Site 4, 11th International IEEE Conference on Intelligent Transportation Systems, 2008. ITSC 2008., 809–814.
30. Gaffney, N. (2017). *FHWA announces vehicleto-infrastructure guidance*. [Online]. Available: https://www.transportation.gov/briefing-room/fhwa0317. Accessed 10 Jun 2017.
31. Anderson, J. M., Kalra, N., Stanley, K., Sorensen, P., Samaras, C., & Oluwatola, T. A. (2014). *Autonomous vehicle technology: A guide for policymakers*. [Online]. Available: http://www.rand.org/pubs/research_reports/RR443-1.html. Accessed 2014.
32. *Self-driving cars: The next revolution*. (2012). KPMG: Ann Arbor.
33. Cottrella, N. D., & Bartona, B. K. (2011). The role of automation in reducing stress and negative affect while driving. *Theoretical Issues in Ergonomics Science, 14*, 53–68.
34. Rosenbloom, S., & Ståhl, A. (2003). The convergence of environmental, safety, mobility and community design issues. *European Journal of Transport and Infrastructure Research, 2*, 197–213.
35. Viereckl, R., et al. (2016). *Connected car report 2016: Opportunities, risk, and turmoil on the road to autonomous vehicles*. [Online]. Available: https://www.strategyand.pwc.com/reports/connected-car-2016-study. Accessed 10 Jun 2017.
36. Available: https://static.googleusercontent.com/media/www.google.com/lt//selfdrivingcar/files/reports/report-0316.pdf
37. Available: http://www.driverless-future.com/?page_id=384
38. Furda, A., & Vlacic, L. (2011). Enabling safe autonomous driving in real-world city traffic using multiple criteria decision making. *Intelligent Transportation Systems Magazine, IEEE, 3*, 4–17.
39. Chen, C.-T. (2000). Extensions of the TOPSIS for group decision-making under fuzzy environment. *Fuzzy Sets and Systems, 114*, 1–9.
40. Zeleny, M. (1974). A concept of compromise solutions and the method of the displaced ideal. *Computer & Operations, 1*, 479–496.
41. Opricovic, S., & Tzeng, G.-H. (2004). Compromise solution by MCDM methods: A comparative analysis of VIKOR and TOPSIS. *European Journal of Operational Research, 156*, 445–455.
42. Eshlaghy, A. T., & Kalantary, M. (2011). Supplier selection by Neo-TOPSIS. *Applied Mathematical Sciences, 5*(17), 837–844.
43. Kalbar, P. P., Karmakar, S., & Asolekar, S. R. (2012). Selection of an appropriate wastewater treatment technology: A scenario-based multiple-attribute decision-making approach. *Journal of Environmental Management, 113*, 158–169.
44. *Commercial spectrum: Plans and actions to meet future needs, including continued use of auctions*. (2011). November 2011. [Online]. Available: http://www.gao.gov/assets/590/587319.pdf
45. Putic, G. (2014). *Vehicles may soon be talking to each other*. 4 Apr 2014. [Online]. Available: http://www.voanews.com/content/vehicles-may-soon-be-talking-to-each-other-/1886895.html. Accessed 2014.
46. Dalla, B., Deflorio, F., & Diwan, S. (2009). Assessing the effects of inter-vehicle communication systems on road safety. *Intelligent Transport Systems IET*. *3*(2), 225–235.
47. Ozguner, U., Stiller, C., & Redmill, K. (2007). Systems for safety and autonomous behavior in cars: The DARPA grand challenge experience, Proceedings of the IEEE, 95 397-412.
48. Nemet, G. F. (2009). Demand-pull, technology-push, and goverment-led incentives for non-incremental technical change. *Research Policy, 38*, 700–709.
49. Morgan, L. O., & Daniels, R. L. (2001). Integrating product mix and technology adoption decisions: A portfolio approach for evaluating advanced technologies in the automobile industry. *Journal of Operations Management, 19*, 219–238.
50. Kraus, S., Althoff, M., HeiBing, B., & Buss, M. (2009). Cognition and emotion in autonomous cars. In *Intelligent vehicles symposium*, 2009 IEEE, Xi'an.
51. Mitchell, W. J. [Online]. Available: http://h20.media.mit.edu/pdfs/wjm2007-0509.pdf

52. *A heritage of innovation*. (2014). Volvo cars. [Online]. Available: www.volvocars.com/us/about/our-company/heritage/innovations. Accessed 2014.
53. Linstone, H. A. (1999). *Decision making for technology execuitves: Using multiple perspectives to improve performance*. Boston: Artech House.
54. *Shrink that foot print*. (2014). [Online]. Available: http://shrinkthatfootprint.com/wp-content/uploads/2013/02/Shades-of-Green-Full-Report.pdf. Accessed 2014.

Chapter 13
Technology Roadmap: Drone Delivery – Amazon Prime Air

Shiva Ram Reddy Singireddy and Tugrul U. Daim

13.1 Introduction

Technology roadmapping is becoming more popular in the recent days because of the value it delivers to the organizations, helping them plan strategically and align the technology with business objectives. This paper presents a creation of technology roadmap for drones, used by Amazon for their latest service Amazon Prime Air. The competition in the e-commerce industry is growing every day, and one major area where it makes a huge difference is the shipping prices and time for the delivery. To tackle this problem and overtake its competition, Amazon has come up with the drone delivery concept. Shipping costs and time are what have driven Amazon to choose drones for a faster delivery, low costs, low emissions, and happy customers. It is always difficult to predict the engineering technologies and advancements because of how fast the improvements are taking place. Without any historical data, it is not so easy to forecast them. Drones have been around us since not long ago, which is why predicting the future is not so easy. The focus of this paper is on the drones, and Amazon is going to use for 30 min Prime Air deliveries directly to home. Time is very precious today and that is one of the driving factors for the idea of using drones. Drones are now able to serve the military, for surveillance (wildlife), to help in search and rescue operations, and in shooting movies and sports. Drones are proving to help us in every aspect possible because of the pace at which the technology is improving every day [1].

When we look at the past, it is easy to understand how crucial delivery prices and delivery time are to compete in the industry and to reach consumers expectations. Over the year's transportation, shipping industry, and supply chain management

S.R.R. Singireddy • T.U. Daim (✉)
Portland State University, Portland, OR, USA
e-mail: shiv2@pdx.edu; tugrul.u.daim@pdx.edu

T.U. Daim et al. (eds.), *Infrastructure and Technology Management*,
Innovation, Technology, and Knowledge Management,
https://doi.org/10.1007/978-3-319-68987-6_13

played a very important role in cutting costs. Now Amazon's 30 min delivery costs around 1$ per delivery, and it is going to make a huge difference [2].

Shipping duration and shipping price are the key factors that play an important role in today's e-commerce industry. When we observe the price of any particular product in Amazon, eBay, and other similar websites, the price of the product itself remains almost the same, but the shipping time and cost vary. In my opinion Amazon has an advantage already in this aspect. Amazon Prime is a very successful business idea that Amazon implemented in 2005, and the main idea behind was to make customers spend more. With a monthly subscription of $79, Prime members can get a free 2-day shipping on unlimited purchases, unlimited videos, and also books (Amazon Kindle). It is said that Amazon Prime members spend more than double what nonmembers do [3].

13.2 Literature Review

Robert Phaal and Gerrit Muller suggested that roadmaps and its derivatives have become one of the most widely used management techniques for supporting innovation and strategy, at firm, sector, and national levels [9]. Martin Rinne described roadmaps as tools for managing the future of technology [10]. Daim et al., 2012 proposed that technology roadmaps link business and technology planning and provide a meaningful direction to the R&D efforts. Roadmaps also identify the present status of technology and market landscape [11]. Technology roadmap is a high-level planning tool used to support the development and the implementation of strategy and plans, and it also used for communication of the plan. Strategic objectives and vision is defined in a roadmap and both long-term and short-term goals are established [11].

In a roadmap detailed strategies and framework are presented for the implementation of technologies and products keeping in view political, economic, technical, social, cultural, and environmental conditions, constraints, and limitations in order to accelerate technology growth and deployment. Strategies for implementing technologies and detailed actions plans are deliberated to achieve the goals and targets identified in the roadmap. Roadmap also offers guidelines for decision-makers from government and private sector for formulating policies and strategies in order to exploit emerging technologies. Generally roadmaps portray a concise and high-level integrated view of future course of action in a graphical format [12].

Visually linkages among goals, market drivers, products, technologies, and technology components are highlighted in the roadmap indicating dependencies among various tiers of the roadmap. TRM applications include business strategy development, policy formulation, product and technology planning, strategy planning, understanding technology trends, keeping track of product and technology breakthroughs, and prioritization of R&D and product development projects. Technology roadmaps are also used for enhancing communication and information sharing within a company or entire industry, defining problems and needs, identifying barriers and hindrances, investigating technology and market gaps, establishing future vision and strategy, deciding short- and long-term action items, assessing impacts of new technologies and market development, and helping mangers for decision-making, resource allocation, program/policy support, and evaluation [13, 14]. Main objectives of using roadmaps are to establish long-term goals and targets, create a common vision, assess of promising technology alternatives, identify markets drivers, gaps, key challenges, and barriers, formulate strategies and action plans to overcome all those barriers, provide guidelines for policy-makers and decision-makers, prioritize R&D projects, give direction to the energy sector, and improve communication and coordination for technology development [11]. Roadmaps also present high-level strategies for developing or acquiring required technologies identified during the roadmapping process and provide a framework for public-private collaboration.

Technology roadmapping is a comprehensive approach for strategy planning to integrate science/technology considerations into product and business aspects, at the same time providing a way to identify new opportunities. A roadmap is " an extended look at the future of chosen field of inquiry composed for the collective knowledge and imagination of brightest drivers of change" according to Robert Galvin, a former chairman at Motorola, who was the reason behind first using roadmaps successfully.

Amazon filed a patent in April 2015 for "sense-and-avoid" drone technology that would allow delivery drones to avoid obstacles. But, Amazon declines to comment on the company's drone patent [7]. The patent is available from the official USA Patent Application Publication [5]. This provided most of the key information that was not available from the Internet or research papers.

13.3 Methodology

Let us take an example of any industry as of today. From an organization's perspective, the changing needs of the customers, how fast the technology advances, and how the government policies change with time is difficult to assess. To build a roadmap, which maps the needs of customers/drivers and technologies to support the products is very much essential.

From the literature review, a basic framework is used to structure and create the roadmaps [15].

- Identifying of the needs and drivers
- Identifying of products/services to meet the needs and the drivers
- Identifying technologies to support products or services
- Establishing the links among drivers, needs, and technologies
- Developing plans to acquire or develop the technologies
- Assigning resources to accomplish the plans

This roadmap will be of great value to Amazon as it will clearly

- Illustrate the linking strategy to product plans to technology plans.
- Enable corporate-/national-level technology plans.
- Focus on long-term planning.
- Improve communication and ownership of plans.
- Focus on planning with priorities.

13.4 Prime Air Proposal

13.4.1 Application

Like Amazon Prime, Amazon Prime Air is a proposal that promises the customers to deliver its products purchased online within 30 min or less but using drones. The unmanned aerial vehicles are expected to replace the delivery trucks within the cities to reduce pollution, reduce delivery cost, and make the delivery way faster compared to the present day.

Drones will only be used to deliver packages from warehouse to home, located within the delivery range (10 miles). As it is just the beginning, Amazon is expecting to use drones starting with only a few major cities within the USA. These drones will be shipping the products from the city warehouse within a radius of 10 miles.

Proposed home delivery – customers can expect the drone to drop off their package in their yard or a dedicated drop off area for multistoried buildings.

Amazon-owned drones will only be used – to reduce the complications around operating drones, Amazon will only use their own drones. It also helps in reducing the costs. Amazon currently uses services like FedEx or UPS to deliver most of its packages; if the company doesn't have to rely on other service providers, having their own solution for package deliveries will help Amazon to reduce the market or companies like UPS save its money from becoming profit of others.

This will help in the vertical integration of the company making it self-sufficient. Vertical integration can be an important strategy to the organizations, but it is difficult to implement successfully. If it turns out to be a wrong strategy, it can be costly for the organization to fix it.

On the other hand, there is a lot of debate going on that no matter the improvements in technology, the drones cannot replace the mailman [1], because drones are not as flexible as a delivery man. If there is no one available to pick up the consignment, a delivery man can leave a note or try to call the customer, but if it is a drone, it must probably take the shipment back to the warehouse making things too complex. There are recent new comings about the electric delivery truck – *Workhorse Group Inc.* – which is hoping to make an impression by showing the Postal Service that the future could involve a drone that can deliver packages while the mail carrier works their normal route. It will probably take a year or two for more research and trails before finding the best and efficient way to use drones.

Proposal In July 2015, Amazon met at NASA's Ames Research Center to lay out their first public proposal for safely operating a drone highway.

- Amazon drones would operate in a proposed "high-speed" transit lane between 200 and 400 feet.
- 100 foot buffer zone between high-speed transit and integrated air space.
- Below that corridor, amateur or hobby UAV would operate freely.

The proposed drones would be installed with advanced GPS system and online flight planning control. This will enable the drone to travel using the map and plan its journey according to the shipping addresses. Drones will be able to communicate among themselves and share information related to traffic and weather conditions [8]. The drones will come in a variety of sizes depending on the size of the order: it's a safe bet to assume that a drone delivering a single Blu-ray disc won't be as large as one deployed to deliver a box of college textbooks. But the drones will also be equipped with cameras and GPS infrared lights that locate landing places and, if all goes according to plan, steer clear of humans and animals.

"If it is determined that the navigation path and/or failure path intersects with a human and/or other animals, roads, walkways, etc., the navigation path may be altered to avoid the humans, animals, roads, walkways," the patent states. An approved patent does not mean all the plans laid out in the filing will be completed as described; we must remember that the results can always be different from what has been planned earlier [8].

In July 2015, Amazon met at NASA's Ames Research Center to lay out their first public proposal for safely operating a drone highway. The above picture depicts the fly zone and no-fly zone for the drones clearly. The drones would operate in a proposed "high-speed" transit lane between 200 and 400 feet and 100-foot buffer zone between high-speed transit and integrated air space to ensure that they do not enter into the air space designated for airplanes. Below that corridor, amateur or hobby UAVs would operate freely. The drones cannot fly near the airports or cannot interact into the integrated air space. In crowded cities like New York, it makes it almost impossible for a drone to fly in the range of 200–400 feet, so it will be interesting to see how Amazon will tackle this problem.

13.5 Opportunities

The first drone delivery happened in Nevada, which is the first FAA-approved urban delivery [5].

- Developing aerial vehicles that travel over 50 miles per hour and will carry 5-pound payloads, which cover 86% of products sold on Amazon. These packages can be delivered using drones while consignments that cannot be shipped by drones will be transported using trucks or other methods.

- Amazon ships approximately 608 million packages per year, so approximate drone market at 86% extends to 522 million packages. If drones successfully deliver this many packages, it will be a lot of money saved on transportation and shipping.
- Amazon shipping revenue is $4.48 billion, and shipping costs $8.7 billion, so the opportunity to vertically integrate their supply chain is over $4 billion dollars.

Amazon's shipping revenue is very less compared to the outbound shipping costs. As discussed earlier if every drone delivery costs $1, there will be a scope to improve the shipping revenue too. Drones industry is expected to create 100,000 jobs in 10 years, adding $13.7 billion to the American economy [6]. But at the same time, there are debates going on that there might be layoffs in areas where employees are associated with shipping trucks. FAA wants service providers to use a licensed pilot to drive the drones in cities and public spaces to avoid any fatalities in case of failures. The FAA also states that the drones must be under a designated pilot's surveillance during its journey.

In 2012, the ATA predicted that by 2023, the total population of trucks in the USA will grow by 26%, the total miles driven will increase by 38%, and the total tonnage carried will increase by 26%. The trucking will have a rise of nearly 66% in overall revenue, accompanied by a decline in rail tonnage and revenue to around 14.6% of the total transportation industry. Similarly, the US Department of Transportation's Federal Highway Administration forecasted a 44% increase in long-haul trucking tonnage from 2007–2040. From the illustration above, it is clear that trucks carry 43% of US freight, and it is evident how Amazon is keenly trying to have its own shipping [16]. The Colis Privé purchase is just the latest in a series of moves Amazon has made over the past 2 years to take more control over its transportation and shipping costs. In 2014, Amazon purchased a 4.2% stake in Yodel, a UK shipping service [17]. Adding drones to their fleet will definitely help in not relying on trucks in congested/urban areas.

Of course, trucks have to be driven by someone, and with the increase in trucking tonnage and miles come an increase in employment opportunities.

13.6 Package Drop

- Companies have tested dropping packages at customers' doorstep and lowering packages on a line.
- Inaccurate GPS data may be a concern as the package will be lost or delivered to a wrong address.
- Delivery to centralized location or Amazon storage lockers could be a solution.

According to the patent, the drones will find their destination by continuously tracking the location of the purchaser's smartphone. While this might seem strange at first glance, this implementation enables delivery to customers who might not be at home. The patent, for instance, references how a package might even be delivered to a boat [18].

The packages are dropped by the drone at a delivery location set by the customers while ordering the product. The user interface allows to pick a location like work or home or the drone has the capability to track the customer in real time and deliver it. For starters, Amazon is thinking beyond home delivery. They're thinking of delivery to wherever you are at the moment.

The patent application describes a customer option called "Bring It to Me." With this option, using GPS data from the consumer's mobile device, the drone locates and delivers the item to that location. Once the customer places, the order he or she does not have to remain in one place.

While there are concerns about how the drone will return the package to the warehouse in case there is no one to pick it, there are articles which talk about how the drones can be used to pick up locations from warehouses, making it less interactive to common public.

13.7 Technology and Infrastructure

Copter drones are more wind resistant, agile, and reliable. Hybrid drones or plane drones tested by Google that take off like a copter and glide like a plane are difficult to control. Amazon used copter drones as seen in the commercial video and Amazon's website.

The infrastructure needed to accommodate small flying delivery will be a crucial area and the future developments of drones very much depend on how drones advance. Houses today have mail slots and curbside mailboxes to accommodate the traditional flow of mail and packages. Nothing yet exists to make the drone's job easier [4].

Kopardekar suggested 10-foot-tall mailboxes – perfect for landing drones where people and their fingers won't interfere. Or transforming chimneys into delivery chutes for drone-dropped packages. Others imagine installing delivery lockers on the roofs of apartment buildings [4]. Amazon websites revealed the working of drones and how the packages are delivered; in its website and other social media, they illustrated that the drones will drop off the packages in houses with a backyard or an empty space before the house, but it is not clear as to how the children or pet animals are going to react. Children's and pet animal's safety might be at risk considering the drone has propellers moving at a speed which can cause an injury. Practically, there might be incidents where the package or drone might be attacked by bullies or pets itself. Situations like these remind us how difficult it is for FAA to approve drones for commercial uses of drones, like for Amazon Prime Air.

While the trucks have been around in the market for decades now but there is still no perfect solution to prevent deaths and accidents, it is equally difficult to prevent accidents in the case of drones too, but FAA does not want to take risks which is why it takes a lot of time to observe and conduct tests before letting the drones enter into public air space. Its vision is more ambitious than the FAA's proposed rules for commercial drone flight, which do not allow operation outside of a pilot's line of sight. Those rules are expected to be finalized within a year. Now we'll see if drone operators such as Amazon can demonstrate to the FAA and others that autonomous drones can safely fly in a range of environments. If that happens, the full potential of drones could be realized [19].

13.8 Roadmapping

13.8.1 Drivers/Needs

The data collection for this chapter was accomplished by a team of professionals who are taking a graduate class in technology roadmapping. The team members are listed in the acknowledgements. The drivers are identified and categorized by the team together after brainstorming. First the team members came up with individual driver/needs. After getting the inputs from the team members, the drivers are then clubbed into respective categories as shown below. Each driver is assigned with a code like D1, D2, etc. to use in the roadmapping process, not to make it complicated or difficult to understand at later stages of mapping. A similar procedure has been followed in later stages of roadmapping and will be explained in detail, respectively (Fig. 13.1).

In the first category, speed and efficiency, the first driver's "30-min delivery" indicates that customers are expecting deliveries to be quicker than the present day speed. The Prime Air proposal promises 30-min deliveries, which is here considered as a driver that drives the growth and improvements of drones in the years to come (Table 13.1).

After the drivers are shortlisted based on relativity and similarities between each other, they are mapped on a time line of 15 years, i.e., 2015–2030. This mapping is based on where the drivers are currently and how long it might take to reach there (Fig. 13.2).

Fig. 13.1 A snapshot of the teams identifying process

Table 13.1 List of drivers with codes

Market drivers		Code
Speed and efficiency of deliveries	30-min delivery	D1
	Real-time information of delivery	D2
	Last mile problem-convoluted routes	D3
	Delivery possible in remote locations	D4
Economic	Vertically integrate supply chain ($4 billion dollar loss on shipping&###;	D5
	Deliver 86% of Amazon products (5 lbs. or less)	D6
Transportation	Commercial drone highway	D7
	Reduced road traffic	D8
Ecological	Reduced carbon emissions	D9
	Potential for eco-fuel drones	D10
Industry	Commercial needs (agriculture, medical) will drive UAV usage	D11
	Untapped market	D12
	Expansion of business	D13

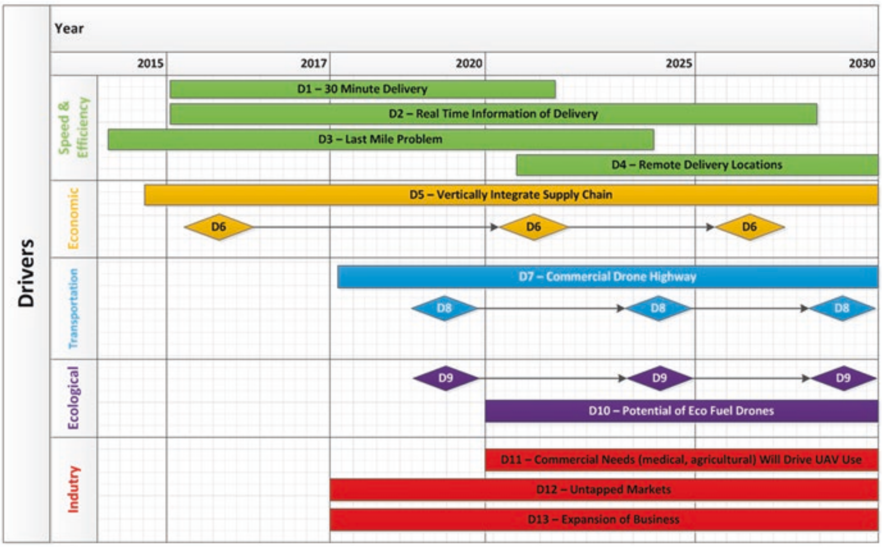


Fig. 13.2 Roadmap of the drivers

Let us consider D1 30-min delivery (customers are expecting quick deliveries); we know Amazon has recently announced the 30-min delivery and preliminary tests have been conducted too, so this driver is mapped from 2016 to 2021 for 5 years. *D2* is real-time delivery. Amazon's patent provides information about how the customer is going to order in the user-friendly UI from any browser. While ordering any shipment, the customers can select their saved location like work or home, or they can also let the drone track the customer's location real time and deliver it on the go. The shipment can be tracked before the drone reaches its destination, providing customers with real-time information. This will remain a driver and it keeps improving with time. *D3* is the last mile problem which refers to the final leg of the delivery networks before reaching the end user. The drones can solve this last mile problem. While the UPS truck carries out deliveries to warehouses, the drones deliver packages from warehouses to customers or pickup locations, thus reducing carbon emissions and saving time. Last mile problems cause higher fuel costs due to the amount spent driving around making deliveries [20]. Drones can solve this problem eliminating the issues of insufficient facilities, save time, and reduce traffic. *D4* remote delivery location – currently drones are expected to serve in the major cities, but it is expected that at least by 2020, the drones will be serving in cities with full force so the focus will shift toward using them to deliver packages in remote areas. Once the drones have the efficient battery and power supply that lasts for longer times, it will be possible to deliver to remote areas as well [21].

D5 vertically integrate supply chain – shipping is a very big expense for Amazon; it spent $3.2 billion for packages delivery in the third quarter, 2016. The costs are increasing every year as Amazon tries to further enhance its delivery system to compete with its rivals. *The Seattle Times* reported in an article that Amazon is expected to vertically integrate by acquiring French company Colis Privé. This buy out in second half of 2016 is seen as an attempt to take on UPS and FedEx. This is a slow process which will remain a driver throughout the time line [22]. *D6* – deliver 86% of Amazon's products (5 lbs or less) which extends to 522 million packages saving a lot of money on shipments, and this is mapped throughout the time line. *D7* commercial drone highway – the drones should be operated between 200 and 400 feet. These highways mentioned by Amazon are dedicated air space for drones which will facilitate the journey of the drones [23]. *D8* reduced road traffic and D9 reduced carbon emissions – by 2018 the drones will be transporting at least some shipments, and it will be evident how the drones help in reducing the carbon emissions as the use of trucks and heavy vehicles will be reduced, so it will act as a driver after making an impact in the market. D10 eco-fuel drones – the drones will be soon categorized in to micro, mini, and nano-drones after which the eco-friendly drones will be developed in the future [24]. Industry drivers D11 – the commercial needs (medical and agriculture) will drive UAV use by 2020 after drones successfully serve the Amazon market [25]. D12, new markets, and D13, expansion of business, will act as drivers after the initial market penetration in the next 2 years, i.e., by 2018, after showing proven profitability and efficiency.

13.9 Product Features and Gap Analysis

13.9.1 Product Features

Product features are nothing but the features of the drone itself. Just like the market drivers, the individual team members gave their inputs on product features after the basic roadmapping research and literature review. All the inputs from the team members are based on “what product features will impact the adoption of drones? And how are they going to impact?” The Amazon business and drone regulations (FAA regulations) must be kept in mind during this time and must be categorized carefully. The product features – the team came up with categories which are *efficiency*, *safety*, *economic*, *security*, *service*, *industry*, *and ecological*. A product feature is assigned with a code (PF1, PF2, etc.), and a brief description of each feature is also provided (Table 13.2).

Product features are mapped on a time line of 10 years, similar to how drivers were mapped as described earlier. The mapping is approximate based on where the features are today and when might it be available in the market (how long it might take to reach the necessary standard). The product features which are *t* = related to the drone itself, like the propellers, arms, power module, GPS system, etc. will be continuously updated with latest technology coming in every year, so in the time line it extends throughout the time line. The roadmap of product features is shown below.

F1 motor and blade and F2 lightweight materials technologies will be continuously evolving with time and so the performance keeps improving too, so they are mapped from now on through 2030. F3 package weight – the drone that is currently used by Amazon for drones can carry 5 lbs now; as the technology progresses, the drone will be capable of carrying more weights, so this is one of the features that will impact on drone’s growth in the market. F4 delivery range – the current delivery range is about 15 miles or 24 kilometers [26]. It is enough for deliveries within the cities, but as technology improves with time, the drones should be capable to fly for longer times, being able to reach remote areas. F5 UAV to UAV communication is a feature where the drones will be able to communicate with each other. In areas where the operator cannot see the drones, they communicate between themselves sharing information like traffic conditions, weather, and routes. This feature is mentioned in the Amazon’s patent [7]. F6 UAV rescue – the drones will be able to call for help while another drone reaches out to help, mapped from 2020 onward. F7 guidance system – this is a GPS-linked feature which allows the drone to travel from place to place while transferring live information to its customer and pilot. This is present in the early models of drones as the FAA’s regulations require the pilot should be able to see the drone through-

Table 13.2 Product features and codes – on a time line

PRODUCT FEATURES		CODE	2015	2017	2020	2025	2030
Drone Performance and Flight Capabilities	Motor&Blade	F1		Evolving			
	Lightweight Materials	F2		Evolving			
	Package Weight	F3	5lbs		7lbs	9lbs	11lbs
	Delivery Range	F4	10Miles		15Miles	20Miles	25Miles
Secure and Safe Travel Features	UAV to UAV Communication	F5			Evolving		
	UAV Rescue	F6			Evolving		
	Guidance System	F7		Evolving			
Energy Usage	Power Module	F8		Evolving			
Prime Air Service and User Experience	Prime Air Membership/Prime Air Standard	F9		Available for Prime Air Members Only	Drone delivery Method-Standard. Traditional Delivery(UPS, USPS, FedEX, OnTrac, etc.) - Paid		
	Smart Connectivity	F10		Evolving			
	Delivery Location	F11		Evolving			

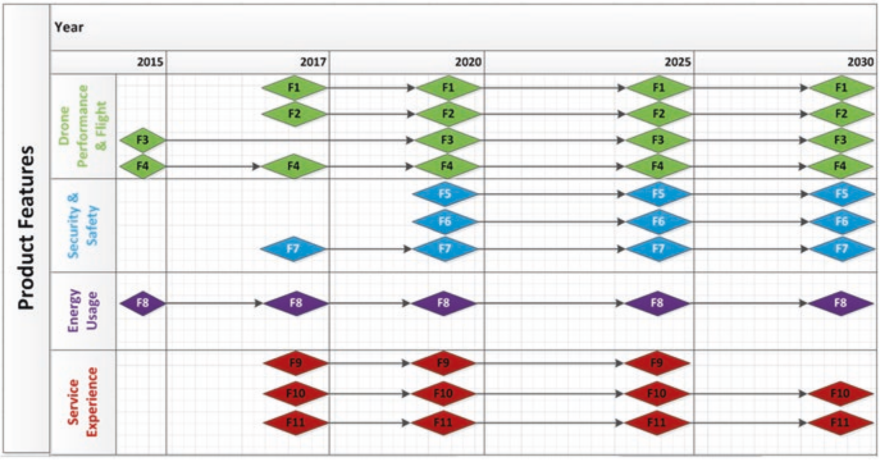


Fig. 13.3 Roadmap of product features

out its journey. This feature will also improve with time so it is mapped from 2016 to 2030, representing different forms of the same feature. F8 power module is the main source of energy for the drone which keeps it running. This technology improves every year, which is why it has been mapped throughout the time line. F9 Prime Air membership will become the standard form of shipping by 2025, taking step-by-step transformations. F10 smart connectivity – the drone fleet will be interconnected with a smart connectivity system through which drones share information related to traffic, temperature and weather conditions, and location services. F11 delivery location – the preciseness and accuracy of the drone will depend on the GPS. With gradual improvements in technology, the preferences for delivery location can be made more user friendly; as these two features need to be upgraded frequently with latest features, they are mapped throughout the time line (Fig. 13.3).

13.9.2 Gap Analysis

After listing out the product features and short-listing them into categories, every feature is analyzed from a customer's perspective who uses services from Amazon. Some product features have a gap or a required level, and let us take the example of P3 power module. The gap/required level here is that the battery in present drones discharges quickly (Li-Ion) and alternative source or technology is needed. Similarly gaps for other product features are mentioned wherever applicable. This way research and development can be directed in the areas that are key for the development of drones and related technologies that can be important for Amazon's commercial use of drones (Table 13.3).

Table 13.3 Product features – efficiency, definitions, and gaps

Product features		Code	Definition	Gap and required level
Efficiency	Blades	P1	Propeller spinning at 10,000 revolutions per minute	
	Motor	P2	Propellers driven by 8 motors to lift the UAV. Functional even if one fails	
	Fever module	P3	Provide power for UAV control system and propeller motor. One or more power modules configured such that it is autonomously removed/replaced with another. Container may also include power module which can be utilized on engagement. When the container is disengaged, it used the power from UAV power module	Lithium polymer batteries discharge quickly as they operate like those in smartphones and laptops. Alternative power generation required
	Delivery range	P4	Delivery range is restricted to 10 miles from the distribution center	No restriction to distance from source and delivery location
	Relay location	P5	Delivery location/materials handling location. Battery replaced or recharged	Locations and processes need to be established where drones can stop on route and either recharge or hand package off to secondary drone for last leg of delivery. Example**:** drone #1 flies 10 miles to relay location and drops off package, and dome #2 picks it up and delivers to final destination
	Package integrity	P6	Package delivered in a good condition without any damage	Return policy for damaged goods delivered by drone
	Seamless return	P7	Drones can pick up returns from particular locations and take them back to the source location	Return policies have to be reconsidered
	Package weight	P8	Limited to small and 5-pound package	No restrictions to package weight or size

Efficiency Delivery range P4 drones can only travel 14 miles or they are expected to deliver within 10-mile radius once the service begins. Not being able to cover a large area for deliveries is the gap here, and required level is that there must not be any restrictions to distance from source and delivery location [27]. P5 relay locations – Amazons plan also includes relay locations to drop off packages for further transport or to allow the drones to recharge [28]. The required level is that the drones must be able to use this relay locations where drones will relay the package, i.e., drone A travels the first 10 miles and drone B picks up to travel another 10 miles. This way the delivery range increases too. P6 package integrity and P7 seamless returns – the return policy for damaged goods that are delivered by drone has to be precise to avoid losses on these damaged goods. Unlike a UPS driver, the drone will not be able to talk to the customer in case of any issues so the return policy has to be reconsidered and reviewed. P8 package weight – the drones are capable of carrying packages that weigh less than 5 lbs. In the future the drones must be gradually able to increase the weight they can carry (Table 13.4).

Table 13.4 Product features – safety: definition and gaps

Product Features		Code	Definition	Gap and Required Level
Safety	UAV rescue	P9	Drones packages can be rescued/picked up by a replacement drone in the event of a malfunction. Drones can be picked up by replacement drone and brought back to shop	Additional "service" drone capable of lifting and returning a standard Amazon delivery drone needs to exist.
	UAV to UAV communication	P10	Provide information on weather, landing condition, and traffic. This information is used for route planning to modify the actual route	Artificial intelligence technique, tested and verified over and over for rerouting.
	Leg	P11	Provide gentle landing on the surface	
	Grabber	P12	Clamps that secure package before lift off	
	Anti-crash technology	P13	An algorithm to detect crash beforehand and prevent it	
	Guidance system	P14	Guidance is a revolutionary visual sensing system that has a powerful processing core, integrated visual cameras, and ultrasonic sensors to detect object up to 65 feet (20 meters) away	
	GPS	P15	To deliver the product in the current location, GPS data will be retrieved from the customer's mobile service	
	Inventory management system	P16	Inventory is engaged such that it is enclosed within the frame and does not create drag during transport	

Safety P9 UAV rescue – there is possibility of drones facing some technical issues on the way to its delivery; in that case, another drone will reach out and continue the delivery. But the drone needs to be back in the warehouse, and it really needs a lot of time and money to go pick up the drone in person. So in the future there should be scope for additional "service drones" capable of lifting and returning a standard Amazon delivery drone (Table 13.5).

Table 13.5 Product features – security and economic: definitions and gap

	Product features	Code	Definition	Gap and required level
Economic	Lightweight materials	P17	Drones will be made of lightweight materials which are strong enough to handle flight and payload. Idea is to maximize load capacity and minimize drone weight	Initially up to 5.5lbs package, then to x lb. by 2025 and finally Y lbs. by 2030
	Line of sight	P18	Line of sight – flight less than 400 ft. in all operating areas. Transiting between 200 ft. and 400 ft. 400 ft.–500 ft. – buffer between drone and conventional aircraft	
	No-fly zone	P19	Drones cannot fly in controlled (airports), prohibited (government prohibited-military), and restricted (nuclear power plant) areas	Create a mobile app to register addresses as no-fly zone with customized feature like "do not disturb time periods," camera-equipped drones not flying overhead
	Privacy	P20	Usage of camera to detect and avoid objects questions civil liberties. Hack data from smartphone in open Wi-Fi network region	Wi-Fi needs to be turned off. It gets location data to user credentials. Advanced anti-hack features to be developed.
Security	Biometric verification	P21	Scanners attached to the drones	Finger print/retina/facial scanners attached to make sure personal/important package is delivered to the correct recipient

Economic P17 lightweight materials – the drones will be made of materials with lightweight, which are strong enough to handle the flight and payload. The idea is to minimize the drone weight, maximizing the load capacity. Now the initial models of drone that are going to serve soon are made of basic materials; in the future if the focus is shifted to building the drone using lightweight materials, the drone will be automatically able to carry heavier weights (Initially 5.5 lbs., X lbs. by 2025, Y lbs. by 2030). When these technologies improve together, it gives improved performance to the drone. For example, battery, lightweight materials, and GPS technologies will improve the delivery range, and shipments above 5 lbs will also be delivered using drones [29]. P19 no-fly zone – in case the drones enter unauthorized air spaces, it is prone to accidents. A mobile app to register the addresses as no-fly zone would prevent accidents. P20 privacy – the drones are equipped with cameras and sensors to avoid objects, but a question of civil liberties arises as it is most likely possible that the drone gets hacked. So advanced anti-hack feature must be installed to prevent such incidents. P21 biometric verification – if a UPS driver delivers a package, he will take a signature from the receiver and he will be able to talk in case of any discrepancies, but we cannot expect the drone to do a similar job. So the drone must be able to read advanced information like fingerprint scanning or facial recognition to make sure the package is delivered to the right person.

Industry P26 Prime Air is to be offered at an additional cost which Amazon claims is very low (10 cents to deliver a 4.4-pound (2-kilo) package over 6 miles (9.7 km) using a drone) to "early adopters." The Amazon Prime Air feature must be field tested and thoroughly proven to become a standard delivery method. Prime subscription should be inclusive of free drone delivery, and other traditional deliveries which will have to use services like UPS or FedEx should be "paid." It would be more profitable for Amazon if most number of shipments are delivered by drones, and for customers who live in remote areas – the packages will be delivered using traditional methods and they will be charged for the same (Table 13.6).

13.10 Market Drivers Vs Product Features

We now have the product feature roadmap and driver/needs roadmap, but we are not aware of the relation between the drivers and features which is very important. It is important for Amazon in this particular roadmap to understand how the features and

Table 13.6 Product features – industry: definition and gaps

	Product features	Code	Definition	Gap and required level
Service	Delivery location/ real-time connectivity	P22	Products are delivered to the preferred location(home, workplace, current location – determined by GPS data, location of the wireless network)	
	Smart connectivity	P23	Reroute to find package recipient through their smartphone	
	Graphical UI	P24	Select delivery option/method for the delivery of an item	
	Proof of delivery	P25	Drones are able to notify customer and Amazon once package is delivered. "Delivery confirmations" are available today with commonly used carriers	
Industry	Prime Air membership/ Prime Air standard	P26	Prime Air to be offered on an additional fee basis to "early adopters." X amount per year	Prime Air model needs to be field tested and thoroughly proven to become a standard delivery method. Prime subscription with free drone delivery option. Traditional delivery methods: UPS, USPS, FedEx, OnTrac, etc. will be paid
Ecological	Environmental impact	P27	Modify navigation of UAV to avoid human or animals	

Product Feature Vs Market Drivers	
Strong Relationship	(green)
Medium Relationship	(yellow)
Weak Relationship	(purple)
Priority	
High	(red)
Medium	(blue)
Low	(orange)

Product Features			Market Drivers													
			Efficiency				Economic		Transportation		Ecological		Industry			
			30- minute delivery	Real-time information of delivery	Last mile problem	Delivery possible in remote locations	Vertically integrate supply chain ($4 billion dollar loss on shipping)	Deliver 86% of Amazon products (5 lbs or less)	Commercial drone highway	Reduced road traffic	Reduced carbon emmisions	Potential for eco-fuel drones	Commercial needs (agriculture, medical) will drive UAV usage	Untapped Market	Expansion of business	
			D1	D2	D3	D4	D5	D6	D7	D8	D9	D10	D11	D12	D13	Priority
Drone Performance and Filght Capabilities	Motor and Blade	F1	2		3	2	3	2	2	2			2			18
	Lightweight materials	F2	2				2	3								7
	Package weight	F3						3						3	3	9
	Delivery range	F4	3		3	3	3	3		2	2		2	2	3	26
Secure and Safe Travel Features	UAV rescue	F5				2			2							4
	UAV to UAV communication	F6		2					2				2			6
	Guidance system	F7			2				3							5
Energy Usage	Power module	F8	2		3	2		2	3			2				14
Prime Air Service and User Experience	Prime Air Membership/Prime Air Standard	F9					3	3						3	3	12
	Smart connectivity	F10	2	3												5
	Delivery location	F11	3	3	3	3	2							2	2	18

Fig. 13.4 Scoring model – market drivers vs product features

drivers are interlinked so that future investments and policies can be made accordingly. So, to understand the links between the two, a scoring model is used.

Market drivers/needs are horizontally aligned in a table, whereas the product features are vertically aligned. D1 30-min delivery is our market driver; it is matched with every single product feature to see if there is any direct or indirect relation. Blades, motor, and power module are marked. The scoring model results are one high priority driver, *delivery range*, and four medium prioritized drivers, *motor and blade*, *power module*, *Prime Air membership/standard shipping*, *and delivery location* (Fig. 13.4).

13.11 Technologies

After mapping out the drivers and product features, it is time to think about the technologies present in the real world that are going to impact drones. Just like the drivers and product features, technologies area also identified as a team, after brainstorming. The technologies are clubbed into the following categories: *regulatory technologies*, *navigation technologies*, *aviation technologies*, *power system*, *package delivery technologies*, *and materials technologies*. Each category comprises of some technologies that constitute to improvement of the drone technology and infrastructure.

The representation in the picture above also shows if the technologies are currently available in the market or if they are evolving based on the information gained from research. T1 geofencing and geographical boundaries are a regulatory technology as they act as a surveillance for the drones, making sure they do not go out of the designated airspace. Geospatial Environment Online (GEO) is a similar software used in DJI drones and will provide pilot with up-to-date guidance on locations where flight may be restricted by regulation or raise safety concerns. Drone opera-

Table 13.7 Technologies and codes in a time line

	TECHNOLOGY	CODE	2015	2017	2020	2025	2030
	Geofencing and geographical boundaries	T1			Evolving		
	Encryption of data	T2			Evolving		
	Noise reduction technology	T3			Evolving		
Regulatory Technologies	Operating system	T4			Evolving		
	Onboard Navigation	T5			Evolving		
	Lasers	T6				Evolving	
	Video Cameras	T7			Evolving		
Navigation Technologies	Infared cameras	T8			Evolving		
	Higher intensity LED lights- orientation during flight	T9			Evolving		
	Robotics (Improved arms, legs)	T10				Evolving	
Aviation Technologies	Remote Monitoring	T11			Evolving		
	Li-ion	T12		Evolving			
	Li-po batteries	T13				Evolving	
	Solar power	T14				Evolving	
Power System	Hydrogen fuel cell	T15					Available
	Barcodes and QR codes	T16		Evolving			
	Logistics	T17			Evolving		
	Inventory management (SAP)	T18			Evolving		
Package Delivery Technologies	RFID	T19				Evolving	
	Face recognition tech	T20				Available	
	Retina Scan	T21					Available
Biometric Technologies	Fingerprint	T22			Available		
	Aluminum	T23		Available			
	Titanium	T24			Available		
	Magnesium	T25				Available	
Materials Technologies	Graphite	T26					Available

tors will have, at the time of flight, access to live information on temporary flight restrictions due to forest fires, major stadium events, VIP travel, and other changing circumstances (Table 13.7).

The system will also include restrictions around locations such as prisons, power plants, and other sensitive areas where drone operations raise non-aviation security concerns [30]. T2 encryption of data to make sure that the customer's private information is safe and T3 noise reduction technology to reduce the noise generated by drones are mapped from 2016 to 2030. Similarly other technologies are evaluated and mapped as shown below (Fig. 13.5).

13.12 Resources

Now we have the technologies and we need to observe what resources will play an important role in the development of the technologies that we identified. *Finance* – money is always an important resource and to a company that is Amazon's size, hoping to implement certainly the drone technology it is really an important resource. *R&D Amazon Seattle laboratory* – increased interest in the drone technology needs a lot of research and development. *Universities and research institutions* are also an important resource where there will be academic involvement toward the drone technology that can contribute to the development of drones. There is need for support from *government organizations* including FAA; the more interest they show toward this technology, the faster growth can be achieved. This delivery-by-drone plan still requires years of testing and approval from the FAA, which bans

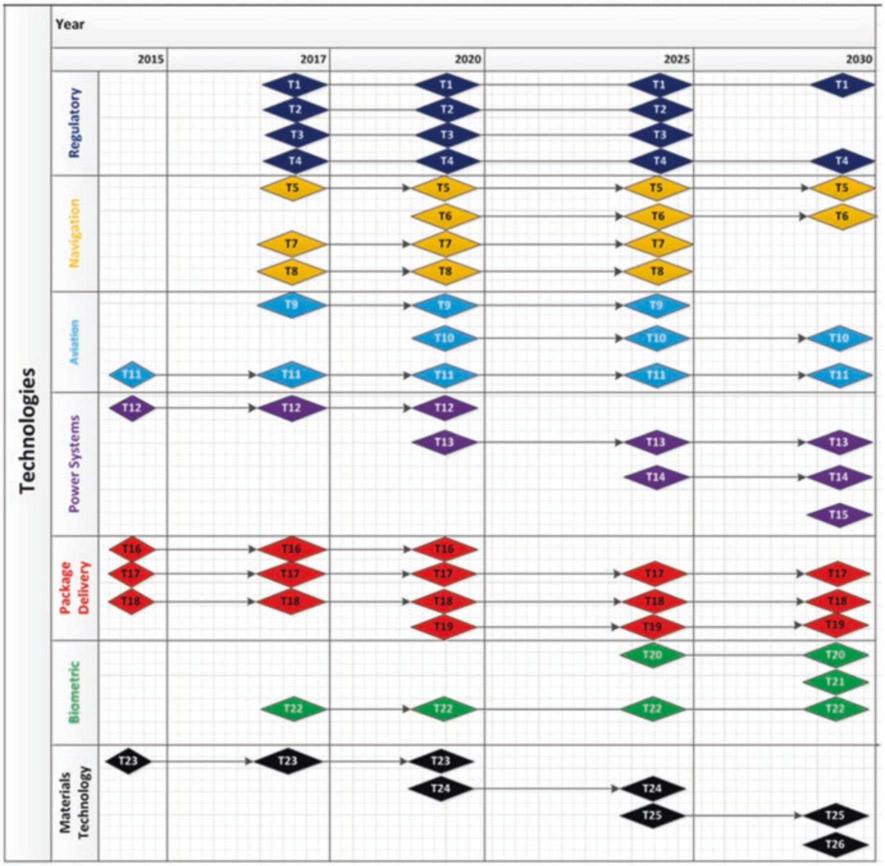


Fig. 13.5 Roadmap of technologies

non-recreational use of drones in the USA without approval. Drones obviously don't play a role in Amazon's current business, but it's easy to see how they could be a game change in the e-commerce industry. Lockheed Martin, Boeing, Google, GE, Rolls-Royce, defense contractor Raytheon, and AeroVironment are a few of the industry's giants who are already known for their research and developments in the drone technology. More companies should take part in the research and development of similar technology as it will create a movement where authorities will start realizing the importance of the technology enabling to make better policies and regulations. *Natural resources, material scientists* – we have discussed about metals like aluminum, titanium, magnesium, and graphite which can be made only using natural resources. After testing and research, it is important to make sure about the availability of these resources to ensure a timely improvement over time. *User acceptance* – there are a lot of customers who are happy about the drone deliveries, but at the same time many customers complain about privacy issues, like about the cameras mounted on the drone or about the customer information that the drone has

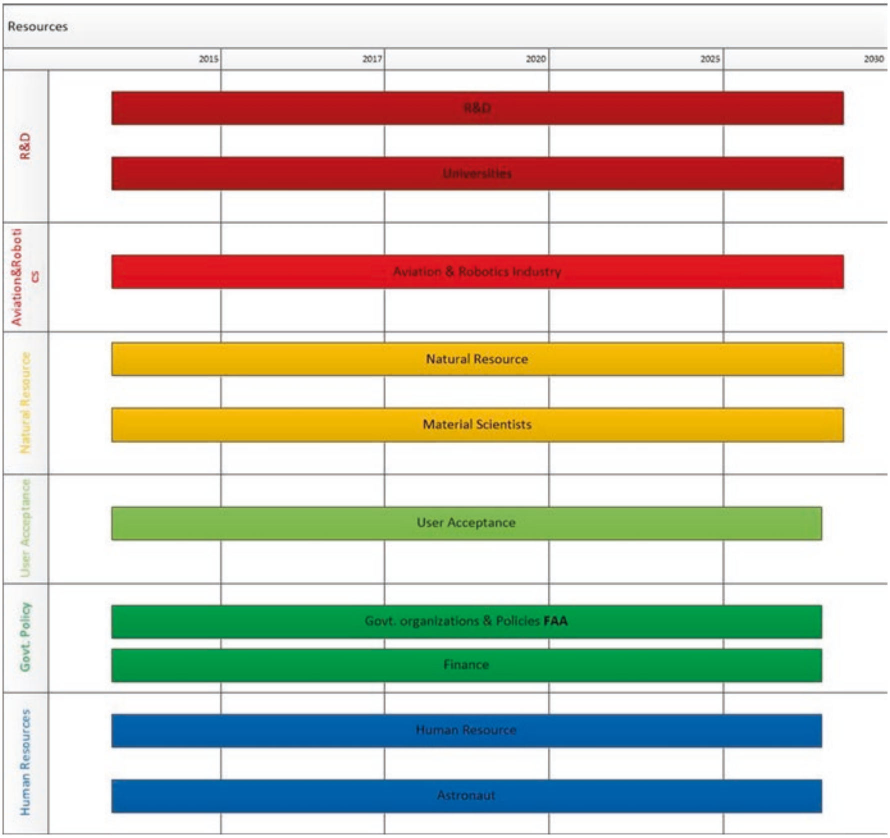


Fig. 13.6 Resources roadmap

access to. In fact many people just don't like this new idea because they are not completely aware of how it works. So events/programs that help customers will play an important role in educating them – which improves the user acceptance (Fig. 13.6; Table 13.8).

The resources defined are necessary as long as the drone technology exists and some of the resources are necessary for any industry (R&D, finance), and as a result the resources are mapped throughout the time line (Fig. 13.7) .

13.13 Conclusion

Amazon is successful in getting the patent approved by Federal aviation administration, but there is a need for more user acceptance and more friendly guidelines. Paul Misener, Amazon's global head of policy, stated "the permission the FAA granted is more restrictive than are the rules and approvals by which we conduct outdoor

Table 13.8 Resources and codes

Resource	Code
Finance	R1
Research and development – Amazon Seattle laboratory	R2
Universities	R3
Government organization and policies – FAA	R4
Aviation and robotics industry – Boeing	R5
Natural resources	R6
User acceptance/customers	R7
Human resource	R8
Material scientist	R9
Astronaut – NASA	R10

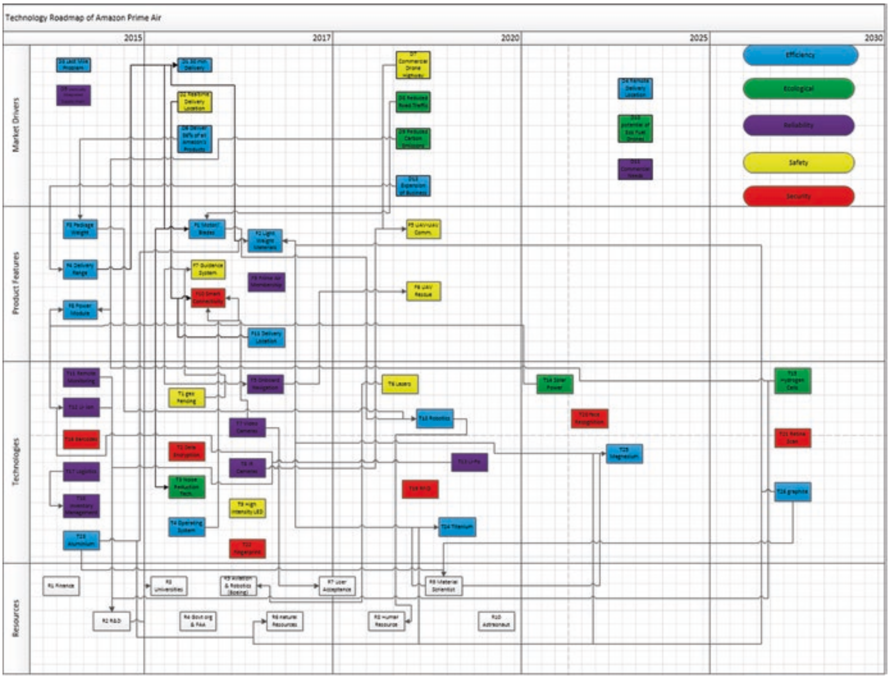


Fig. 13.7 The final roadmap

testing in the U.K. and elsewhere," with regard to the March 19 issuance of an experimental airworthiness certificate to Amazon Logistics. He also thinks that it took far too long for the permission than it usually takes in other courtiers [31].

Amazon has increased its lobbying push for more favorable transportation rules significantly over the past 2 years, according to the data from the Center for

Responsive Politics. The number of people Amazon listed as its lobbyists – both employees and contractors – has doubled to more than 60 people. That list includes Trent Lott, the former senate majority leader. The private sector is putting in all its efforts to make the necessary improvements, but the government also needs to keep up to support the technology.

The Prime Air Service has got all the attention needed after the patent was approved. There are tests being conducted but there still are a few concerns, with regard to the commercialization of drones:

- The sociotechnical hurdles associated with Amazon drones are complex. The promotional video shows how the drone functions, but it does not include most scenarios. The drone, flying in residential areas, is raising serious concerns of how it could cause any injuries to pets or children. They tend to go near the drone as they get attracted.
- *Battery life*: Amazon cannot afford to see their drones fall from sky before reaching a destination as they are expensive. The drone delivery might only cost $1 and the product that has to be delivered is cheaper than the drone. If there is any malfunction or quick battery drain, it is a great loss to the company, and it is a fact that technology will never always work as expected.
- *Protection*: It is also not clear as to how Amazon is going to protect their drones from people who try to aim the drones and collect the package for themselves. The insurance policy, which is difficult to access at this instance, needs to be very clear and efficient.
- *Weather*: The company claims the delivery will take 30 min, but it is equally important to think about climatic conditions which are difficult to predict at times. Are the drones capable of withstanding powerful winds, rains, and thunderstorms? If not, does it mean Prime Air Service cannot be offered yearlong?
- *Timing*: Is the drone going to wait for the customer at the drop off location? If so who will acknowledge the receipt? If the drone is just going to drop off the package, what if it goes missing? What happens if a customer is late to pick up?

Considering the pace of user acceptance, FAA regulations, and the above discussed concerns, it seems like it might take more time than expected. Amazon's website mentions "We will not launch Prime Air until we are able to demonstrate safe operations." And it is not clear as to how much time Amazon is going to take to satisfy FAA for the commercial use.

13.14 Recommendations

If we look at the history of drones, there is not much data we can find. Most of the people do not support this idea of drone delivery as they are concerned about the safety, privacy, and environment issues. The drones in use today are to capture sports, photography, surveillance, and military purposes. A big portion of the common population has not seen a drone or used it, and so there are a lot of misconceptions and confusion. We are entering in to a different era; after the combustion engines, electric vehicles, and hybrid vehicles, people now need to know about this new technology.

Walmart's drone ambitions are sensible, real, and practically possible today. Walmart's idea is to use the drones within the warehouses to check warehouse inventory, using the drones that are capable to capture 30 frames per second [32]. The company claimed they are going to use a custom-built drone and that they are 6–9 months away to include drones in their warehouse. FAA will obviously not raise a lot of concerns like for Amazon, as Walmart limited their drone usage, within drones, avoiding public, air traffic, birds, etc. Workhorse Group Inc. as described earlier is using their drones only to deliver the package from a fully electric truck to the doorsteps. There is no chance of drone being lost, no need for high-tech drones as of now, and no need of powerful battery. But we can already see Amazon striving so hard to make the drone delivery work.

Amazon Prime Air is not impossible, but it is going to need more time getting approvals from FAA and in testing. If Amazon currently focuses on using the drones away from public and residential areas and proves the safety and efficiency of working with drones, it will be easy to get permission for commercial usage in near future. There has to be more market penetration in terms of drones, which will make it easy for Amazon and FAA for later stages. While testing at designated sites is underway, there's still a long way to go before regulators fully open the skies for commercial use.

Acknowledgments The data for this chapter was gathered and analyzed previously by a team of students including Horatiu Corban, Nicole Tuite, Sivagamasundari Sathappan, Kranthi Rapolu, Shiva Singireddy, and Anusha Srivatsa.

References

1. Popper, B. (2015). Drones could make Amazon's dream of free delivery profitable, The Verge. [Online]. Available: http://www.theverge.com/2015/6/3/8719659/amazon-prime-air-drone-delivery-profit-free-shipping-small-items. Accessed 22 Jun 2016.
2. Hutchinson, S. (2016). How not to lose your job to a Robot, Inverse. [Online]. Available: https://www.inverse.com/article/3232-why-drones-may-not-replace-your-delivery-guy. Accessed 23 Jun 2016.
3. D'Onfro. (2016). Amazon prime members may spend more than double what Non-Members Do, Business Insider. [Online]. Available: http://www.businessinsider.com/amazon-prime-members-may-spend-more-than-double-what-non-members-do-2015-1. Accessed 14 May 2016.
4. Daim, T., & Oliver, T. (2008). Implementing technology roadmap process in the energy services sector: A case study of a government agency. *Technological Forecasting and Social Change, 75*(5), 687–720.
5. The First Urban Drone Delivery Just Happened In Nevada. (2016). Popular Science. [Online]. Available: http://www.popsci.com/first-urban-drone-delivery-successful. Accessed 13 Jun 2016.

6. Jenkins, D., & Vasigh, B. (2013). *The economic impact of unmanned aircraft systems integration in the United States*. Arlington, VA: The Association for Unmanned Vehicle Systems International (AUVSI).
7. United States Patent and Trademark Office.
8. McNabb, M. (2015). Amazon's Sense and Avoid Patent for Drones – DRONELIFE, DRONELIFE. [Online]. Available: http://dronelife.com/2015/12/04/amazons-sense-and-avoid-patent-for-drones/. Accessed 15 Jun 2016.
9. Phaal, R., & Muller, G. (2007). Towards visual strategy: An architectural framework for road mapping. PICMET '07 – 2007 Portland International Conference on Management of Engineering & Technology. n. pag. Web.
10. Rinne, M. (2004). Technology roadmaps: Infrastructure for innovation. *Technological Forecasting and Social Change, 71*(1–2), 67–80.
11. Daim, T., Amer, M., & Brenden, R. (2012). Technology road mapping for wind energy: case of the Pacific Northwest. *Journal of Cleaner Production, 20*(1), 27–37.
12. Phaal, R., & Muller, G. (2009). An architectural framework for road mapping: Towards visual strategy. *Technological Forecasting and Social Change, 76*(1), 39–49.
13. Kostoff, R., & Schaller, R. (2001). Science and technology roadmaps. *IEEE Transactions on Engineering Management, 48*(2), 132–143.
14. Winebrake, J. J. (2004). Technology roadmaps as a tool for energy planning and policy decisions. *Energy Engineering: Journal of the Association of Energy Engineering, 101*, 20–36.
15. Daim, T. U., & Oliver, T. (2008). Implementing technology roadmap process in the energy services sector: A case study of a government agency. *Technological Forecasting and Social Change75., 5*, 687–720.
16. The Amazon Effect: Impacts on Shipping and Retail | Shorr Packaging Corporation. (2016). Shorr.com. [Online]. Available: http://www.shorr.com/packaging-news/2015-06/amazon-effect-impacts-shipping-and-retail. Accessed 12 Jun 2016.
17. Amazon quietly builds its own shipping company. (2016). USA TODAY. [Online]. Available: http://www.usatoday.com/story/tech/news/2016/01/12/amazon-shipping-france-colis-priv/78686016/. Accessed 17 Jun 2016.
18. Heisler, Y. (2015). Now we know how Amazon's crazy drone delivery service will work, BGR. [Online]. Available: http://bgr.com/2015/05/08/amazon-prime-air-patent-drone-delivery/. Accessed 17 Jun 2016.
19. McFarland, M. (2016). Amazon details its plan for how drones can fly safely over U.S. skies, Washington Post. [Online]. Available: https://www.washingtonpost.com/news/innovations/wp/2015/07/28/amazon-details-its-plan-for-how-drones-can-fly-safely-over-u-s-skies/. Accessed 12 Jun 2016.
20. Overcoming Last Mile Logistics Challenges. (2016). Mitchellsny.com. [Online]. Available: https://www.mitchellsny.com/blog/overcoming-last-mile-logistics-challenges/. Accessed 14 Jun 2016.
21. Szondy, D. (2016). Jeremy Clarkson unveils Amazon's new delivery drone, Gizmag.com. [Online]. Available: http://www.gizmag.com/amazon-clarkson-drone-delivery/40641/. Accessed 20 Jun 2016.
22. Amazon.com,Inc.(2016).PlansforaVerticalIntegrationtoTakeonRivals",Businessfinancenews.com. [Online]. Available: http://www.businessfinancenews.com/27258-amazon-plans-for-a-vertical-integration-to-take-on-rivals/. Accessed 12 Jun 2016.
23. Lavars, N. (2016). Amazon makes its case for dedicated drone highways in the sky,Gizmag.com. [Online]. Available: http://www.gizmag.com/amazon-drone-highways/38669/. Accessed 23 Jun 2016.
24. Small Drones Market by Application – 2020. (2016). MakretsandMarkets, Marketsandmarkets.com. [Online]. Available: http://www.marketsandmarkets.com/Market-Reports/small-uav-market-141134567.html. Accessed 23 Jun 2016.
25. Welcome to the Drone Age. (2015). The Economist. [Online]. Available: http://www.economist.com/news/science-and-technology/21666118-miniature-pilotless-aircraft-are-verge-becoming-commonplace-welcome. Accessed 23 Jun 2016.

26. Soper, Taylor. (2015). Amazon reveals new delivery drone design with range of 15 miles. GeekWire. N.p.,. Web. 21 Jun 2016.
27. Soper, T. (2015). Amazon reveals new delivery drone design with range of 15 miles, GeekWire. [Online]. Available: http://www.geekwire.com/2015/amazon-releases-updated-delivery-drone-photos-video-showing-new-prototype/. Accessed 21 Jun 2016.
28. Crowe, S. (2016). How Amazon Drone Delivery Will Work – Robotics Trends, Roboticstrends.com. [Online]. Available: http://www.roboticstrends.com/article/how_amazon_drone_delivery_will_work. Accessed 15 Jun 2016.
29. Allain, R. (2016). Physics of the Amazon Octocopter Drone, WIRED. [Online]. Available: http://www.wired.com/2013/12/physics-of-the-amazon-prime-air-drone/. Accessed 15 Jun 2016.
30. DJI Introduces New Geofencing System for its Drones. (2015). DJI NEWS. [Online]. Available: https://www.dji.com/newsroom/news/dji-fly-safe-system. Accessed 13 May 2016.
31. Wilcox, Tracy. (2016). Amazon spends big money lobbying to change transportation rules (NASDAQ:AMZN). Daily Mail Times. N.p. Web. 22 July 2016.
32. Wal-Mart Says It Is 6–9 Months from using drones to check Warehouse Inventory. (2016). Reuters. N.p. Web. 23 Jun 2016.

Part IV
Infrastructure

Chapter 14
Technology Roadmap: Google's Eco-friendly Mobile Phones

Xuran Dai and Tugrul U. Daim

14.1 Introduction

By the increased use of smartphone on day-to-day life, there is a huge impact on the environment because of the non-environmentally friendly production process, carbon emission, the use of toxic material, recycled process, and e-waste. For the success of making an eco-friendly phone, this paper helps in enlightening the need for technology developments and constructing the roadmap for the pioneer of eco-friendly phone. This paper first uses SWOT as a tool to analyze Google's internal and external issues, and then a list of 9 market drivers and 14 product features are presented and used to develop the driver-product feature rankings. According to the ranking, technology benchmarking and resource allocation are presented. A final technology roadmap of developing a Google eco-friendly phone of the three timelines is provided at the end.

Nowadays, technology roadmapping is a popular planning process to help develop technology alternatives to satisfy product needs, and the main benefit of technology roadmapping is to identify technology gaps, which need to be filled to meet the targets. Because of the increasing awareness of the e-waste and the environment, this chapter presents a creation of technology roadmap for Google's eco-friendly phone; thus strategic market analysis, market driver analysis, product feature and gap analysis, technology benchmarking, and resource allocation will be discussed in this chapter in order to develop the technology roadmapping for the coming 3 years. We chose to include this chapter in this section, because we think the trends in communication technology are impacting the whole infrastructure ranging from transportation to emergency services. Besides Google is also investing into sectors ranging from transportation to energy and they should be leveraging their efforts in other sectors.

X. Dai • T.U. Daim (✉)
Portland State University, Portland, OR, USA
e-mail: xuran@pdx.edu; tugrul.u.daim@pdx.edu

T.U. Daim et al. (eds.), *Infrastructure and Technology Management*, Innovation, Technology, and Knowledge Management,
https://doi.org/10.1007/978-3-319-68987-6_14

14.2 Literature Review

14.2.1 History of Mobile Devices

Mobile phones have a significant impact on people's life, and over the past years, mobile phones have evolved immensely in design and function since 1983. The Motorola DynaTAC 8000x went on sale in the USA in 1983; it was considered the first mobile phone since it was small enough to carry. The phone use had not spread to the general public due to the high price, and it became a culture symbol [1]. From 1990 to 1995, the cell phones focused on design and portability, and by the 1990s, cell phones were fast appearing in the hands of average consumers [2]. Early cell phones were just for talking, and then many features were expanded in 2002, "the purpose of the cell phone has shifted from a verbal communication tool to a multimedia tool" such as checking email, video game, snapping photos, surfing the web, and music streaming. When 2G introduced cell phone networks to people, everyone needed a mobile phone in their daily lives, and people have more expectation on the speed; thus, 3G which allowed for faster data transmission speeds started to roll out around the world [3]. In 2003, BlackBerry 5810 was produced and it had a QWERTY keyboard. In 2007, iPhone was introduced by Apple chief executive Steve Jobs; it combined the feature of a cell phone, pocket computer, and multimedia player [4]. In 2008, Google launched the Android operating system, and the first Google Android-powered phone was launching in the USA as the T-Mobile G1. iPhone introduced millions of people to apps; in 2010, the App Store opened; there were over 4 billion total downloads [5]. Moreover, iPhone provided the most attractive design of any mobile released to date, and the shape of cell phone has changed over time, just "like computers, the cell phone over time has become drastically smaller" [2]. In the same year, Google released the first Google Nexus phone, which was manufactured by HTC. Before the end of the first decade of the twenty-first century, 3G was being overwhelmed and 4G was introduced, "4G's main improvement over 3G technology was its data-optimization, which promises to offer speeds up to 10 times faster than existing 3G technologies" [3]. Mobile phone is not just a telephone, it combines the advanced mobile phone technology and computer technology, and smartphone becomes many people's best friend.

14.2.2 E-waste

"In 1985 there were less than half a million cell phones in the United States. There are 233 million in 2006," as Bette Fishbein from Inform says that is a "tremendous expansion" [7]. Billions of phones have been thrown away around the world, 130 million amounts of cell phones retired in the USA per year, and 65,000 tons weight of electronic garbage is created by cell phones per year [7]. Cell phones are worst for toxic chemical, and most end up in landfills, rivers, or incinerators; these chemicals leach into the groundwater, lead to cancer, and damage human's brain development system. When unwanted cell phones are incinerated, the toxics contaminated the air [8]. The emerging of mobile phone technology forces users to switch more often to the latest product version of mobile devices. This has led to increase of electronic wastes, and cell phones may be the most valuable form of e-waste. An average phone contains about $1 in precious metals, mostly gold [7].

14.2.3 Technology Roadmapping

Technology roadmap is a planning tool used to support the development and the implementation of strategy and plans and help link the technological capability to product and business plans; it also can be used for communication of the plan. "A 'roadmap' is an extended look at the future of a chosen field of inquiry composed from the collective knowledge and imagination of the brightest drivers of change in that field, and it is defined as the views of a group of stakeholders as to how to get where they want to go to achieve their desired objective" [9]. Technology roadmapping is one part of technology planning process to help develop technology alternatives to satisfy product needs; it is driven by a need. Technology roadmapping provides a way to develop, organize, and present information about the requirements and targets and identifies technologies that need to be developed to meet those targets; it also provides the information about selecting different technology alternatives [10].

Technology roadmapping can be used to help in understanding how to balance investment and project priorities, provides a mechanism to help experts forecast technology development in targeted areas, and provides a framework to help plan and coordinate technology developments [11] [10]. The main benefit of technology roadmapping is to identify technology gaps which need to be filled to meet the targets and "identify ways to leverage R&D investments through coordinating research activities" [10]. Technology roadmapping is also a marketing tool that shows the key gaps in the market and technical knowledge [12] and links values, products, markets, technologies, and resources plans together.

The process of developing roadmaps is more important than the roadmaps themselves because of the associated communication and collaborative problem solving. Also, the process needs to fit the context, along with the structure of the roadmap. Many different approaches to roadmapping have been developed in the workshop; the use of workshop helps build consensus about what the key issues of interest and concern are and the tasks that needed to be put on the plan [13]. S-Plan is one of the roadmapping approaches that can be used to guide the discussion; a roadmap wall chart is used to share different points of view of the subject of interest, to develop a strategic landscape and address all the issues of concern. Then, specific topics can be explored in more detail by using common template, in order to develop roadmaps for project priorities and further discussion [13].

14.3 Strategic Market Analysis

SWOT analysis is a key step in planning; it is a straightforward model that analyzes an organization's internal issues, which are strengths and weaknesses, and external issues which are opportunities and threats. In order to develop a technology road-mapping for Google's phone, SWOT analysis is used during this development process.

14.3.1 Strength

14.3.1.1 Android Platform

Google developed Android mobile operating system, and Google provides major updates to Android every 6–9 months. Google launched its Nexus series of smart-phones. h use the Android operating system and built them through manufacturer partners; also Android is more cost-effective [14].

14.3.1.2 Financial Liquidity

Google incorporation is in good financial health; the current ratio and quick ratio of Google are 4.58 and 4.25, respectively; liquidity ratios greater than one mean that it is less likely fall into financial difficulties; the high ratios showed Google's capability to settle all debt with all available assets [15] [16]; and asset can be easily converted into cash for any emergency times. Thus, it reduces the chance of shutting down the project due to the financial problem during times of emergency.

14.3.1.3 Patent Portfolio

Google was awarded only four patents in 2003, but Google started to realize that they need to earn more patents in 2007 to compete with Apple, because at that time, Apple launched the iPhone, "which came to market defended by a thicket of patents and trademarks on everything from the 'home button' to the design of its rounded corners." Then Google released Android as an open source, and Google has been working very hard to win more patents on its own ideas [17]. Google was awarded around 1800 patents in 2013, and in 2014, Google was awarded 2566 patents which was 38% more patents than 2013 [18]. In 2015, Google was awarded 2835 patents, on an average of 10 patents per day [19].

14.3.1.4 Product Integration

Many Google products and services such as Google Drive, Google Maps, Gmail, YouTube, etc. are integrated with the Android operating system, and this provides a lot of ease of use for customers. Also, this pushes Google+ into the mainstream and catches more Gmail users that currently have no interest to try the other Google products.

14.3.2 Weakness

14.3.2.1 Lack of Competency in Mobile Manufacturing

Many mobile manufacturers are using Android OS, so the compatibility test have to be done to those manufacturers; the upgraded version of its OS need to wait until all tests are done [14].

14.3.2.2 Competitors and Partners Are the Same Companies

Google has many partners; in 2010, Google announced the Nexus One which was the first device to run the Android 2.1; Nexus One was manufactured by HTC. Then Google switched from Android pioneer HTC and partnered with Samsung for the Nexus S, and Galaxy Nexus was also manufactured by Samsung. In 2012, Google switched the partner to LG for Nexus 4 and 5; Nexus 6 was made by Motorola. The Nexus tablet family was manufactured by different partners, Nexus 7 was made in conjunction with ASUS, and Nexus 10 was released in the end of 2012 by Samsung. In 2014, Google partnered with HTC again for Nexus 9 in the latter part of 2014; like the Nexus 6, the Nexus 9 was one of the first devices to ship with Android 5.0 [20]. If Google was going to release their own eco-friendly mobile phone, customers will compare Google phone with phones from other brands; those partners will become competitors.

14.3.3 Opportunity

14.3.3.1 Environmental Concern in Social

The fact shows that "we tend to use a phone for only about 18 months, or a staggering 12 months in the U.S" [21]. About two in ten people had cell phones, which were in storage, and about four in ten people replaced their phone last year [21].

It is an opportunity for Google to develop an eco-friendly phone because more and more people have concerns about the environmental issues and their health issues, and they pay more attention to the words such as reusing, recycling, nontoxic.

14.3.3.2 Modular Platform Partners

Google Ara team developed a modular smartphone which contained all the functionality of a smartphone plus six flexible slots for easy swapping (Lego style) [22, 24]. Instead of a basic frame that customers can buy and upgrade forever, they can style the phone by adding different hardware function modules onto their phones, which is a very ambitious vision. Google also expected that these modules can be a universal way to add hardware functionality to anything [23]. Project Ara is "opening up a whole new hardware ecosystem and partner platform for Google," Google was starting with a list of partners such as Panasonic, TDK, Wistron, E-Ink, Toshiba, Harman, Samsung, Sony Pictures, and some health companies; some of them create different parts of phones such as bigger speakers, extended batteries, glucose meters, and so on [23].

14.3.3.3 Increasing Mobile Market

Mobile market increases really fast; in 2014, there were 4.55 billion people worldwide using a mobile phone [25]; growth of developing regions of Asia, Middle East, and Africa is on the high; about 80 percent of the new smartphone owners will be located in these areas [14, 26]. Between 2013 and 2017, percentage of people who own smartphone will increase from 61.1% to 69.4%; by 2020, there will be 6.1 billion smartphone owners which works out to 70% of the world's population [25] [27].

14.3.4 Threat

14.3.4.1 Risk of Acceptance in Modular Platform

The idea of turning phones into Legos was a good idea, but there were also downsides. The customer cannot truly customize the shape and size of phone because those are fixed by the frame, and each module has a magnet which adds some weight to the phone. The magnets should be strong enough to hold the modules together; if the magnets were damaged, the phone might be broken into pieces when dropped [28]. In addition, few people will happily spend a lot of money to buy parts and put together their own computers; the majority of people do not want to put any extra input, and they want a complete product [28].

14.3.4.2 Multiple Strong Competitors

The main competitors in the smartphone industry were Samsung and Apple; they took together 88.1% of the $215 billion profit over last 6 years [29]. Furthermore, Google cannot truly compete against Apple without retail stores; when the iPhone breaks, customer's first instinct is to take it to the Apple store, but Google's customer service is virtual. "The Apple stores are laid out to showcase each product to its full potential and to give customers a unique hands-on experience"; the Apple employees are trained really well on each Apple products in order to convince people to buy their products [30].

14.3.4.3 Patent Litigation

Google and Microsoft had about 20 lawsuits pending over uses of patents in mobile phone and other technologies. Microsoft sued Motorola in 2010 for patent infringement; when Google bought Motorola, all the lawsuits were inherited by Google, and also the software giant says that Google's Android operating system infringes many of its patents. In 2011, Microsoft collected patent royalties on 50 percent of Android makers, but Motorola was not paying up. Even though the two companies released an announcement that will dismiss all pending patent infringement litigation between them in 2015, they will collaborate on certain patent and provide better services to customers. We will not know if Motorola agreed to pay up or Microsoft will find other ways to fill the big hole [31].

14.4 Market Drivers Analysis

Market drivers are the trends that cause the market to develop and grow; they are "the underlying forces that compel consumers to purchase product" [32]. Drivers can be collected by brainstorming, and large roadmap wall chart can be used to share perspective about the purpose and the benefits of the topic of interest. Nine market drivers (Table 14.1) that make customer purchase the Google's eco-friendly mobile phone are defined; each driver is assigned with a code and explained below.

14.4.1 D1 Customization: Focus on Users

Google Ara team has already developed a modular smartphone in which customers get to choose the configuration and features of the smartphones. Customers can easily customize their own smartphone by purchasing a basic frame and modules; also the modules in the future can be a universal way to add hardware functionality to anything. For example, customer purchases a camera module, and then it can be used on the phone, the tablet, or even the doorbell [23]. This will remain a driver and it keeps improving with time.

Table 14.1 Market drivers

	Market drivers
D1	Customization: focus on users
D2	Changing phones in less than 18 months
D3	Environmental awareness
D4	EPA's/government/institutional norms and regulations
D5	Eco-friendly raw materials
D6	Health awareness
D7	Multifunction
D8	Eco-friendly production process
D9	Energy-efficient devices and accessories

14.4.2 D2 Changing Phones in Less than 18 Months

Customers get rid of the phone due to various reasons; about one-third customers want new features, about one-fifth customers change phones because their battery could not hold a charge, and one-fifth customers changed service plans [21]. Google's eco-friendly mobile phone and module phone can improve the situation eliminating the issue of features and batteries.

14.4.3 D3 Environmental Awareness [6]

Nowadays, more and more people understand that our planet's resources and ecosystem need to be sustainably managed. People start changing their behavior, and they think about "how long they run the faucet, the bin they toss their garbage in and the cleanliness of the air they breathe" [33]. Governments and corporations are being pushed by activist and consumers to pay more attention to the maintenance of our forests; young people have grown up and been educated during the environmental era. Moreover, without throwing away the old phones, many people choose to recycle their old mobile phones, and some mobile phone companies also have a trade-in program. People who have lower income benefit from mobile device trade-in programs, because secondhand and refurbished phones are less expensive than new phones [34]. The reason why environmental awareness became a major concern was that people can see the objective degradation of environmental conditions around them and through the media; also people are paying more attention to their physical and psychological health [33].

14.4.4 D4 EPA's/Government/Institutional Norms and Regulations

The mission of Environment Protection Agency (EPA) is to develop and enforce regulations which protect human health and environment, they believe that protecting the environment is everyone's responsibility, and they enforce the regulations and help companies understand the requirements [35]. These regulations will become a driver in creating eco-friendly phone.

14.4.5 D5 Eco-friendly Raw Materials [9]

Using eco-friendly raw materials that are less hazardous to the environment at each stage of the product developing process can be another market driver. The use of chemicals in the products is strictly controlled. Recycled plastic, eco-friendly packaging, and smart battery charger help enhance phone recyclability and energy efficiency, also promoting e-waste collection and build a better future for customers [36]. In addition, the need to become sustainable was treated as a corporate social responsibility, divorced from business objective by most executives. "The fight to save the planet has turned into a pitched battle between governments and companies, between companies and consumer activists, and sometimes between consumer activists and governments." In order to solve this problem, not only legislation and education are necessary but also more corporate leaders need to understand how sustainable development can benefit their bottom line. According to the research, the companies can reduce the inputs they use when they make sustainable products, so environment friendly actually lowers costs; smart companies now treat sustainability as innovation's new frontier [37].

14.4.6 D6 Health Awareness

Nowadays, the increasing focus of personal healthcare monitoring and rise in chronic disease is driving the market forward. People live on their mobile phone, read books, share thoughts on Twitter, and broadcast snapshots across Instagram, but technology is not just keeping people connected and entertained; technology is catching on people's health [38]. According to Nielsen's Health and Wellness survey, more than 70 percent of Americans say they are actively working to become healthier or maintain their current health. Awareness of wearable technology is high among customers (70%), 15 percent of Americans are currently using fitness bands [39], and health conscious consumers are also looking to smartphone apps to keep track of their health. "In January 2014, 45.8 million US smartphone owners used a fitness and health app, an 18 percent increase from 39 million users during the same month a year ago" [39].

14.4.7 D7 Multifunction

Instead of carrying many gadgets such as cell phone, digital camera, a GPS receiver, and MP3 player, maybe a portable video game device every day, a multifunctional device, will help people save space. Take a close look at the technology market; many devices now incorporate functions traditionally performed by other gadgets. For instance, manufacturers began adding digital camera to cell phones and consumers responded with enthusiasm. Now most of the smartphones incorporate a camera, GPS receiver, MP3, and other features; also many third-party applications can be installed on smartphone [40].

14.4.8 D8 Eco-friendly Production Process

Through increased channels of communication and access to scientific research, climate change becomes a major threat to the sustained life forms [41]; because of this evolving perspective, environmentally friendly production process has emerged as a significant market driver in the marketplace. Environmentally friendly manufacturing process saves the planet from the exploitation of natural resources, the materials of products are more sustainable, and waste is reduced through remanufacturing, reuse, and recycling. Furthermore, business' costs can be reduced through reduced energy use, and the green production process offers the consumer a guarantee that a product has met relevant environmental standards set; capturing a greater market share in this manner shows to be mutually beneficial to vendor and consumer alike [42].

14.4.9 D9 Energy-Efficient Devices and Accessories

The growing need for energy-efficient device and accessories is one of the most important drivers of the eco-friendly phone market, using the accessories such as charger, battery, and charging sockets which will use less energy, save money, and save the environment. The energy-efficient devices as a solution to help person eliminate wasted or inefficient energy usage and just a few minutes could save thousands of dollars.

14.5 Product Feature

Product features are the qualities and characteristics of the eco-friendly Google phone itself such as size, shape, materials, and its functionalities and capabilities; all the inputs on product features can be listed after the basic roadmapping research and literature review and their impact ranked for each market driver. Product feature are

Table 14.2 Product features

		Features
12 months	P1	Extra-long battery life
	P2	Low-energy display
	P3	Modularity
	P4	Eco applications
	P5	Eco-friendly packaging
24 months	P6	Recyclable materials
	P7	Wireless charger
	P8	Toxic-free materials
	P9	Health monitoring features
36 months	P10	Biodegradable
	P12	Human motion technology
	P13	Solar charger battery
	P14	Flexible screen

mapped on the time period of 12 months, 24 months, and 36 months; the mapping is approximately based on where the features are today and when it might be available in the market. Fourteen product features (Table 14.2) of Google's eco-friendly mobile phone are defined; each feature is assigned with a code and explained below.

14.5.1 P1 Extra-long Battery Life

Battery life is always griped by people, a company called SolidEnergy discovered that increasing battery energy density will extend the life of a cell phone battery, this company has taken in $20.5 million to develop their "anode-free" lithium metal battery, and based on research, their ultrathin metal anode can double energy density. SolidEnergy also has "dual-layer electrolyte" that is combined with their anode, it provides four times the energy density of today's best Li-ion batteries, and this company is going to build a battery module for Google [43].

14.5.2 P2 Low-Energy Display

Organic light-emitting diodes (OLEDs) are the future of displays and lighting, "OLEDs can be defined as solid-state semiconductor devices that are made from thin films of organic molecules that create light when electrical power is applied to them, these devices are 200 times thinner than a strand of human hair" [44]. The "giant lightening industry" LG had a great OLED design which makes the digital signage display incredibly lightweight and thin [45], and "OLED may lead to a new age of low-energy display and lighting products that re larger, transparent and flexible" [44]. For Google's next phone, Google is seeking to invest $880 million in LG's display business to help build OLED screen [46].

14.5.3 P3 Modularity

Modular phone is one that users have the freedom of compiling modules of their own choice into a final product. The processor and RAM, speaker, camera, battery, and all the other components are put in modules which can be changed simply by sliding [48]. Also, a company Lapka has the idea of turning project Ara device into a health scanner with different concept modules, so a set of sensors can be for tracking air quality, carbon dioxide, UV sensor, as well as a heart rate monitor, glucose sensor, and breathalyzer [47].

14.5.4 P4 Eco Applications

Eco apps can be built in a Google phone; those apps help users to optimize their energy and water consumption, help them save money, and also change their daily habits in order to save the environment. For example, users can track how much water is used in their daily activities, and the app can send notice and hints to help user save, as well as reward users every time a member took a step in the right direction. The reward points that users earned can be redeemed as discounts with retailers [49].

14.5.5 P5 Eco-friendly Packaging [25]

In order to reduce CO2 emission, energy use, support the recycling of unused resources and produce more eco-friendly products, 100% recyclable paper which is made from agricultural waste from banana, coffee, lemon plantations will be used for the manual and packaging. Also, inks can be made from foods or milk proteins rather than chemicals and bioplastics [50]. The normal plastic packaging is the most hard to degrade, thus Google phone will use naturally degrading plastic and recycled plastic packaging material for charger cases and other packaging [51].

14.5.6 P6 Recyclable Materials

Most regular phones are using a large percentage of toxic materials which are harmful to our environment and the planet, and they are dumped, hard to be biodegraded, and not recycled which leads to around 6 thousand metric tons of toxic waste around the world every year [52]. Google phone will use recyclable plastic and sustainable material; the casing can be made of aluminum which is derived from aluminum cans and surplus wood which is derived from forest project. This phone not only retains a pattern of the wood and color but is also resistant to yeast, bugs, and water [52]. During the manufacturing process, there will be less greenhouse gas emission, and radiation emission rates will be kept at the minimum.

14.5.7 P7 Wireless Charger

Wireless charging has been around for a bit; there are three types of wireless charging, close-range, midrange, and long-range wireless charging. Close-range wireless uses inductive charging technology, and it is highly efficient and cost-effective; midrange wireless charging uses resonance charging technology such as Qi and Rezence, and they are more accessible. Both technologies are available in the market. In addition, long-range wireless charging will be the future focus; it is using a variety of different technologies, for example, radiofrequencies, infrared light, ultrasound, etc. [53]. Also, it must overcome health and safety concerns, for example, which range from radiofrequency waves to ultrasound to lasers [54]. Additionally, the efficiency of long-range wireless charging is also one of the concerns.

14.5.8 P8 Toxic-Free Materials

Most of hazardous chemical substances should be avoided in manufacturing, for example, Brominated flame retardants (BFRs) have been primarily used in the casing and circuit boards, bromine's is added to BFRs in order to protect plastic components which can be exposed to high temperatures. Polyvinyl chloride (PVC) that is a chlorine-based compound is primarily used as coatings for cables and wires. Chlorine is also used in chlorinated flame retardants (CFRs). These hazardous chemicals will accumulate over time; they will finally become widespread pollutants in our environment [55].

14.5.9 P9 Health Monitoring Features

Mobile health monitoring features are more and more effective and helpful for people to track their health; sometimes they can be a very powerful life-saving tool. "Smartphones supported by high-speed data networks can do much more by monitoring heart disease, diabetes, hypertension, and all other modern day ailments [56]." Additionally, John Rogers created a stretchy skin patch which uses light pulses to monitor heart rate or sun exposure; it can be powered by radio signals from a phone equipped with a chip [57]. The number of people who are using healthcare application is increasing, and people have begun to focus on their health and fitness; patients can use apps to manage medical appointments and access their medical records [56].

14.5.10 P10 Biodegradable

Hemp plastic is a bioplastic that can be 100% biodegradable; it is "five times stiffer and 2.5 times stronger than polypropylene (PP) plastic" [58]. "Hemp certainly is a versatile plant, it grows easily and prolifically, making it an extremely efficient crop for these sustainable plastics known as bioplastics" [58]. Many oil-based plastics can be replaced by Hemp plastics.

14.5.11 P12 Human Motion Technology

Motion charging which "uses kinetic energy from human's movements to charge up a battery cell" will be the future human motion technology. The traditional model is to harness the power of your arm swinging back and forth throughout the day to charge the phone, and the future technology will be charging the phone by collecting smaller-scale movements experienced by a phone in a pocket or handbag rather than on the end of an arm [59]. Therefore, the energy that is otherwise wasting on things will be collected and reused.

14.5.12 P13 Solar Charger Battery

Solar charger technology will be another path that Google phone technology could take in the future. Sunpartner Technologies has developed a lightweight case for mobile device to collect energy from light; it works both in indoor and natural light [59]. Sunpartner is also developing transparent photovoltaic material, and a company called Ubiquitous Energy has created a kind of tech which acts as an invisible coating, which is used in solar panels [60]. Moreover, the efficiency gains are the first concern of this photovoltaic cell technology; also where those cells are placed on our devices and where we store them are the following concerns. Once solar charger tech is mature, it will change people's behavior of keeping their smartphone stuffed in a pocket and charging their phone overnight instead of reaching the sun's energy [61].

14.5.13 P14 Flexible Screen

Nowadays, most of smartphones are rectangular, and people are getting bored of the shape, so flexing and bending smartphone will be more visually and intellectually cool, and also folding a device makes it a smaller and more portable package to carry [62]. Even though Google invests $880 M in building OLED screen, the biggest challenge is the internal rigid components such as battery; in order to make a flexible phone, they need to make those components more flexible [63].

14.5.13.1 Driver and Product Feature Ranking

The mapped drivers and product features were prioritized (Table 14.3).

14.6 Technology Benchmarking

After mapping out the drivers and product features, the highest ranking of the product features are P2, P3, and P5 for short period; P6, P8, and P9 for mid period; and P10, P11, and P12 for long period. Tables 14.4, 14.5, and 14.6 showed the comparison of four different brands of smartphones in the market on these product features.

Table 14.3 Driver and product feature ranking

			D1	D2	D3	D4	D5	D6	D7	D8	D9	
		Features	2	2	4	4	4	2	4	4	4	Total
12 months	P1	Extra-long battery life	4	2	2	1						24
	P2	Low-energy display	4	2	4	4						44
	P3	Modularity	4	4	4	1						36
	P4	Eco applications	1	1	4	1						24
	P5	Eco-friendly packaging	1	1	4	4						36
24 months	P6	Recyclable materials					4	2	1			24
	P7	Wireless charger					1	1	1			10
	P8	Toxic-free materials					4	4	1			28
	P9	Health monitoring features					1	4	4			28
36 months	P10	Biodegradable								2	2	16
	P12	Human motion technology								1	4	20
	P13	Solar charger battery								1	4	20
	P14	Flexible screen								1	1	8

Table 14.4 Technology benchmarking (short term) [63–71]

		Google (Pixel)	Samsung (S8)	Apple (7)	Huawei (Mate 9)	Target
P2	*Low-energy display*					
	Screen type	AMOLED	Curved AMOLED	LED-backlit IPS	Super AMOLED	Curved AMOLED
	White screen consumption	4–5 mW	4–5 mW	18.1 mW	4–5 mW	
	Black screen consumption	None	None	20.4 mW	None	
	Overall screen consumption	2.5 mW	2.5 mW	None	2.5 mW	
P3	*Modularity*					
	Platform	No	No	No		Build platform
P5	*Eco-friendly packaging*					
	Box	n/a	Eco paper	Highly recyclable	80% recycled paper	At least 80% recycled paper
	Printing	n/a	Soy ink	n/a	Soy ink	Soy ink

Table 14.5 Technology benchmarking (medium term) [63–71]

		Google (Pixel)	Samsung (S8)	Apple (7)	Huawei (Mate 9)	Target
P6	*Recyclable materials for phone components*					
	External parts	n/a	20% of recycled material	28% bio-based content	30% bio-based materials	20% of recycled material
P8	*Toxic-free materials/process*					
	Greenhouse gas emission	n/a	n/a	56 kg CO_2e	69.26 kg CO_2e	56 kg CO_2e
	Toxic-free material	n/a	Yes	PVC-free, BFR-free, arsenic-free, beryllium-free	PVC-free, BFR-free, arsenic-free, beryllium-free, phthalates-free, CFR-free	Yes, bio-based materials
P9	*Health monitoring features*					
	Biometric technology	No	Yes	Yes	Yes	Yes
	Stepcounters integration	No	Available for other models	No	Yes	Yes

14.7 Resource

Resource is another important part of this roadmapping, because resources will play an important role in the development of the technologies that we identified. As Table 14.7 showed that only P3 and P9 will be developed by the internal R&D of the Google team, others will be done by partners and outsources.

Table 14.6 Technology benchmarking (long term) [63–71]

		Google (Pixel)	Samsung (S8)	Apple (7)	Huawei (Mate 9)	Target
P10	Biodegradable	No	Available for other Samsung models	No	No	Yes
P11	Human motion energy harvesting	No	No	No	No	Yes
P12	Solar charging	No	Available for other Samsung models	No	No	Yes

Table 14.7 Resource allocation

		Features	Technology	Internal RD	Partners	Outsource
12 months	P1	Extra-long battery life	"Anode-free" lithium metal battery			SolidEnergy
	P2	Low-energy display	OLED		LG	
	P3	Modularity	Platform	Google team	Senheisor	
	P5	Eco packaging	Eco paper, soy ink			EnviroPak
24 months	P6	Recyclable materials	Recyclable plastics		BASF	
	P7	Wireless charger	Long-range wireless charger			Energous WattUP, Ossia Cota
	P8	Toxic-free materials	Nontoxic plastic		University of Minnesota [72]	
	P9	Health monitoring features	Biomarkers	Google team		Polytechnique Montreal and Corning, Dexcom
36 months	P10	Biodegradable	Hemp plastic			Hemp UK
	P12	Human motion energy harvesting	Smaller-scale movements harvesting		Georgia Institute of Technology	
	P13	Solar charging	Transparent photovoltaic material, invisible coating			Sunpartner, Ubiquitous Energy

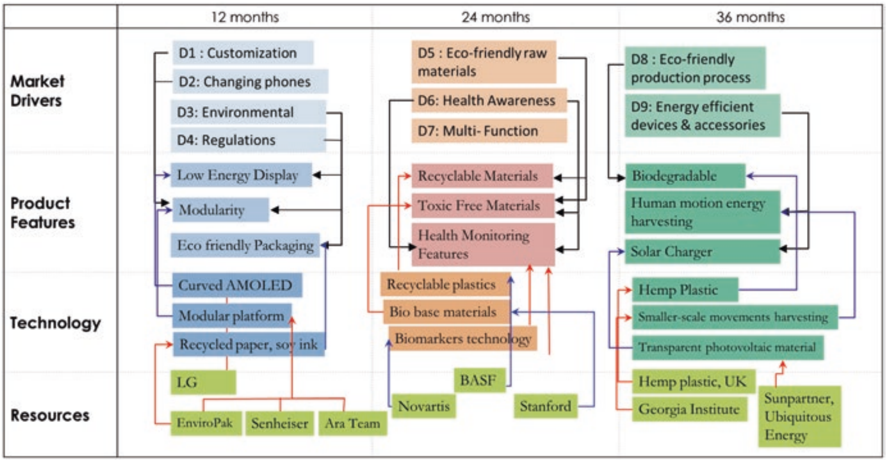


Fig. 14.1 Final technology roadmap

14.8 Technology Roadmap

Nine market drivers under each timeline are shown in the Fig. 14.1, and based on the driver-product ranking, nine technologies of the highest ranking are aligned with market drivers under each timeline. Then, the technologies and resources are listed according to the important product features. All the arrows show the connection between the items.

14.9 Conclusion

Every year there are around 130 million amount of phones retired in the USA and 65,000 tons weight of electronic garbage created per year. All the wastes continue to harm the environment and danger the human beings. This is the main reason that Google will need to develop an eco-friendly phone; during the market analysis, we found that Google developed the Android mobile operating system and owned many patents which are two of its strengths. Also more and more people are concerned about environmental issues and health issues, which can be a good opportunity to have an eco-friendly phone in market. On the other side, there are many strong competitors such as Samsung, HTC, Apple, etc. that will be the main threats.

The goal of this paper is to develop a roadmap for Google's eco-friendly phone, and this paper considers all market drivers, products, and relevant technology together to form into a roadmap. Short term (12 months), medium term (24 months), and long term (36 months) are the three timelines that are considered in this plan. For short term, low-energy display, modularity, and eco-friendly packaging are the main technologies that need to be focused on. For medium term, recycled material, toxic-free material, and human monitoring features are the technologies that need to develop. For long term, biodegradability, human motion technology, and a solar charger battery are the three priority technologies to be developed. Some technologies have already developed some companies, but they are not available in the markets, and some technologies are in the process; Google needs to be partner or outsource with these companies in order to finish the final products.

Overall, technology roadmapping methodology (TRM) is really helpful in the planning stage, and it easily collects the ideas and combines different perspectives into one form. This technology roadmapping process aimed at a better understanding of market drivers and in improving the product creation process; helped to identify what the focus of the development activity should be and which technologies were the highest priorities that the company would develop over the next 3 years; and helped the business plan to gain a better understanding of when technology developments are probably going to be deployable.

Acknowledgments The initial data collection and analysis were done by Abhishek Jain, Kshiti Shah, and Paweena Kongsansatean.

References

1. Goodwin, R. (2017). The history of mobile phones from 1973 to 2008: The handsets that made it all happen. *Know Your Mobile*. [Online]. Available: http://www.knowyourmobile.com/nokia/nokia-3310/19848/history-mobile-phones-1973-2008-handsets-made-it-all-happen. 06 Mar 2017.
2. Blog. *The history and evolution of cell phones*. [Online]. Available: https://www.artinstitutes.edu/about/blog/the-history-and-evolution-of-cell-phones
3. Hur, J. History of mobile cell phones | The first cell phone to present time. *History of Mobile Cell Phones | The First Phone To Present Time*. [Online]. Available: http://bebusinessed.com/history/history-cell-phones/. 09 Feb 2017.
4. Staff, W. P. The history of the mobile phone. *The Washington Post*. [Online]. Available: https://www.washingtonpost.com/news/the-switch/wp/2014/09/09/the-history-of-the-mobile-phone/. 09 Sep 2014.
5. T. Important moments in mobile Phone History. *Important Moments In Mobile Phone History*. [Online]. Available: http://www.tiki-toki.com/timeline/entry/151269/Important-Moments-In-Mobile-Phone-History/#vars!panel=1470939!
6. Rao, V. S., & Murali Krishna, T. (2014). A Design of Mobile Health for Android Applications. *American Journal of Engineering Research, 3*, 20–29.
7. Oppenheim, L. The Secret Life of Cell Phones. *TreeHugger*. [Online]. Available: http://www.treehugger.com/clean-technology/the-secret-life-of-cell-phones.html. 01 May 2017.
8. Cell phones all contain toxics: Older ones the most. *ENS*. [Online]. Available: http://ens-newswire.com/2012/10/11/cell-phones-all-contain-toxics-older-ones-the-most/.
9. Centindamar, D., Daim, T. U., Beyhan, B., Başoğlu, N. , & Beyhan, B. Strategic planning decisions in the high tech industry.
10. Garcia, M., & Bray, O. (1997) Fundamentals of technology roadmapping.
11. Ronan, S. Why you need a strategic IT roadmap. *CIO*. [Online]. Available: http://www.cio.com/article/2889361/it-strategy/why-you-need-a-strategic-it-roadmap.html. 02 Mar 2015.
12. Strategic technology roadmapping. *Develop & visualise your strategic technology roadmap quickly – Roelto*. [Online]. Available: http://roelto.com/strategic-technology-roadmapping/

13. Phaal, R. 2015 Roadmapping for strategy and innovation. *IEE Seminar on justifying and selecting innovation projects*.
14. Bhasin, H. SWOT analysis of android–android SWOT analysis. *Marketing 91*. [Online]. Available: http://www.marketing91.com/android-swot-analysis/. 29 Nov 2016.
15. Latif, M., Hassan, M., Latif, A., Rasheed, I., & Yousaf, U. (2014) The financial performance analysis of Google Inc. V/S industry technology. *Research Journal of Finance and Accounting, 5*(17), 103–109.
16. Liquidity ratios. *Financial analysis and accounting book of reference: Statement of financial position | IFRS Statements | IFRS Reports | ReadyRatios.com*. [Online]. Available: http://www.readyratios.com/reference/liquidity/
17. Regalado, A. Despite anti-patent rhetoric, Google ramps up its own filings. *MIT Technology Review*. [Online]. Available: https://www.technologyreview.com/s/521946/googles-growing-patent-stockpile/. 30 Nov 2013.
18. Hackett, R. The tech companies with the most patents in 2014. *The tech companies with the most patents in 2014 | Fortune.com*. [Online]. Available: http://fortune.com/2015/02/24/most-patents-companies-2014/. 24 Feb 2015.
19. Nordrum, A. Which company earned the most US patents in 2015?. *International Business Times*. [Online]. Available: http://www.ibtimes.com/which-company-earned-most-us-patents-2015-2262346. 13 Jan 2016.
20. History of the nexus family. *Android Authority*. [Online]. Available: http://www.androidauthority.com/history-nexus-smartphone-line-536352/. 24 Feb 2015.
21. Pasternack, A. The environmental costs (and benefits) of our cell phones. *TreeHugger*. [Online]. Available: http://www.treehugger.com/clean-technology/the-environmental-costs-and-benefits-of-our-cell-phones.html. 01 May 2017.
22. Ara. *Google*. [Online]. Available: https://atap.google.com/ara/
23. Bohn, D. Google's project Ara is about more than just modular phones. *The Verge* [Online]. Available: http://www.theverge.com/2016/5/24/11748428/google-project-ara-modular-phones-iot-store. 24 May 2016.
24. Statt, N. Google confirms the end of its modular project Ara smartphone. *The Verge* [Online]. Available: http://www.theverge.com/2016/9/2/12775922/google-project-ara-modular-phone-suspended-confirm. 02 Sep 2016.
25. Smartphone users worldwide will total 1.75 billion in 2014. *eMarketer* [Online]. Available: https://www.emarketer.com/Article/Smartphone-Users-Worldwide-Will-Total-175-Billion-2014/1010536#sthash.30BLENiP.dpuf. 16 Jan 2014.
26. Boxall, A. The number of smartphone users in the world is expected to reach a giant 6.1 billion by 2020. *Digital Trends*. [Online]. Available: http://www.digitaltrends.com/mobile/smartphone-users-number-6-1-billion-by-2020/. 03 Jun 2015.
27. Lunden, I. 6.1B smartphone users globally by 2020, overtaking basic fixed phone subscriptions. *TechCrunch*. [Online]. Available: https://techcrunch.com/2015/06/02/6-1b-smartphone-users-globally-by-2020-overtaking-basic-fixed-phone-subscriptions/. 02 Jun 2015.
28. Hill, S. Will project Ara work? The good and bad of Google's plan to turn phones into Legos. *Digital Trends.* [Online]. Available: http://www.digitaltrends.com/mobile/heres-project-ara-needs-overcome-succeed/#/2. 25 Apr 2014.
29. A. Apple is a global company in the field of innovation and electronics. *Home*. [Online]. Available: http://www.researchwriting.education/index.php/component/k2/item/1461-apple-is-a-global-company-in-the-field-of-innovation-and-electronics
30. Raymundo, O. Why Google can't truly compete against Apple without retail stores. *Macworld.* [Online]. Available: http://www.macworld.com/article/3127611/hardware/why-google-cant-truly-compete-against-apple-without-retail-stores.html. 05 Oct 2016.
31. Joe Mullin–Sep 30, 2015 9:38 pm UTC, Google and Microsoft end all patent litigation. *Ars Technica.* [Online]. Available: http://arstechnica.com/tech-policy/2015/09/google-and-microsoft-end-all-patent-litigation/. 30 Sep 2015.
32. Understanding market drivers. http://wvprime.org/resources/understanding-market-drivers/

33. Cohen, S. The growing level of environmental awareness. *The Huffington Post*. [Online]. Available: http://www.huffingtonpost.com/steven-cohen/the-growing-level-of-envi_b_6390054.html. 29 Dec 2014.
34. Practicing sustainability with mobile device trade-in programs. http://blog.hylamobile.com/practicing-sustainability-with-mobile-device-trade-in-programs
35. Our mission and what we do. *EPA*. [Online]. Available: https://www.epa.gov/aboutepa/our-mission-and-what-we-do. 28 Mar 2017.
36. 2015 Samsung electronics sustainability report. [Online]. Available: http://www.samsung.com/us/aboutsamsung/sustainability/sustainabilityreports/download/2015/samsung%20sustainability%20report%202015_eng%20-%20environment.pdf
37. Ram Nidumolu, Prahalad, C.K., & Rangaswami, M.R. Why sustainability is now the key driver of innovation. *Harvard Business Review*. [Online]. Available: https://hbr.org/2009/09/why-sustainability-is-now-the-key-driver-of-innovation#comment-section. 31 Jul 2014.
38. Tech-styles: Are consumers really interested in wearing tech on their sleeves?. *What People Watch, Listen To and Buy*. [Online]. Available: http://www.nielsen.com/us/en/insights/news/2014/tech-styles-are-consumers-really-interested-in-wearing-tech-on-their-sleeves.html
39. iHealth: How consumers are using tech to stay healthy. *What People Watch, Listen To and Buy*. [Online]. Available: http://www.nielsen.com/us/en/insights/news/2014/ihealth-how-consumers-are-using-tech-to-stay-healthy.html
40. Should you consolidate all your technology into one device?. *HowStuffWorks*. [Online]. Available: http://electronics.howstuffworks.com/everyday-tech/consolidate-technology-device.htm. 23 Apr 2009.
41. Making manufacturing processes eco-friendly. *Chron.com*. [Online]. Available: http://smallbusiness.chron.com/making-manufacturing-processes-ecofriendly-38937.html
42. ValpoScholar. *Site*. [Online]. Available: http://scholar.valpo.edu/cba_fac_pub/15/
43. N. 7 startups looking to improve cell phone battery life. *Nanalyze* 02-May-2017. [Online]. Available: http://www.nanalyze.com/2016/07/7-startups-improving-smartphone-battery-life/. Accessed 26 May 2017.
44. T. D. K. Electronics, Industry market trends. *Industry News*. [Online]. Available: http://news.thomasnet.com/imt/2014/05/21/oleds-illuminate-the-future-of-lighting-and-displays. 21 May 2014.
45. S. Future of OLEDs: A road map from technology to market. *Scientifist* [Online]. Available: http://scientifist.com/future-oleds-technology-market/. 04 Mar 2017.
46. Katie Collins April 10, 2017 4:14 AM PDT @katiecollins, Google reportedly investing $880M in LG OLED for Pixel phones. *CNET*. [Online]. Available: https://www.cnet.com/news/google-reportedly-investing-880m-in-lg-oled-for-pixel-phones/. 10 Apr 2017.
47. Lowensohn, J. Here's what your project Ara phone could look like as a health tracker. *The Verge* [Online]. Available: http://www.theverge.com/2015/1/21/7868915/project-ara-lapka-health-sensor-concept. 21 Jan 2015.
48. Times, T. PuzzlePhone vs. fairphone 2 vs. project Ara: Which modular smartphone should you look forward to?. *Tech Times*. [Online]. Available: http://www.techtimes.com/articles/103040/20151106/puzzlephone-vs-fairphone-2-vs-project-ara-which-modular-smartphone-should-you-look-forward-to.htm. 06 Nov 2015.
49. Lannucci, L. Green apps can raise environmental awareness. *The Poughkeepsie Journal*. [Online]. Available: http://www.poughkeepsiejournal.com/story/tech/science/environment/2015/10/17/environment-green-apps/73980938/. 17 Oct 2015.
50. 5 Ideas for environmentally friendly packaging. *JohnsByrne*. [Online]. Available: http://www.johnsbyrne.com/blog/5-ideas-environmentally-friendly-packaging/. 12 May 2017.
51. Samsung applies advanced, eco-friendly packaging to the galaxy series. *Samsung Global Newsroom*. [Online]. Available: https://news.samsung.com/global/samsung-applies-advanced-eco-friendly-packaging-to-the-galaxy-series
52. What's next: Eco friendly cellphones made using green materials. *Ecofriend*. [Online]. Available: http://www.ecofriend.com/eco-friendly-cellphones-green-materials.html. 02 Aug 2012.

53. State of wireless charging–The present and the future. *ChargeSpot* 07-Feb-2017. [Online]. Available: https://www.chargespot.com/news/state-of-wireless-charging-the-present-and-the-future/. Accessed 26 May 2017].
54. Kharif, O. Phone dead? These companies want to charge it from a distance. *Bloomberg.com.* [Online]. Available: https://www.bloomberg.com/news/articles/2016-09-23/phone-dead-these-companies-want-to-charge-it-from-a-distance. 23 Sep 2016.
55. Home. *Electronics Take Back Coalition*. [Online]. Available: http://www.electronicstakeback.com/toxics-in-electronics/flame-retardants-pvc-and-electronics/.
56. P. M. R. P. Ltd. Future of global mobile health monitoring market 2016–2026. *Medgadget*. [Online]. Available: https://www.medgadget.com/2017/01/future-of-global-mobile-health-monitoring-market-2016-2026.html. 14 Jan 2017.
57. Bourzac, K. New electronic skin patch is powered by a cell phone. *MIT Technology Review.* [Online]. Available: https://www.technologyreview.com/s/602067/a-health-monitoring-sticker-powered-by-your-cell-phone/. 03 Aug 2016.
58. How hemp plastic can replace plastic products that have a negative impact on the environment. *Natural.News – Natural Health News & Self-Reliance*. [Online]. Available: http://natural.news/2016-05-17-how-hemp-plastic-can-replace-plastic-products-that-have-a-negative-impact-on-the-environment.html
59. Price, D. 40 amazing features we could see in future iPhones. *Macworld UK*. [Online]. Available: http://www.macworld.co.uk/feature/iphone/iphone-9-latest-rumours-release-date-uk-price-features-specs-3646340/. 25 May 2017.
60. Caddy, B. Why our phones still aren't powered by the sun *TechRadar.* [Online]. Available: http://www.techradar.com/news/phone-and-communications/mobile-phones/why-our-phones-still-aren-t-powered-by-the-sun-1329646. 30 Sep 2016.
61. McDougall, P. Where's my solar-powered phone?. *Scientific American.* [Online]. Available: https://www.scientificamerican.com/article/where-s-my-solar-powered-phone/. 23 May 2016.
62. Jessica Dolcourt January 15, 2017 6:00 AM PST @jdolcourt. Future phones could bend and fold like this. *CNET.* [Online]. Available: https://www.cnet.com/news/bendable-and-foldable-phones-will-break-us-from-the-smartphone-rut/. 15 Jan 2017.
63. B. Mayo and Benjamin Mayo @bzamayo Benjamin develops iOS apps professionally and covers Apple news and rumors for 9to5Mac. Listen to Benjamin, every week, on the Happy Hour podcast., Apple considering flexible LCD Japan Display tech for 'possible future' iPhones. *9to5Mac.* [Online]. Available: https://9to5mac.com/2017/01/25/bendable-iphone-future-flexible-lcd/. 25 Jan 2017.
64. Compare The Google Pixel vs These Phones. *Phonerated.com*. [Online]. Available: http://www.phonerated.com/compare_phones_using_google_pixel_versus_huawei_mate_9_porsche_design_versus_iphone_7_versus_samsung_galaxy_s8
65. Most-complete Google Pixel Specs. *Phonerated.com*. [Online]. Available: http://www.phonerated.com/specs-google_pixel
66. Complete Samsung Galaxy S8 Specs *Phonerated.com*. [Online]. Available: http://www.phonerated.com/specs-samsung_galaxy_s8
67. Most-detailed iPhone 7 Specs, *Phonerated.com*. [Online]. Available: http://www.phonerated.com/specs-iphone_7
68. Most-complete Huawei Mate 9 Porsche Design Specs. *Phonerated.com*. [Online]. Available: http://www.phonerated.com/specs-huawei_mate_9_porsche_design
69. P. S. Difference Between. *Difference between similar terms and objects* [Online]. Available: http://www.differencebetween.net/technology/difference-between-amoled-and-super-amoled/. 23 Aug 2011.
70. iPhone 7 Plus Environmental Report. vol. 9, no. 11, Sep. Available at https://images.apple.com/environment/pdf/products/iphone/iPhone_7_Plus_PER_sept2016.pdf.
71. Home. *Huawei product environmental information – Huawei support – Huawei official site*. [Online]. Available: http://consumer.huawei.com/en/support/product-environmental-information/index.htm
72. University of Minnesota. [Online]. http://csp.umn.edu/

Chapter 15
Technology Assessment: The Evaluation of Residential Pool Sanitation Options Using TOPSIS

Ori Wolman, Joseph C. Edmondson, and Leong Chan

15.1 Introduction

In the United States, the backyard swimming pool is an iconic upgrade to the standard residential pool. For some, a pool represents that success has been achieved; for others it is used as a social setting point during the hot summer; and lastly the swimming pool is used for recreation. The recreational pool industry also has a vested interest in the construction and maintenance of swimming pools. The total number of new residential pools installed in the United States has dropped from 140,000 installations per year in 2007 to 50,000 installations per year in 2009. These numbers are similar for other Western countries. But, the number of pool installations has remained flat at 50,000 installations per year, in the United States, since the financial crisis of 2008. As such, the residential swimming pool industry has a vested interest in improving the ability to install and sell pools [2].

Pool sanitation is essential for the safe and efficient use of a pool or hot tub. The objective of pool sanitation is simply to destroy harmful pathogens while maintaining a safe swimming environment (not harmful to the swimmer), a pool experience that is pleasing to the swimmer.

Some of the pathogens that a swimmer risks contracting in an improperly sanitized pool are *Giardia*, *Shigella*, *Norovirus*, and *E. coli* 0:157:H7. The Centers for

O. Wolman • J.C. Edmondson
Portland State University, Portland, OR, USA

L. Chan (✉)
Pacific Lutheran University, Tacoma, WA, USA
e-mail: chanla@plu.edu

T.U. Daim et al. (eds.), *Infrastructure and Technology Management*,
Innovation, Technology, and Knowledge Management,
https://doi.org/10.1007/978-3-319-68987-6_15

Disease Control and Prevention reported that there was a rise in cryptosporidium from 3411 cases (2004) to 10,500 cases (2008) during a 4-year period. The large majority of pool use chlorine as a disinfectant. The use of chlorine is not without criticism, for example, there are complaints skin irritation and asthma, vaporous chlorine in enclosed spaces, and failure to control cryptosporidium.

The alternate residential pool sanitation technologies for this study have been identified as (1) salt systems, (2) ozone/UV systems, (3) pool filtration systems, (4) ionization plus oxygen, (5) bromine, and (6) PHMB [3, 4]. Each of these swimming pool sanitation technologies has advantages and drawbacks in view of the initial sunk costs, ongoing maintenance, and regulatory compliance.

This article uses a TOPSIS (Technique for Order of Preference by Similarity to Ideal Solution) to provide and determine the proper residential pool sanitation technology [1]. Five steps were used to acquire data for the TOPSIS analysis: (a) determine the candidate technologies, (b) literature review, (c) gather survey data, (d) analyze survey data using TOPSIS, and (e) recommend residential pool sanitation technologies based on the TOPSIS results.

15.2 Literature Review

15.2.1 Water Sanitation Technologies

The most widely used and understood sanitation technology for residential pools is chlorine. Chlorine is generally introduced into the water in the form of large tablets and/or granular pellets. Frequently chlorine is added to “shock” the water system with excess chlorine to further disinfect the system.

Elemental chlorine is a highly reactive with viral and bacterial cellular membranes. As a result it will typically kill most harmful pathogens with the exception of *Cryptosporidium*, having been shown to be resistant to chlorine. Cryptosporidium is frequently cited as cause of pool-related sanitation incidents.

Given the common use of chlorine, alternate residential pool sanitation technologies had to be identified by literature survey. This literature review resulted in several alternatives: salt systems, ozone and UV systems, pool filtration systems, ionization plus oxygen, bromine, and PHMB [5, 6, 7].

Salt system technology involves in-line electrolysis of NaCl to create disinfecting chlorine. Ozone/UV Systems use ultraviolet light technology to cause unstable ozone (O_3) to form in water. Pool filtration systems involve moving water through a series of filters, typically made of sand or diatomaceous earth. Ionization plus oxygen systems use the passage of electric current within water in combination with elemental copper. Bromine is a chemical with the same valence as Chlorine and provides similar disinfecting properties. PHMB is organic disinfectant that causes death in a number of target pathogens.

15.2.2 Methodology

The TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) method that has been developed by [8] is based on order preference by identifying a solution out of the different options that are the closets (similar) to the ideal solution (i.e., minimizing the distance to the ideal point and maximizing the distance from the nadir point) [1, 14]. The underlying concept is that the most preferred alternative should not only have the shortest distance from "ideal" solution but also the longest distance from an "anti-ideal" solution [15]. In order to evaluate the relative closeness of the alternatives to the ideal solution, Euclidean distance approach is proposed [16]. The TOPSIS method first converts the various criteria dimensions into non-dimensional criteria and then calculates the distance. TOPSIS can incorporate relative weights of criterion importance [17, 18].

TOPSIS is a popular multi-criteria decision technique where good evaluation of one criterion may offset the poor evaluation of another criterion [9]. The attractiveness and advantage of TOPSIS are that it is perhaps better suited to computational analytical techniques [10]. This has spawned a number of software applications, including Excel spreadsheet add-on's that can perform TOPSIS analysis [11]. The simplicity of applying TOPSIS has advantages when the decision results can be quantified as opposed to techniques that use comparative analysis. TOPSIS has spawned variants in the core analytical methods. For example, basis TOPSIS has spawned such techniques as "modified TOPSIS," "extended TOPSIS," and "fuzzy TOPSIS." For this application, conventional TOPSIS is used as the analytical technique. Figure 15.1 shows the TOPSIS procedure.

15.2.3 Determination of the Candidate Technologies

The next step in this analysis was to remove non-candidate technologies. A literature review of industry-specific magazines, vendor information, and other sources of information were reviewed to determine the applicability of candidate technologies. Candidate technologies are described in trade magazines and comparative online literature from vendors.

The operation of "salt" sanitation systems are best described in the product literature available from Cascade Pools [4]. The salt system was developed in New Zealand in 1973 as a reaction to the high cost of imported chlorine and the local regulations regarding the storage of chlorine. The system involves an electrolytic reaction between two electrodes that cause the disassociation of the chlorine ions ($Cl-$) and atomic sodium ($Na+$). This process causes enough chlorine to be disassociated resulting in a sanitation effect. Cascade Pools was the first to market a "salt" system in 1973 under the product number IG450, which was copied in Australia and the United States. It was not adopted widely in the United States due

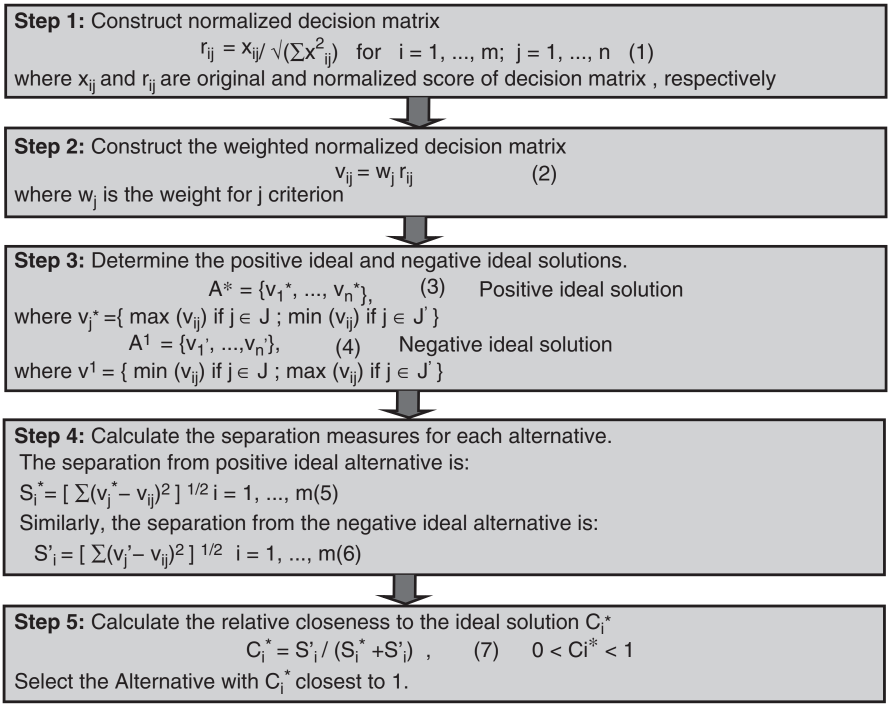


Fig. 15.1 Procedure of the TOPSIS methodology

to wide availability and lower cost of granular chlorine. But, as this technology is used internationally, it is included as a viable candidate technology.

Ozone technology was developed in United States, likewise in the 1970s.The technology consists of creating ozone using coronal discharge. The resulting ozone is dissolved in water to act as a germicide [12].Ozone is at least ten times more effective as a germicidal agent than chlorine. Of the ozone providers, the leading market provider of this technology is DEL Ozone based in San Luis Obispo, CA. DEL Ozone indicates that in excess of 1 M ozone units have been installed. This market penetration indicates that ozone technology a viable candidate technology.

Bromine is a halide chemical similar in nature to chlorine and therefore a good candidate as a disinfectant. The active form of bromine, hypobromous acid (HOBr) is produced when elemental bromine dissociates from bonded bromine in the water [13]. The application of bromine is similar to that of chlorine, minimizing operational and training costs. Although ozone application costs are significantly higher, it still is a good candidate for an alternate technology.

Ionization plus oxygen systems use the passage of electric current within water in combination with elemental copper or zinc. The elemental metal ions act as a sanitizing agent in the water, but at a level where ingest metallic ions are not a health risk. Since the electrodes leach metallic ions into the water, it requires replacement of the electrodes. Although criticism is leveled at the technology as causing staining of concrete by the ions and the requirement that periodic shocking with chlorine is required, it is a technology that is widely accepted and is a candidate technology [14].

PHMB is an organic germicide that is presented as a replacement for chlorine. As such, it has higher application costs as a drawback but an application schedule that is not unlike chlorine [7, 9]. Because it is marketed in the residential pool sanitation channel, it is considered a candidate technology. Pool filtration was eliminated as a candidate technology as it does not provide disinfection of the water [5].

The literature provided some GAP analysis mainly in the form of trying to sell an "alternative" to the traditional chlorine systems. For example, DEL Ozone pool systems provide a chart "comparing" ozone to a number of technologies at http://www.delozonepool.com/our-technology. Ozone is touted as not having the problems with mold or slime buildup of PHMB, lack of oxidizers of ionization, etc. No academic studies were found that compare each of the technologies against each other.

15.3 Research Approach

15.3.1 Gathering Survey Data

In order to get a better understanding of the real factors people consider when selecting the filtration method and the importance of these factors, a field study was conducted. The field study covered identifying and interviewing residential pool owners in the NW Portland metro area. One of the challenges was to identify houses with a residential in-ground pool. Satellite imagery was used to locate the houses that had pools. The next step was the in-person interview. Two cycles of interviews were conducted. The first cycle asked questions related to the cost and key drivers of the filtration system, and the second cycle was targeted toward identifying the importance of each factor for selecting a filtration system. Twelve in-person interviews candidates were attempted, and there were ten successful responses for the first cycle and six successful responses for the second cycle. During the first cycle, the home owners were asked the following questions:

1. Did you help select the pool filtration system?
2. What type of filtration system do you have?
3. What is the monthly cost of the pool system (without electricity)?
4. What was the cost of installation?
5. What large future pool maintenance costs do you have?
6. How often does the pool cleaning system fail?
7. Electricity cost per month?
8. What is your "turnover" rate for the pool water (in hours)?
9. Pool size in kilo gallons?
10. How often is your pool used in months every year?
11. How many people use the pool daily on average?

Table 15.1 Interview 1 responses

Question #	1	2	3	4	5	6	7	8	9	10
1	Y	Y	N	N	Y	Y	Y	N	Y	N
2	C	C	C	C	C	C	C	C	C	C
3	$50	$75	$50	$40	$50	$25	$100	$40	$55	$120
4	$30 K	$38 K	D	D	$30	$20	$40 K	D	$25 K	D
5	N	N	4 K	N	2 K	N	5 K	N	N	1.5 K
6	N	D	D	N	N	1	D	2	1	N
7	$100	$150	$85	$100	$110	$80	$200	$130	$150	$230
8	6	6	Didn't know	6	8	4	6	6	4	Didn't know
9	15	20	10	12	15	12	20	15	15	20
10	4	4	4	4	4	4	4	4	4	4
11	2	2	4	3	1	2	3	3	1	4

Table 15.2 Table key

Question #	Key
Question 2	C is for chlorine
Question 5	N—None
Question 6	N—none, D—don't remember

The table below includes the responses that we got from the interviews (Tables 15.1 and 15.2).

The average of these results indicated that the monthly cost of the pool, less electricity costs, is approximately $ 60.50/mo. The average cost of pool installation is $ 28,500.00, with future capital costs of $2.8 K. Electricity costs amounted to $133.50 per year. Total monthly costs are approximately $200.00 per month.

During the second in-person interview in order to get qualitative measurements, respondents were asked to rate their results on a five-point scale. These questions that were asked in the survey included:

1. Initial pool investment
2. Monthly maintenance cost
3. Difficulty in maintenance
4. Electricity cost
5. Health impacts
6. Perceived equity increase
7. Sanitation factor

The following survey resulted in these relative values (Table 15.3).

Below is a comparative representation of the results in a bar graph. It is clear from looking at the bar graph that the highest driving factors are sanitation, health, and price (Fig. 15.2).

Table 15.3 Survey 2 responses

	1	2	3	4	5	6
Price	4	4	4	5	5	4
Cost of maintenance	4	3	3	2	2	3
Amount of maintenance	4	3	3	3	4	4
Electricity cost	2	3	3	2	3	3
Health factor	5	5	5	4	5	4
Equity increase	3	3	2	2	3	1
Sanitation factor	5	5	5	5	5	5

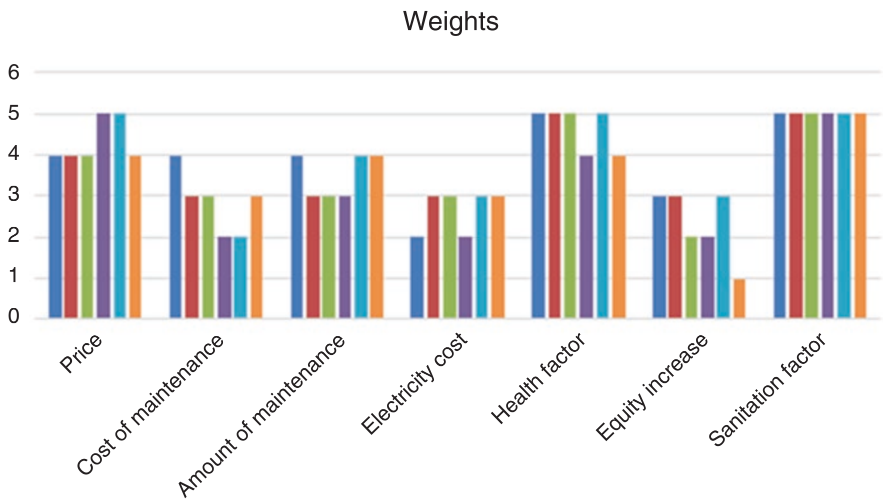


Fig. 15.2 Weight bar graph

15.3.2 Analyzing Pool Sanitation Data with TOPSIS

The application of TOPSIS to this data was first performed using a spreadsheet created by a third party. This third-party application required limiting the number of parameters analyzed, but the initial TOPSIS analysis were positive based on this limited capability of this program. The TOPSIS spreadsheet was then rewritten to accommodate all of the variables needed for analysis. Chlorine is the baseline technology with alternate technology as comparisons. The parameters for the TOPSIS spreadsheet are shown on Table 15.4.

These parameters are weighted by the user preferences gathered in the field survey as shown in Table 15.5:

Applying the TOPSIS analysis, the following rankings were produced for each of the technologies shown on Table 15.6.

Table 15.4 TOPSIS parameters

	Price	Consumables	Maintenance factor	Health factor	Equity increase	Sanitation
Chlorine	0	60	5	1	0	5
Salt system	69.4	10	3	5	69.4	5
Ozone	27.7	0	2	4	27.7	5
UV	22.2	0	2	4	22.2	5
Ionization	20.8	10	2	4	20.8	1
Bromine	0	120	1	3	0	5
PHMB	4.17	360	2	3	4.17	4

Table 15.5 TOPSIS weights

Criteria	Price	Consumables	Maintenance factor	Health factor	Equity increase	Sanitation
Weights	0.2	0.12	0.15	0.2	0.1	0.23

Table 15.6 TOPSIS results

Technologies	Results
Chlorine	0.62
Salt system	0.40
Ozone	0.45
UV	0.48
Ionization	0.50
Bromine	0.62
PHMB	0.55

15.3.3 Result Discussion

The interpretation of these results is that chlorine, as the incumbent disinfecting technology, is clearly the preferred method of treating residential pools. This technology is tied with bromine, despite bromine's higher cost. This is followed by PHMB.

What is relevant to note is that chlorine, bromine, and PHMB are all treatment methods that require no fixed capital investments, require incremental application costs, and involve little or no additional training to the pool owner. This suggests that any technology should closely emulate chlorine's characteristics as closely as possible.

The next class of technologies involve system modifications. Ionization, UV, and Ozone are somewhat equal in rankings. This would suggest that residents prefer systems with only small investments in capital costs.

Finally, ranked at the bottom, are Salt Systems. Salt Systems are a prominent technology in New Zealand and Australia. One possible issue could have impacted the results is the fact that we only surveyed people in a limited area and in a similar cohesive environment. This might have biased results of the TOPSIS analysis. The research didn't look into the influences of the geographical location of the pools, the income of the families that installed the pools or any other external factor that might have an influence on the selection of the filtration system.

15.4 Conclusion and Future Research

Residential pool owners tend to stay with technologies that either they are familiar with or were present when the pool was purchased. The ease of treating pools with chemical chlorine makes this technology the preferred method of treating pools.

As was shown in this TOPSIS analysis, only similar technologies will be successful as alternative choices. User-managed sanitation technologies, like bromine and PHMB, fall into this class and are potential alternatives. Technologies that require retrofitting or upgrading existing pool system fare poorly.

This survey does have a geographic bias. While Portland metropolitan residents enjoy swimming, they tend to do so at public pools. The short summers do not encourage pool ownership. This survey may yield different results in the Southwest (Arizona, Texas, etc.) where pools are used year-around.

This survey also does not account for regulatory factors. Some jurisdictions may limit the use of chlorine and/or foreclose the use of alternate technologies in view of zoning. The survey also suggests that pool owners may need more education regarding sanitation options. Broader surveys, which would include data from pool suppliers and third-party pool maintenance providers, may provide better data sets.

References

1. Yoon, K. (1987). A reconciliation among discrete compromise situations. *Journal of Operational Research Society, 38*, 277–286.
2. G. EESM High Efficiency Residential Swimming Pool Initiative. Found at http://library.cee1.org/sites/default/files/library/9986/cee_res_swimmingpoolinitiative_07dec2012_pdf_10557.pdf. Downloaded on 11/10/2014.
3. Jablonský, J. (2009). Software support for multiple criteria decision making problems. *Management Information Systems, 4*(2), 029–034.
4. Salt water swimming pools. Found at http://www.cascade.co.nz/SaltWater2009.htm. Downloaded on 11/21/2014.
5. A review of swimming pool sanitization methods – AutoPilot Blog found at http://www.autopilot.com/blog/post/211-A-Review-of-Swimming-Pool
6. Swimming pools: Alternatives to Chlorine|Naperville, IL Patch. Found at http://patch.com/illinois/naperville/bp--swimming-pools-alternatives-to-
7. Baquacil vs chlorine – Swimming pool help. Found at http://x.havuz.org/viewtopic.php?t=8006
8. Hwang, C. L., & Yoon, K. (1981). *Multiple Attribute Decision Making: Methods and Applications*. New York: Springer-Verlag.
9. Lucas, A. D. (2012). Environmental fate of polyhexamethylene biguanide. *Bulletin of Environmental Contamination and Toxicology*, *88*(3), 322–325.

10. Autopilot Ozonator, product literature available at http://www.autopilot.com/blog/post/211-A-Review-of-Swimming-Pool-Sanitization-Methods
11. Product Literature, Amazon.com, Del Ozone, Solar Eclipse AOL for Pools.
12. http://www.delozone.com/files/Ozone and UV Advanced Oxidation Nov 1 2012_2.pdf
13. Aquatics International. (2002). Profile of ozone/bromine sanitation systems for city of Tucson Municipal Pools. In Ted K. Rich, ClearWater Tech, LLC and written for Billy Sassi, City of Tucson.
14. Comments found at: https://answers.yahoo.com/question/index?qid=20070916195848AAEkmck
15. Olson, D. (2004). Comparison of weights n TOPSIS models. *Mathematical and Computer Modeling*, *40*(7–8), 721–727.
16. Yilmaz, B. (2014). *Multi-criteria decision making for water resource management: A case study of the Gediz River basin* (pp. 563–576). Water SA. Available at https://www.ajol.info/index.php/wsa/article/view/61990
17. Martin Aruldoss, T. M. (2013). A survey on multi criteria decision making methods and its applications. *American Journal of Information Systems, 1*(1), 31–43.
18. Nikoomaram, H., Mohammadi, M., Javad Taghipourian, M., & Taghipourian, Y. (2009). Training performance evaluation of administration sciences instructors by Fuzzy MCDM approach. *Contemporary Engineering Sciences*, *2*(12), 559–575.

Chapter 16
Technology Assessment: Cloud Service Adoption Decision

Greg Wease, Kwasi Boateng, Chih-Jen Yu, Leong Chan, and Husam Barham

16.1 Introduction

Cloud computing emerged in its current form in the last decade and quickly became popular as it offers a different way to develop, implement, and maintain and pay for IT services in compare with the traditional on-premise approach [1]. The fast-growing adoption of cloud computing is attributed to the benefits it offers to firms over the on-premise environment, like sharply reduced capital expenditure and upfront investment, increased speed to market, more flexible costs and capacity: use it and pay for it when you need it only, cheaper disaster recovery solutions, access to the latest technologies, and more efficient collaboration of global teams [2, 3].

In fact, firms spending on cloud computing are expected to reach $162 billion by the year 2020, from more than $67 billion in 2015. Moreover, according to Gartner, the market size for clouding has reached $209 billion in 2016 and is expected to be more than $383 billion by 2020 [4].

Cloud computing is growing very fast. Cloud market share, both public and private, was almost 25% in 2016 and is expected to jump to 40% by 2020 [5]. And the three main providers of cloud solutions, Amazon, Microsoft, and Alphabet, have reported accelerated increase in revenue year over year (YoY). For example, infrastructure as a service (IaaS) market experienced an increase of 38% YoY growth from 2015 to 2016 [6].

A previous version of this paper was presented at Portland International Conference on Management of Engineering and Technology 2015

G. Wease • K. Boateng • C.-J. Yu (✉) • H. Barham
Portland State University, Portland, OR, USA
e-mail: yuchihjen@gmail.com; hbarham@pdx.edu

L. Chan
Pacific Lutheran University, Tacoma, WA, USA
e-mail: chanla@plu.edu

T.U. Daim et al. (eds.), *Infrastructure and Technology Management*, Innovation, Technology, and Knowledge Management,
https://doi.org/10.1007/978-3-319-68987-6_16

However, cloud computing adoption is facing several challenges. According to IDC, top-ranking challenges for cloud adoption are security (87.5%), availability (83.3%), and performance (82.9%), which are based on a survey of 263 IT executives and their colleagues to gauge opinions about IT cloud services [7].

This paper aim is to offer better understanding of the decision-making process involved in choosing between different hosting environments, including public cloud, private cloud, hybrid – combination of public and private cloud – and on-premise hosting and to propose a decision framework to help evaluate the various IT hosting alternatives available and make a decision about the best suitable solution based on firm needs and capabilities. The proposed framework is based on a combination of literature findings, the hierarchical decision model and technology acceptance model.

16.2 Literature Review

Following is a review of the literature about cloud computing, with focus on what does cloud computing means, what are the main models under cloud computing, what benefits makes it appealing, and what are the challenges in adopting it.

16.2.1 What Is Cloud Computing

There are many definitions of cloud computing. One comprehensive definition is provided by Marston et al. in which they identified cloud computing as "[A]n information technology service model where computing services (both hardware and software) are delivered on-demand to customers over a network in a self-service fashion, independent of device and location. The resources required to provide the requisite quality-of-service levels are shared, dynamically scalable, rapidly provisioned, virtualized and released with minimal service provider interaction. Users pay for the service as an operating expense without incurring any significant initial capital expenditure, with the cloud services employing a metering system that divides the computing resource in appropriate blocks" [8].

Cloud computing addresses two major challenges in the IT sector: achieving IT efficiency, through better utilization of IT resources, and business agility, by being able to respond to business changing and fluctuating needs in a timely manner [8, 9]. Cloud computing is possible through the leveraging on advances in technologies like virtualization, web services, and multi-tenancy [10].

NIST identified five essential characteristics of cloud computing: on-demand self-service, broad network access, resource pooling, rapid elasticity, and measured service [11].

Moreover, cloud computing can have different deployment models:

Public Cloud is offered by third party based on sharing computing resources with different clients that are logically separated and can't see each other and can be accessed via web browser interface, and users pay only for the "using time." This is the most cost-effective approach and is more suitable for small to medium businesses.

Private Cloud is owned and managed by one firm; it exists within the boundaries of that firm. Private cloud computing costs more; however, it is more secure and still offers most of the cloud benefits, this approach is more suitable for large firms, especially if they have several, geographically separated, branches with several data centers.

Hybrid Cloud is a combination between public and private cloud that usually offer a balance between cost and security.

Community Cloud is similar to public cloud but is offered and customized exclusively for certain group of entities that have certain requirements and concerns, this approach is more popular with government entities [12], and community cloud is not considered in this paper's decision model as it serves a specific need and is not generalized and available for all firms.

There are different service models under the cloud computing that can be categorized under main classifications that includes [2, 11, 13, 14]:

Software as a Service (SaaS) Software here means any application or function made available to customers, by the provider, through various devices like web browser or program interfaces. The application and its underlying infrastructure is controlled and maintained by the provider. Under this model, the customer don't need to worry about, dedicate resources to, or possess any technical knowledge related to maintaining the software and will always have seamless access to the latest version of the software. However, under this model, customers have minimum controls over the data and minimum capability to customize it for their own needs.

Platform as a Service (PaaS) This service model allows customers to create and run their own software using the provider platform, including systems and environments, to support end-to-end developing, testing, and running of software. Under this model, customers have the flexibility of running their own customized software that addresses their own needs without worrying about the expensive acquiring and managing of the underlying infrastructure; it also allows for scalability and flexibility. However, customers must have an IT team that possesses technical knowledge on how to develop and maintain software systems, and the user's software is limited to the platform capabilities and available tools.

Infrastructure as a Service (IaaS) This service model provides customers with direct accessibility to virtual infrastructure over the provider cloud. This includes the provision of computing resources like processing, storage, and networks. Under this model, the customer is granted maximum flexibility and scalability. Infrastructure is available immediately and without high initial investment. However, customers must have an IT team that possesses technical knowledge in configuring and managing infrastructure as well as developing and maintaining software systems.

While those are the most popular clouding models, other XaaS models have evolved over the years [15]; following is a look at two models that are gaining rapid popularity in recent years:

Function as a Service FaaS has emerged as part of a new paradigm to implement cloud computing called serverless services. Under this paradigm, customers develop their own pieces of functionality or microservices and implement them within stateless containers on the provider's cloud platform; they have ephemeral status, run when requested upon only, and are executed using automatic management and scaling capabilities offered by the cloud provider. Under this model, customers only need to possess technical skills to build the micro-functions and will be charged based on functions calls only, so this model offers combination of the benefits of the three models described above with most of the disadvantages removed. This model is fairly new; Amazon Lambda is an example of FaaS [16, 17].

Machine Learning as a Service Machine learning and artificial intelligence are playing an increased role in most types of software systems, especially the ones including making machine decisions and predictions, like approving a credit card application online or advising car drivers on dealing with road conditions and so on. However, machine learning is complex and expensive to configure and manage, and that led to the emergence of MSaaS model to help customers overcome the cost and management challenges of using machine- learning capabilities[18, 19].

16.2.2 Cloud Benefits

Cloud computing is attractive in compare with on-premise hosting for several reasons; following is a review of some of the most important benefits of cloud computing [2, 3, 8, 9, 20, 21, 22]:

Reduced Upfront Cost and Initial Investment Cloud computing allows startups, small firms, and firms in "technology-challenged" countries that are late in term of technology to offer solutions and services that require intensive computer capabilities, which without cloud computing would require a large initial investment that most of those companies can't afford or don't have access to, like in the case of technology-challenged countries.

Reduced Time to Market Acquiring computer capabilities like servers, data storage, and network devices are not only expensive but also the delivery of equipment and then the initial configuration take considerable time. In cloud computing, acquiring and configuring the same capabilities can be done almost instantly.

Underutilized Servers One of the challenges facing on-premise data centers is that servers are underutilized most of the time; still firms need to keep those servers up and running to handle the limited time when there is a surge of demand. Cloud computing on the other hand allows firms to use the capacity they need only. Acquire more capacity when there is a surge in demand, and release that capacity back to the cloud provider when not needed anymore.

Elasticity Cloud computing offers another important feature; elasticity is a dynamic scalability of resources. In cloud, extra resource capacity can be automatically and dynamically assigned when there is a surge in demand and then released when the demand abates. Customer doesn't need to do any technical handling and will pay for the increase in utilization only for the time when it occurred.

High Cost of Maintenance and Operations Cloud computing reduces not only the initial cost of acquiring computing capabilities but also the need to maintain data centers, including hiring dedicated administrators and utilities management.

Environment and Power Cost Cloud computing is offered through data center farms located in areas where power is more clean and cheap than typically available for companies' headquarters.

New Innovative Services that Were Not Possible before The unprecedented possibility of getting cheap and fast access to computing capabilities that are built on top of thousands of computers across the globe allows for the creation of new innovative ideas by small firms that wouldn't be able to do that otherwise, especially in fields like big data analytics and machine learning.

The numerous potential benefits of cloud computing continue to drive individuals and organizations to adopt various cloud applications.

16.2.3 Cloud Adoption Challenges

There are several barriers and concerns preventing firms from making the move from on-premise to the cloud. Following is a review of some of the main reasons making cloud adoption challenging [23–28]:

Security and Privacy The security of the cloud is a main concern when making the decision to move to the cloud. Most cloud providers assure their clients that they don't access their data, nor share it with others and that they implement state-of-the-art security measurements. However, there is no 100% guarantee about that, not to mention that sharing the same infrastructures with others is risky, even if the cloud providers assure all clients that they are logically separated and can't reach each other's data and applications.

Reliability and Availability Any problems or delays in mission-critical applications could have high impact on firms. So, many firms have concerns about moving their mission-critical applications to someone else's environment.

Compatibility with Existing Applications Under most cloud service models, clients are bounded by the cloud provider designs and available capabilities. So, migrating current applications to the cloud becomes a challenge and in some cases an expensive barrier to overcome, as it requires making changes to currently stable, on-premise applications, making the move to the cloud less appealing.

Governance and Compliance Policies There is a lack of clear governance and compliance policies around cloud computing. Some firms have concerns that the lack of governance makes them less protected when using the cloud; other firms have concerns that future, more restricted, regulations might force them to leave the cloud after making considerable investment and internal changes to adapt to the cloud.

Lack of Cloud Expertise Cloud computing is being improved and adopted rapidly, resulting in high demand on IT expertise in this field, but there is not enough skilled people to keep up with the demand.

Private Cloud Challenges Private cloud computing removes security and privacy concerns as the cloud is owned and operated by the firm itself while still getting most of the cloud benefits, except for the fact that the firm needs to make an expensive initial capital investment and to handle the cloud backbone operations.

Cloud providers can address many of these concerns by offering service level agreements (SLA) to their clients that covers those clients' concerns, especially regarding privacy, reliability, and availability. Also, by being transparent and clear about their security measurement and state of the regulations regarding cloud computing. Finally, cloud training and partnership with educational institutes can alleviate the shortage of expertise challenge.

16.2.4 Cloud Adoption Factors and Research Done So Far Regarding Making Decisions

In a study to investigate the determinants of cloud computing adoption with the UK, Lumsden and Gutierrez [29] found out that aspects relating to compatibility, relative advantage, technology management, and top management support are very influential in cloud computing adoption. While cloud computing has its own advantages, the disadvantages that accompany it tend to dissuade a lot of people or organizations from adopting cloud computing although it has the ability to revolutionize businesses. The "technology-organization-environment (TOE) framework", which analyzes IT adoption by different firms in different locations, provided initial insight of key predictors for cloud adoption after a self-created survey was employed to gather data (Fig. 16.1).

Alshamaila and Papagiannidis [30] studied small- to medium-sized enterprises to access how cloud computing could enable them to deliver products and services, which were originally only possible by large enterprises. Using the Technological, Organizational, and Environmental (TOE) framework as a theoretical base, they developed a multi-perspective framework that showed that relative advantage, uncertainty, geo-restriction, compatibility, innovativeness, market scope, external computing support, and among others were some of the factors crucial to cloud

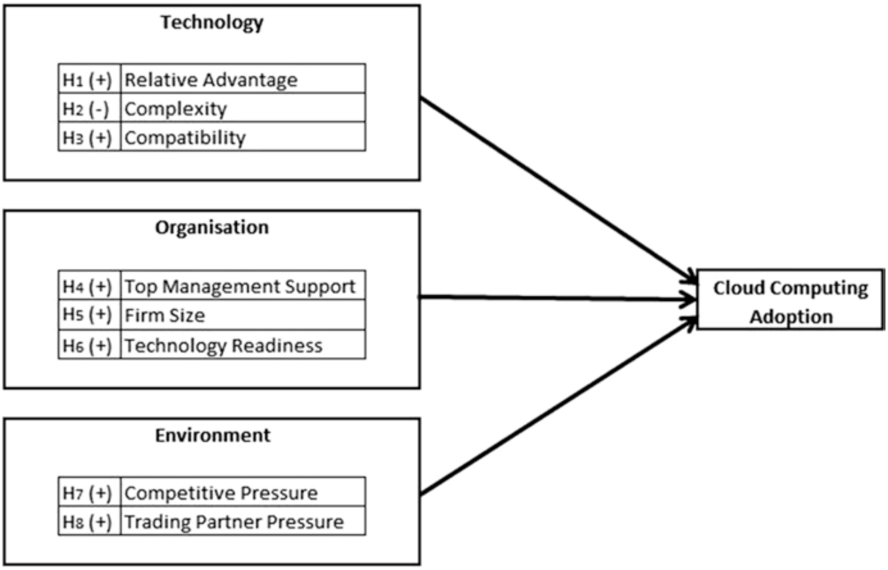


Fig. 16.1 Conceptual model of TOE framework for analyzing cloud adoption [29]

adoption. However, they suggest that not enough evidence point to competitive pressure as being a significant factor in determining cloud computing adoption.

With timeliness increasingly becoming crucial in most business and IT circles, it is imperative for firms to be aware and responsive to competition and the external environment in order to maintain competitiveness. Organizations need to adopt multiple hypothesized relationships, like risk-oriented cultures and normative and coercive pressures, in order to increase how timely decisions are made [30]. This will eventually indicate the factors that are most crucial to the adoption of particular innovative products or services. The immense and considerable uncertainty that surrounds migration to cloud computing continues to pose challenges to adoption. While generally security and business continuity concerns remain two of the biggest drivers of this uncertainty [31]; understanding the real options to decision-making ultimately places firms in a better position to make any migration decision.

16.2.5 Literature Conclusions

Based on the above cloud market review together with some challenges and issues identified from relevant articles, several gaps for cloud service adoption may include three aspects including technical, organizational, and personal perspectives. For technical perspective, the factors may include availability, performance, security, reliability, data confidentiality, data transfer bottleneck, and scalability. In terms of organizational perspective, the factors consist of control, cost, standards, transparency, and licensing. For personal perspective, the privacy, portability, and interoperability should bring customers' attention on the decision of cloud service adoption.

16.3 Methodology

To help firms make the right decision about whether to adopt the cloud or not, a decision model is proposed that builds on the findings of the literature review and uses hierarchical decision model (HDM) and technology acceptance model (TAM).

Following is a review of both HDM and TAM.

16.3.1 Overview of HDM

The hierarchical decision model (HDM) was introduced by Cleland and Kocaoglu. HDM is used to elicit and evaluate subjective judgments of experts' panel. The model suggests that decision criteria should be presented in hierarchy, typically starting from mission, objectives, goals, strategies, and actions, also known as MOGSA [32].

In this model, the criteria hierarchy is given weights based on the evaluation of each criterion, and then the alternatives are evaluated against the criteria to find the best decision possible. The weight is given by experts. The experts evaluate criteria hierarchy and alternatives by conducting pairwise comparisons, with constant-sum measurement scale (1–99 scale) for comparing each two elements. The model offers weights, with the total sum of 1, for each level and on the whole hierarchy, as well as weights for the alternatives against each other for each criterion and a final weight for each alternative in comparison with the other alternatives based on the aggregated evaluations of all experts to find out the best decision possible.

HDM includes disagreement, inconsistency, and sensitivity analysis to validate the reliability of the final model. More details about HDM can be found in this resource [32].

16.3.2 Overview of TAM

According to Davis [33] TAM "specifies the causal relationships between system design features, perceived usefulness, perceived ease of use, attitude toward using, and actual usage behavior," as depicted in Fig. 16.2. TAM is used to link and identify the effects of system characteristics on usage behavior [33].

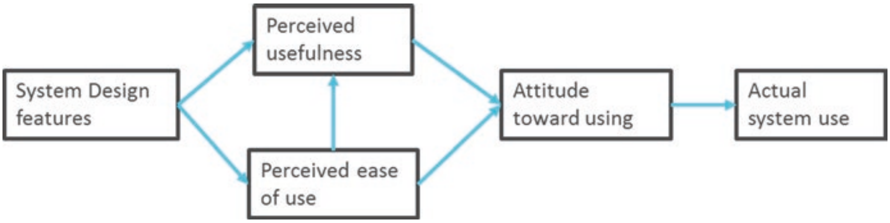


Fig. 16.2 Technology Acceptance Model [33]

TAM has been widely used to explain and predict the use of information systems community. Questionnaires and experts' interviews are found to be the major methods used for testing the hypothesis. Appendix B includes more details about how TAM evolved in addressing information systems by going through several related cases.

16.4 Analysis

16.4.1 HDM Details and Definitions

In our first attempt at building the HDM, simply put, was not successful. The node comparison, context in which they are compared, and any potential future results would not provide significant findings from the researcher's standpoint (Fig. 16.3).

In order to build a reliable HDM, we used consistent information gleaned from the in-depth literature review. We identified key factors, technology requirements, degrees of importance, and how these factors relate to one another – as they relate to "cloud computing" or "non-cloud infrastructure."

Consistent themes from the literature review comprised of the following topics, as well as how they relate to one another, which then in turn enabled us to build the HDM:

Security: cloud provider to offer data security equal to a data center environment
Availability: guarantee an uptime of at least 99.xx percent
Performance: guaranteed high performance of applications over fast connection
Integration with IT: mixing/incorporating with current IT infrastructure services, data, and applications
Elasticity: the ability to expand and contract server utilization at user's discretion
Interoperability: cross platform, cross application, and cross vendor support services
Ease of use: intuitive and easy to learn
Stress: overall reliability in peak demand

Other terms such as "cost," "speed," and "quality of service" really did not need further explanation for the expert panel, as it was self-evident [34, 35].

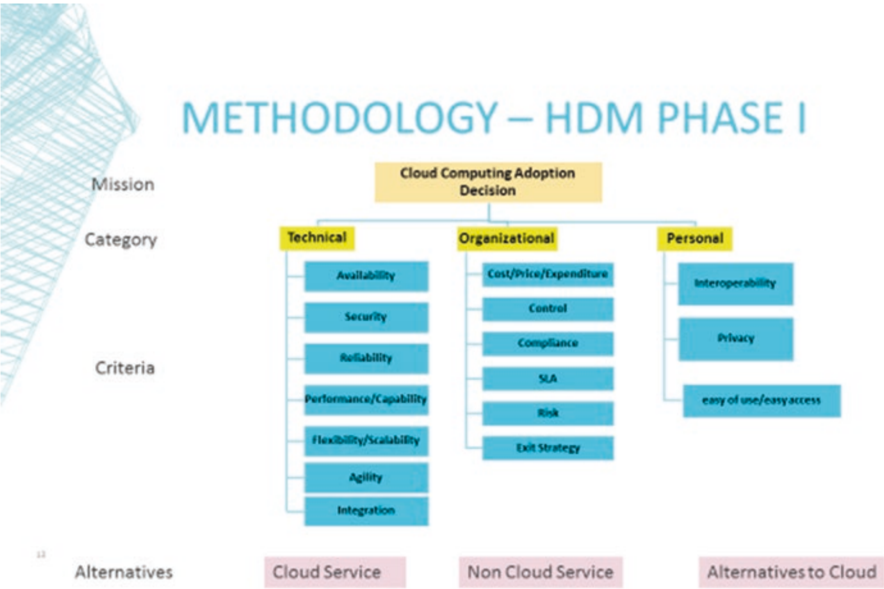


Fig. 16.3 HDM phase I

16.4.2 HDM Results

Again, based on the results of the literature review, we were able to build the final HDM model, see below.

At the mission level, we honed our target to encompass "cloud drivers," essentially what are the key elements that would prompt someone to take action and select a given cloud solution.

From the organizational objective perspective, we selected integration with IT, cost, and elasticity. At the technology requirements level, the key items were interoperability and exit strategy, as they relate to integration with IT; robustness and ease of use, as they relate to cost; and quality of service and speed, as they relate to elasticity. Finally at the organizational priority level, we had our expert panel rank security, availability, and performance – as they each relate to the six technology requirements.

The reason we grouped all nodes at a certain level, against one another, is that these topics were linked (formally and informally) together in the literature review portion of our research. In other words, security, availability, and performance were discussed in the same vein, not as separate and unique entities (Figs. 16.4, 16.5, and 16.6).

What the results show is that each expert has identified the primary characteristics that are important to their given firm. Conversely, how each expert defines "security," "availability," and "performance" is unique to each individual. More on the selection process will be discussed in the conclusion section.

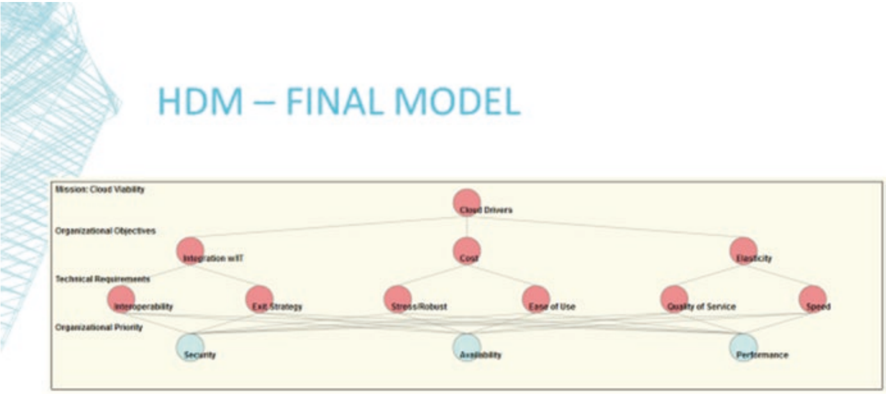


Fig. 16.4 HDM final model

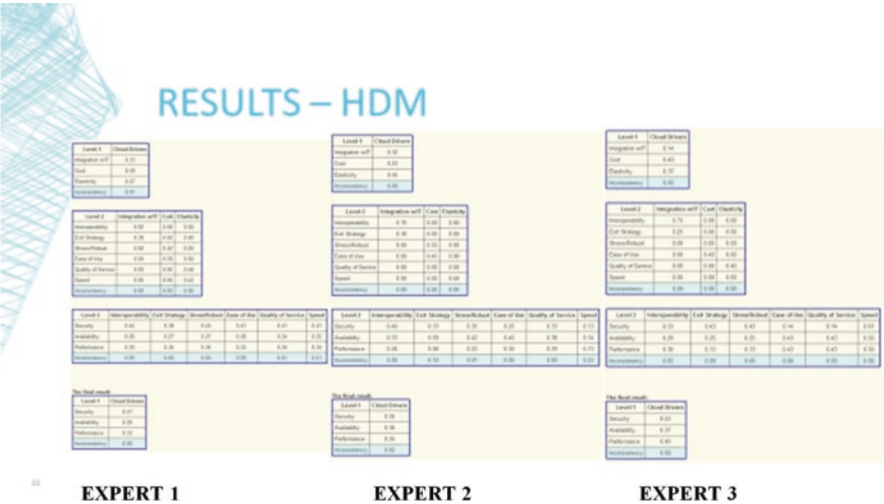
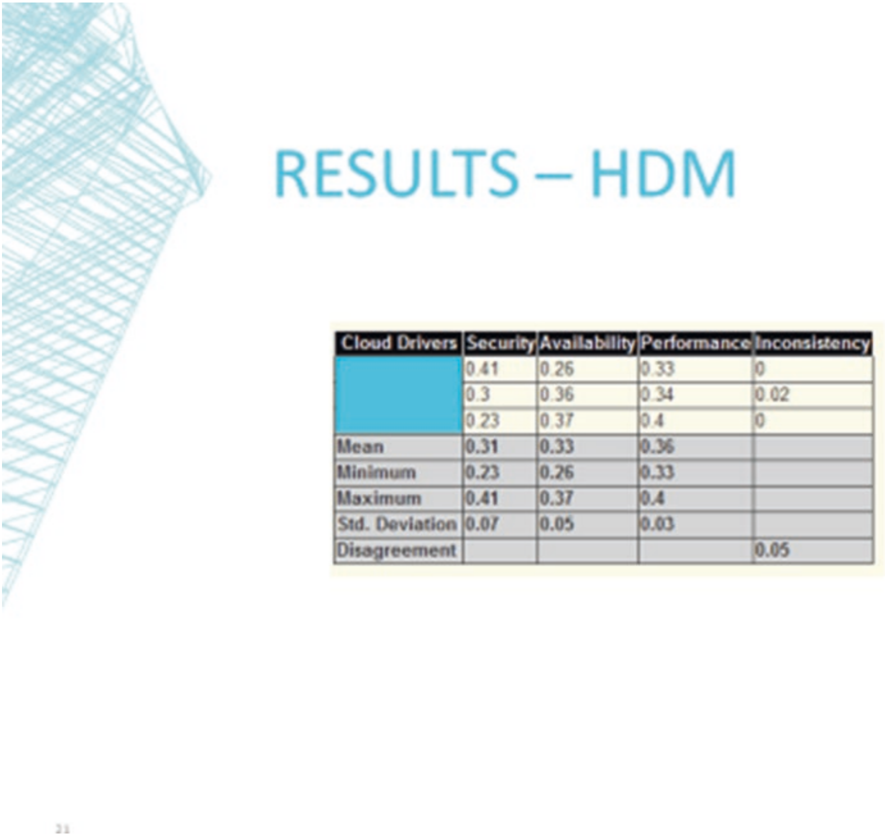


Fig. 16.5 HDM results for three experts

16.4.3 TAM Analysis

16.4.3.1 The Proposed Cloud Service TAM

Based on the above implications from literature and case studies, a "cloud service TAM" is proposed and depicted in Fig. 16.7, which include the following definitions for each factor:



Cloud Drivers	Security	Availability	Performance	Inconsistency
	0.41	0.26	0.33	0
	0.3	0.36	0.34	0.02
	0.23	0.37	0.4	0
Mean	0.31	0.33	0.36	
Minimum	0.23	0.26	0.33	
Maximum	0.41	0.37	0.4	
Std. Deviation	0.07	0.05	0.03	
Disagreement				0.05

Fig. 16.6 HDM result

- Perceived usefulness: the degree to which a person believes that using a particular system would enhance his or her job performance
- Perceived ease of use: the degree to which a person believes that using a particular system would be free from effort
- Perceived security: the subjective probability with which consumers believe that their information will not be viewed, stored, or manipulated during data transmission and storage by inappropriate/unauthorized parties
- Perceived scalability: the ability of a system, network, or process to handle a growing amount of work in a capable manner or its ability to be enlarged to accommodate that growth
- Perceived availability: the amount of time that a client can make use of a service
- Perceived performance: the features and functions of the provided service
- Perceived cost saving: the degree to which a client believes that using a particular service would reduce his or her operating and investment cost

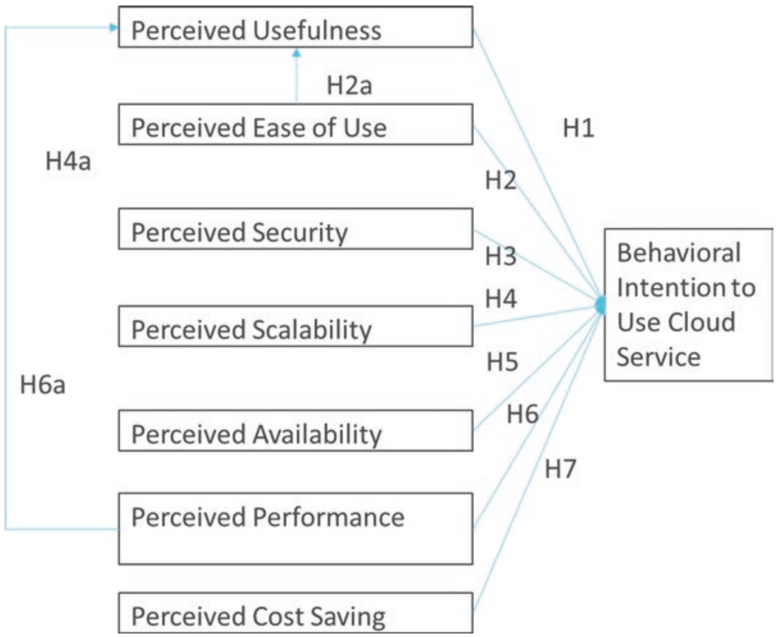


Fig. 16.7 A proposed cloud service TAM

16.4.3.2 Hypothesis of Cloud Service TAM

Based on the model developed above, the hypothesis is described as follows and a questionnaire using Qualtrics web tool is developed for gathering the responses from the experts, in order to validate the strength of the agreement on each influential relationship between key factors and intention to use the cloud service.

- H1: The perceived "usefulness" of cloud service has significant positive influence on consumers' "behavioral intention to use cloud service."
- H2: The perceived "ease of use" of cloud service has significant positive influence on consumers' "behavioral intention to use cloud service."
- H2a: The perceived "ease of use" of cloud service has positive influence on perceived "usefulness."
- H3: Perceived "security" has direct influence on users' behavior intention to use cloud service.
- H4: Perceived "scalability" has direct influence on users' behavior intention to use cloud service.
- H4a: Perceived "scalability" has positive influence on perceived "usefulness" of cloud service.
- H5: Perceived "availability" has direct influence on users' behavior intention to use cloud service.

Table 16.1 The background of the experts

Experts	Organization	Specialty	Industry
1	State university	Computer engineering, marketing, technology management	IT, semiconductor
2	Risk management company	User interface developing, Microsoft hyper-V	Medical/hospital
3	Health solutions provider	Enterprise architecture, IT management	Health care

Table 16.2 The cloud service TAM results

Experts	H1	H2	H2a	H3	H4	H4a	H5	H6	H6a	H7
T.S.	5	4	4	4	5	5	4	4	4	5
CP.	3	5	4	5	3	3	5	2	2	1
P. D.	2	2	2	5	5	2	4	4	2	4
Mean	3.33	3.67	3.33	4.67	4.33	3.33	4.33	3.33	2.67	3.33
Variance	2.33	2.33	1.33	0.33	1.33	2.33	0.33	1.33	1.33	4.33
Standard deviation	1.53	1.53	1.15	0.58	1.15	1.53	0.58	1.15	1.15	2.08

- H6: Perceived "performance" has direct influence on users' behavior intention to use cloud service.
- H6a: Perceived "performance" has positive influence on perceived "usefulness" of cloud service.
- H7: Perceived "cost saving" has direct influence on users' behavior intention to use cloud service.

The strength of agreement for each hypothesis is categorized as the following selections including strongly disagree (1), disagree (2), neutral (3), agree (4), and strongly agree (5).

16.4.3.3 Experts for Conducting Cloud Service TAM Survey and Interview

Three experts were invited to respond to the cloud service TAM and provide some insights regarding the cloud service as a whole and particularly on the content of the cloud service TAM (Table 16.1).

16.4.4 TAM Results

The experts give the strength of agreement for each hypothesis; the results are listed as table below (Table 16.2).

Based on the results, the observation can be summarized as follows:

- Top 3 significant agreement: security (H3), scalability (H4), and availability (H5)
- Top 1 disagreement about the hypothesis: performance influence usefulness (H6a)
- Top 1 diversity (disagreement among the experts): cost saving (H7)

16.4.4.1 Key Findings

The key findings are listed as follows:

- Hypothesis testing results indicate the degree of agreement and variance, which facilitate the selection of decision criteria.
- In connection to HDM, security and availability are validated whereas performance is partly verified.
- There is strong disagreement in Hypothesis 6, 6a, and 7. These disagreements are mainly attributed to different perception of the terms used, industry perspectives, and various kinds of cloud services.
- Although the definitions have been provided, some experts still feel not that differentiated enough and need to answer the survey questions carefully.
- One expert strongly suggests that "agility" should be included in the model and may replace the "usefulness," because "quick to market" is what matters.
- Within one company, cloud service decision may vary depending upon the specific needs and organizational priority.

16.5 Discussion

16.5.1 Strength and Weakness of the Research Methodologies

For ease of comparison across the three research methodologies, the following lists the strengths and weaknesses of each (Tables 16.3 and 16.4):

16.5.2 Contextual Fitness Cloud Service Adoption Decision Process

In views of current environment, cloud market is surging. However, there exist pros and cons regarding the adoption of cloud service as illustrated in Fig. 16.8. The key issues regarding cloud service adoption decision include security, availability, performance, scalability, and so forth. In order to identify the organizational priorities for adopting cloud service, the literature review, hierarchical decision-making (HDM), and technology acceptance model (TAM) are proposed to be used together for this project.

Table 16.3 Strength of the methodologies [13, 36–40]

+++ Strengths +++		
Literature review	TAM	HDM
1. Plethora of articles, journals, newspapers, and blogs depicting cloud services 2. Information highly searchable and somewhat easy to prioritize 3. Due to the speed at which cloud services have evolved, the lit. rev. can be analyzed by date range. This enabled our team to focus on articles/journals that are "fresher" perhaps more relevant	1. Easy for experts to understand concepts behind perceived usefulness, ease of use, security, scalability, availability, performance, and cost savings 2. Based on their understanding, they could easily answer our multi-hypothesis questionnaire 3. Great tool for qualitative analysis. Gives us the opportunity to not only ask questions but to go back to the experts if additional clarification is needed	1. Somewhat difficult to architect. This is actually a plus, because the quality of the output is reflective of the model itself. We generated approx. eight renditions before finalizing our model 2. Experts were introduced to the four unique levels (mission, org. objectives, tech. requirements, and org. priority). Then within each level, experts could easily rank the importance of any two cloud impact factors 3. The results of the HDM are straightforward. This, coupled with the "pros and cons" of cloud service options, makes it easier for the expert to identify the best cloud option that meets their unique/specific needs

Based on the literature and experts' interviews, the cloud service adoption decision is more likely to be unique to the individual needs and requirements. Therefore, the organizational specific and contextual fitness are important during the decision-making process. In views of this concept, a "contextual fitness based cloud service decision process" is proposed to meet the unique and situational requirements for cloud service adoption decision as depicted in Fig. 16.9. These two methods can serve as two complementary approaches to facilitate cloud service decision by means of validating the degree of agreement and identifying the organizational priorities, respectively.

16.6 Conclusion

The choice to adopt or acquire particular technologies or concepts, if not done properly and within the appropriate context, can sometimes come at a cost and cause a lot of unforeseen problems along with its benefits. For example, Basoglu, Daim, and Kerimoglu [37] suggest that defining a framework for projects such as the organizational adoption of enterprise resource planning (ERP) systems will go a long way to address failure factors such as inadequate adoption and implementation failures. According to Daim, Bhatla, and Mansour [43], IT infrastructure such as data centers

Table 16.4 Weakness of the methodologies [13, 39, 40]

--- Weakness ---		
Literature review	TAM	HDM
1. Perhaps too many articles to choose from. Because it's a relatively new technology, there is a large increase in the recent volume of work published. 2. Some information gleaned was more from someone's individual perspective, not necessarily hard/well-researched facts 3. How to prioritize? Can't be solely on most recent. It has to be balanced out by quality of expert giving feedback, along with the organization that published it	1. Due to the limited number of TAM experts, we must base our findings on a somewhat fuzzy perspective 2. Ideally we would have multiple expert inputs making our findings both qualitative and quantitative, essentially more statistically valid 3. Further, having more expert inputs would enable us to run cross-tabulations, i.e., comparing responses from experts that have a similar organizational profile 4. Finally, time constraints make it difficult to rely solely on a single instance of the TAM. Ideally, we would go back to the experts after they completed the first round, asking more probing to generate more qualitative data	1. Experts gave slight differences in priority or preference. Example: a pairwise comparison of 52 to 48 does not reflect strong opinions one way or the other, both represent almost equal importance 2. By this time, we're running out of industry experts to interview, as we did not want to overload our expert panel from TAM with multiple requests 3. Again, would like to have multiple expert opinions, giving greater insight as to what is important – hence not statistically valid data 4. Ideally we would have used two different HDM models: one focusing on the CIO/CTO perspective, the other from the individual customer perspective, both containing slightly different nodes

(DCs) usually require huge amounts of investments not to mention the time required to put up some of these centers. The use of multi-criteria models such as the HDM can therefore prove useful to firms in making the right decisions for say cloud adoption given that companies usually have to deal with the decisions they make for several years.

While cloud service business models continue to emerge and evolve, it should be noted that there are pros and cons associated with application of any particular cloud model in any specific company. While there is no one solution that fits all, cloud service adoption needs to be done within a contextual fitness that is unique and meets the situational requirements of the particular industry that seeks to adopt a particular cloud strategy. In this regard, decision-making theories and models such as the HDM and TAM may be used as complementary approaches to facilitate the cloud adoption decision. Furthermore, TAM, in particular, can be integrated with other broader models with more expansive variables to help to relate better to human and social change processes as well as the general adoption of innovation [44].

PUBLIC CLOUD	
PROS	CONS
Focus more on your business, not on managing data centers Develop new applications faster Leverage cloud provider's API can automate many operational tasks Cloud computing is scalable	Performance on shared infrastructure can be inconsistent People believe that cloud infrastructure is not secure. Cloud computing may not be the right fit for all workloads

PRIVATE CLOUD	
PROS	CONS
Greater level of security more control over the server 'cloud bursting' non-sensitive data is switched to a public cloud to free up private cloud space	Higher initial outlay [cost] more difficult to access the data held in a private. Cost of setting up private cloud services may prove to be cost prohibitive.

HYBRID CLOUD	
PROS	CONS
Cost Savings Virtualization to reduce costs, improve efficiencies & accelerate value Segregate costs of hardware, software purchases, and costs of using cloud services for specific tasks: backup, archiving, disaster recovery. Improved Productivity Virtual environments like hybrid allow orgs to put workloads and data wherever required to help improve overall efficiency	Security concerns by far the major reason why organizations aren't jumping into the hybrid cloud. Worries that hybrid cloud wouldn't meet business requirements, stringent government regulations and high cost Hybrid cloud still has some ground to cover to be readily accepted in the corporate culture.

Fig. 16.8 The pros and cons of the cloud services [36, 41, 42]

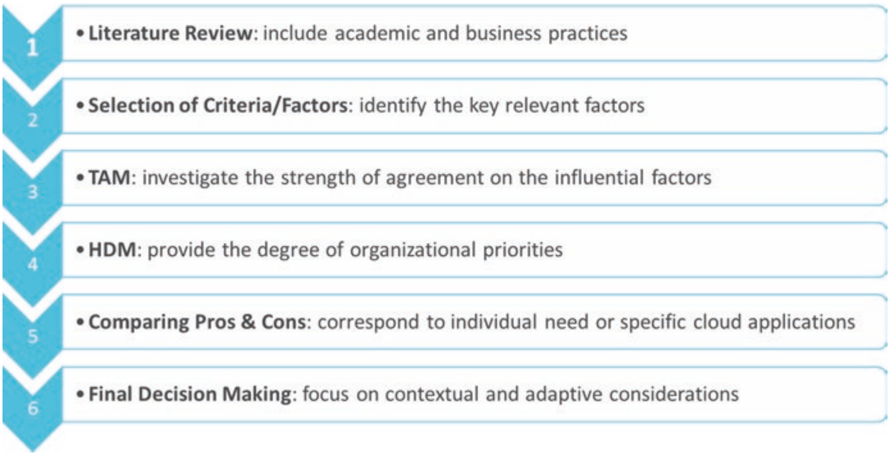


Fig. 16.9 A proposed contextual fitness cloud service adoption decision process

Appendix A: Expert Interview/Email Response Notes

Expert 1

Date and Time: Nov. 26, 2014
Key points from interview

- The terms used in this cloud service TAM questionnaire is not that differentiated enough for responder to select their choice. This leads to taking more time to do the survey.
- It seems that no surprising questions included in the questionnaire, which may look not that interesting to the responders.
- Cost is a major factor regarding the cloud service adoption decision, because no huge amount of investment needed on the infrastructure.
- Scalability and usefulness are also considered critical for cloud service adoption decision.
- If questionnaire can incorporate the demographic information, more detailed analysis of the response can be made accordingly.

Expert 2

Date and Time: Dec. 4, 2014
Key points from email correspondence

- Q8. H6: Perceived "performance" has direct influence on users' behavior intention to use cloud service.
  - I disagree with this because "cloud services" utilize companies' own equipment, and many times these technical specifications are unknown. Another aspect in cloud services like public cloud services are shared resources with other users. The more users who are utilizing cloud services, the more resources are distributed with reduced performance or capped performance. Performance is also affected by the end user from bandwidth, quality of service, poor configurations, intentional server, and non-intentional server downtimes.
  - Technically, measuring performance is difficult to factor with unknown constraints, measurements, specifications, and what configuration is sufficient that meets the performance for users' needs and for what determining standard measurements are being looked upon. Cloud services rarely provide such data. I think with this vagueness, I don't think it can "directly" influence user's intention to use cloud services.
- Q9. H6a: Perceived "performance" has positive influence on perceived "usefulness" of cloud service.

  - I am not exactly sure how performance can fit with usefulness. It comes whether cloud service works that meets the needs or doesn't meet the needs. Assuming users are expecting the services to work or can get it to work, in that case the services are useful, since it is being utilized; for that to happen, some kind of performance has to be there.
  - But the focus is on performance. Slow performance is not desirable and fast performance is desirable. Since performance can be slower and lower than perceived expectation, I disagree because slow performance may happen and will mostly not have a positive influence on the cloud services or to its usefulness.

- Q10. H7: Perceived "cost saving" has direct influence on users' behavior intention to use cloud service.

  - So, if it was perceived "cost" has direct influence on users' behavior intention to use cloud service, my answer would have been the opposite. But I disagree with 'cost saving' because the last 6 years are not that cost saving, although it did go down significantly in the last year.
  - What I know about cloud has "hidden cost" that can add up to quite a large sum. I think many cloud services come as a pay per usage or pay per hours, upgrade fees, bandwidth, and in addition to base pay. Adding all of the cost and fees per month in a year or more, it is quite costly. When comparing the cost from apples to apples, I think cloud services add up at higher cost for now.
  - My answer is from directly comparing it to cloud computing alternatives and the technology that comes with it. I perceived cloud as much higher cost with limited technical specification than the available alternative, and this influences me to not have the intention of using cloud services in a long-term and frequent usage and from what I know that is why I disagree.
  - I do think it is cost-saving at short term with occasional usage compared to buying a server, but not as intensive every day, high capacity, and high bandwidth.

Expert 3

Date and Time: Dec. 4, 2014

Key points from interview

- Cloud service includes SaaS, PaaS, and IaaS. For SaaS, the example will be salesforce.com. PaaS can deliver for web application support. The example of IaaS may include the Rackspace which provide cloud servers and dedicated servers services.
- There are other kinds of cloud services such as desktop as a service and backup as a service.

- For PasS, they are mostly public cloud. For private cloud similar idea, a service called on-premise needs to be distinguished.
- Top priority consideration for adopting a cloud service is "agility," which may substitute the "usefulness," because the "quick to market" is what matters to the company which needs the service desperately.
- Usefulness and ease of use are considered less or even least important to the cloud service decision.
- For health business, security is the most critical thing. For personal health record, in-house will be the best options, due to security consideration. For payroll or CRM, the public cloud may be an option.
- Generally, the requirement of availability is 99.999%.
- Performance is not regarded to have direct influence on the usefulness.

Appendix B: TAM Case Studies

Information Technology

Ammenwerth et al. (2006) reviews the technology acceptance model on IT and finds that previous models fail to include the interaction between user and task. They proposed a FITT framework (fit between individuals, task, and technology) as depicted in Fig. 16.10. A case study on German University Hospital using questionnaire survey is studied in the paper for illustrating the FITT [45].

Health Information Systems

T. U. Daim, L. Chan, M. Amer, and F. Aldhaban (2009) propose a conceptual model for PHR (personal health record) acceptance. The model formulates several hypotheses indicating the relationship between consumers' intentions toward the technology adoption of PHR as shown in Fig. 16.11. The model is validated by interviewing 3 experts [46].

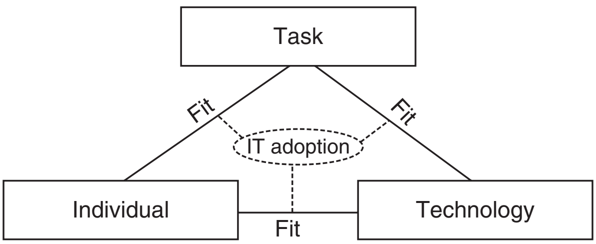


Fig. 16.10 The FITT framework: IT adoption depends on the fit between individual, task, and technology [45]

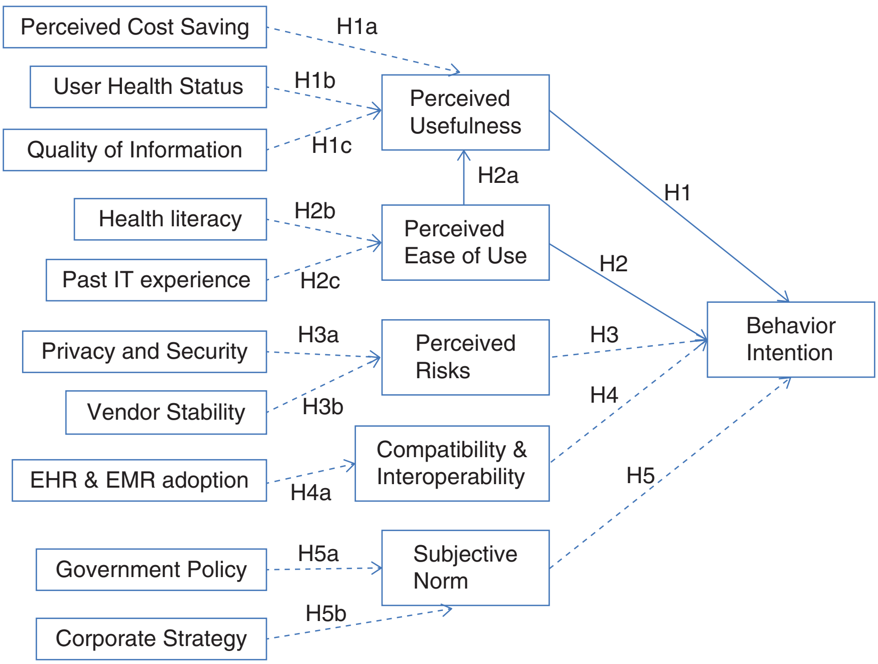


Fig. 16.11 Conceptual model for PHR acceptance [46]

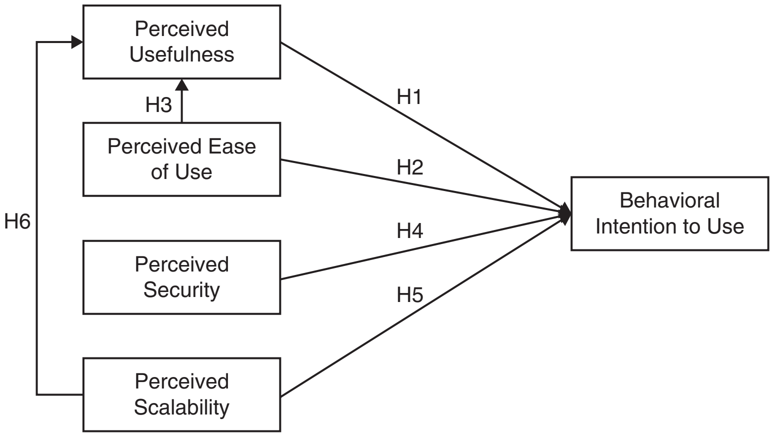


Fig. 16.12 The TAM for B2B IaaS [35]

B2B Cloud Service Adoption

K. –K. Seo (2013) studies on infrastructure as a service (IaaS) adoption by proposing an extended TAM framework and validated by conducting 250 questionnaire surveys in Korea to see the significance of the hypothesized relationship between customers' perception and behavioral intention to use cloud service as depicted in Fig. 16.12 [47].

References

1. IDC Predictions 2014: Battles for Dominance and Survival on the 3rd Platform. (2013, December).
2. Armbrust, M., et al. (2010). A view of cloud computing. *Communications of the ACM, 53*(4), 50.
3. IBM. (2016). IBM – Benefits of cloud computing [Online]. Available: https://www.ibm.com/cloud-computing/learn-more/benefits-of-cloud-computing/
4. Columbus, L. (2017). Roundup of cloud computing forecasts, 2017. *Forbes* [Online]. Available: https://www.forbes.com/sites/louiscolumbus/2017/04/29/roundup-of-cloud-computing-forecasts-2017/
5. Columbus, L. (2017). Roundup of cloud computing forecasts, 2017. *Enterprise Irregulars* [Online]. Available: https://www.enterpriseirregulars.com/115475/roundup-cloud-computing-forecasts-2017/
6. Tran, K. (2017). Cloud drives Q1 for Google, Amazon, Microsoft. *Business Insider* [Online]. Available: http://www.businessinsider.com/cloud-drives-q1-for-google-amazon-microsoft-2017-5
7. Armbrust, M., et al. (2009). *Above the clouds: A berkeley view of cloud computing.* Berkeley: EECS Department, University of California.
8. Marston, S., Li, Z., Bandyopadhyay, S., Zhang, J., & Ghalsasi, A. (2011). Cloud computing — the business perspective. *Decision Support Systems, 51*(1), 176–189.
9. No Man Is an Island: The Promise of Cloud Computing. *Knowledge@Wharton* (2009) [Online]. Available: http://knowledge.wharton.upenn.edu/article/no-man-is-an-island-the-promise-of-cloud-computing/
10. Rimal, B. P., Choi, E., & Lumb, I. (2009). *A taxonomy and survey of cloud computing systems* (pp. 44–51).
11. Mell, P., & Grance, T. (2011). *The NIST definition of cloud computing*.
12. Y. Jadeja and K. Modi. (2012). *Cloud computing – concepts, architecture and challenges* (pp. 877–880).
13. Zhang, Q., Cheng, L., & Boutaba, R. (2010). Cloud computing: state-of-the-art and research challenges. *Journal of Internet Services and Applications, 1*(1), 7–18.
14. Ante, S. E. (2014). H-P to invest $1 billion in cloud computing over next two years. *Wall Street Journal*,
15. Cai, Z., Li, X., & Gupta, J. N. D. (2016). Heuristics for Provisioning Services to Workflows in XaaS Clouds. *IEEE Transactions on Services Computing, 9*(2), 250–263.
16. Baldini, I., et al. (2017). Serverless computing: Current trends and open problems. *ArXiv e-prints, 1706*, arXiv:1706.03178.
17. Roberts, M. (2016). Serverless architectures. *martinfowler.com* [Online]. Available: https://martinfowler.com/articles/serverless.html
18. Li, L. E., Chen, E., Hermann, J., Zhang, P., & Wang, L. (2017). Scaling machine learning as a service. In *PMLR* (pp. 14–29).
19. Amazon Machine Learning – Predictive Analytics with AWS. *Amazon Web Services, Inc.* (2017) [Online]. Available: //aws.amazon.com/machine-learning/.
20. Krešimir Popović, Željko Hocenski. (2010). Cloud computing security issues and challenges. In *MIPRO 2010.*
21. Vmware. (2009). *Addressing Desktop Challenges With VMware Virtual Desktop Infrastructure* [Online]. Available: https://www.vmware.com/pdf/vdi_solution.pdf. Accessed: 29 Jul 2017.
22. Herbst, N. R., Kounev, S., & Reussner, R. (2013). Elasticity in cloud computing: What it is, and what it is not. In Proceedings of the 10th International Conference on Autonomic Computing (ICAC 13) (pp. 23–27). San Jose.
23. Nkhoma, M., & Dang, D. (2013). Contributing factors of cloud computing adoption, a technology-organization-environment framework approach. *International Journal of Information Systems and Engineering, 1*(1), 38–49.

24. Chebrolu, S. B. (2011). Assessing the relationships among cloud adoption, strategic alignment and IT effectiveness. *Journal of Information Technology Management, 22*(2), 13–29.
25. Almorsy, M., Grundy, J., & Müller, I. (2016). An analysis of the cloud computing security problem. *arXiv:1609.01107 [cs].*
26. Daniel, W. K. (2014). *Challenges on privacy and reliability in cloud computing security* (pp. 1181–1187).
27. Lebied, M. (2017). 6 cloud computing challenges businesses are facing. *BI Blog | Data Visualization & Analytics Blog | datapine* [Online]. Available: http://www.datapine.com/blog/top-6-cloud-computing-challenges/
28. Motta, G., Sfondrini, N., & Sacco, D. (2012). *Cloud computing: A business and economical perspective* (pp. 18–22).
29. Lumsden, J., & Gutierrez, A. (2013). *Understanding the determinants of cloud computing adoption within the UK*. EMCIS.
30. Alshamaila, Y., Papagiannidis, S., & Li, F. (2012). Cloud computing adoption by SMEs in the north east of England, a multi-perspective framework. *Journal of Enterprise Information Management, 26*(3), 250–275.
31. Yam, C., Baldwin, A., Shiu, S., & Ioannidis, C. (2011). *Migration to cloud as real option, investment decision under uncertainty*. IEEE ICESS.
32. Daim, T. (2015). *Hierarchical decision modeling: essays in honor of Dundar F. Kocaoglu*. Springer Science+Business Media: New York.
33. Davis, F. D. (1993). User acceptance of information technology: system characteristics, user perceptions and behavioral impacts. *Int. J. Man-Machine Studies, 38*, 475.
34. Grid Computing Environments Workshop, 2008. GCE '08, Issue Date: 12–16 Nov. 2008 , Written by: Foster, Ian; Zhao, Yong; Raicu, Ioan; Lu, Shiyong.
35. How Can the Cloud Help Small Business Owners? *QuartSoft* (2013) [Online]. Available: https://quartsoft.com/blog/201309/cloud-computing-for-small-business-owners
36. HDM (Hierarchical Decision Model) [Online]. Available: http://research1.etm.pdx.edu/hdm2/
37. Basoglu, N., Daim, T., & Kerimoglu, O. (2007). Organizational Adoption of Enterprise Resource Planning Systems: A Conceptual Framework. *Journal of High Technology Management Research, 18*(1), 73–97.
38. Building trust between cloud providers and consumers. *Network World* (2013).
39. Dubie, D. (2010). Interop attendees embrace cloud benefits, expect management challenges… *Network World*.
40. Future is bright for cloud computing; Cloud computing is a wise investment for small and mid-size businesses. *Network World* (2009).
41. Butler, B. (2014). Gartner: Hype could hurt cloud adoption; Cloud computing is hyped up, misused term, research firm says, and market confusion of the term could distract from its benefits. *Network World*.
42. Cloud sourcing – IT risks and rewards. (2014). Section: Chief Executive Officer – CEO022; Feature. *Progressive Media – Company News*.
43. T. Daim, A. Bhatla, and M. Mansour, "Site selection for a data center – a multi criteria decision making model", International Journal of Sustainable Engineering, 6, 1, 10-22, 2013.
44. Legris, P., Ingham, J., & Collerette, P. (2003). Why do people use information technology? A critical review of the technology acceptance model. *Information & Management, 40*, 191–204.
45. Ammerwerth, E., Iller, C., & Mahler C. (2006). *IT-adoption and the interaction of task, technology and individuals: a fit framework and a case study*. BMC Medical Informatics and Decision Making.
46. Daim, T. U., Chan, L., Amer, M., & Aldhaban, F. (2009). Assessment and adoption of web-based health information systems. *Int. J. Behavioural and Healthcare Research, 1*(3), 274–292.
47. Seo, K.-K. (2013). An explorative model for B2B Cloud Service Adoption in Korea- Focusing on IaaS Adoption. *International Journal of Smart Home, 7*(5), 155–164.
48. Fraenkel, J. R., & Wallen, N. E. *How to design and evaluate research in education*. New York: McGraw-Hill.

49. Cronin, P., Ryan, F., & Coughlan, M. (2008). Undertaking a literature review: a step-by-step approach. *British Journal of Nursing, 17*(1), 38–43.
50. Webster, J., & Watson, R. T. (2002). Analyzing the past to prepare for the future: writing a literature review. *MIS Quarterly, 26*(2), xiii–xxiii.
51. Marrelli, A. F. (2005). The performance technologist's toolbox: literature reviews. *Performance Improvement, 44*(7), 40–44.
52. Bauerle,F. (2014). The pros and cons of cloud computing. *Cloud computing news* [Online]. Available: https://www.ibm.com/blogs/cloud-computing/2014/05/pros-cons-cloud-computing/
53. Pros and Cons of Public and Private Cloud. (2017). [Online]. Available: https://learn.infusionsoft.com/growth/planning-strategy/the-pros-and-cons-of-public-and-private-clouds
54. Virtual Private Cloud The Benefits it Holds for Your Business. (2015). [Online]. Available: http://blog.appcore.com/blog/bid/174815/Virtual-Private-Cloud-The-Benefits-it-Holds-for-Your-Business
55. Basoglu, N., Daim, T., & Kerimoglu, O. (2007). Organizational adoption of enterprise resource planning systems: a conceptual framework. *Journal of High Technology Management Research, 18*(1), 73–97.
56. Högberg, D. (2012). *An applied evaluation and assessment of cloud computing platforms*.

Chapter 17
Project Delivery: Highway Construction

Rafaa Khalifa, Tugrul U. Daim, and Robert Stewart

17.1 Introduction

The demand to deliver transportation projects in less time with limited budgets has driven the department of transportation (DOTs) in each state to research, develop, and adapt innovation tools, methods, processes, or programs for its construction projects. Due to the high level of risk and uncertainty in most transportation projects, especially in the cities and towns that have a large density of pollution, the selection of an appropriate delivery method has been more difficult and involves complex decision-making. Furthermore, some research has been conducted on the performance of project delivery methods in transportation and proved that there is a lack of comprehensive comparative approaches combined with adequate orientation into the future to provide a sufficient basis for strategic decisions.

The exploration of alternative project delivery methods and programs for transportation and other infrastructure projects is the result of the insistent need to rapidly improve project delivery strategies. The Transportation Research Board (TRB) of the National Academies, the National Research Council (NRC), the Federal Highway Administration (FHWA), the American Association of State Highway and Transportation Officials (AASHTO), the National Cooperative Highway

R. Khalifa (✉) • T.U. Daim
Department of Engineering and Technology Management, Portland State University, PO Box 751, Portland, OR 97207-0751, USA
e-mail: rkhalifa@pdx.edu; tugrul.u.daim@pdx.edu

R. Stewart
Value Management Strategies, Inc., 10643 SW Riverside Dr., Portland, OR 97219, USA
e-mail: rob@vms-inc.com

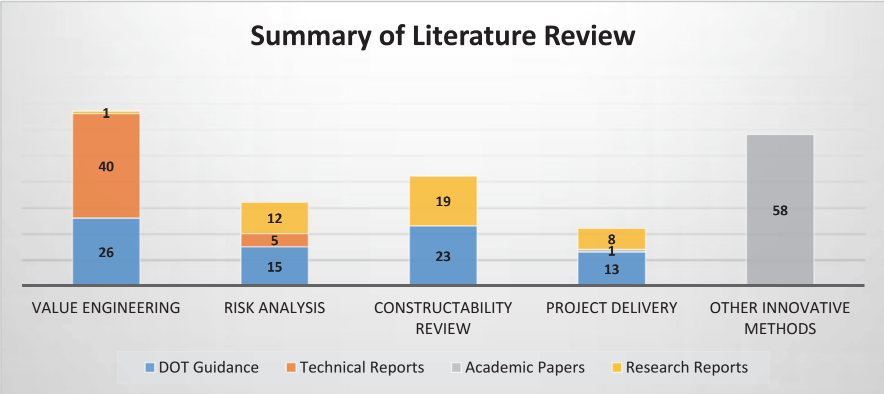
T.U. Daim et al. (eds.), *Infrastructure and Technology Management*, Innovation, Technology, and Knowledge Management,
https://doi.org/10.1007/978-3-319-68987-6_17

Research Program (NCHRP), and the States Department of Transportation are actively researching best practices to allocate risk more effectively while achieving high performance and maximum value for transportation projects. Some DOTs adapt and use the most common project delivery tools in the construction industry such as design-build (DB), construction manager/general contractor (CM/GC), construction manager at risk (CMAR), and at times design-bid-build best-value (DBB-BV) contracts. These tools lead to take advantage of the design and construction industry's ideas for alternative design and construction solutions to highway projects [1]. Stated that the FHWA's "every day counts" program is designed to identify and deploy innovation aimed to reduce the time of project delivery with more concerning of increasing the safety and protecting the environment in new or developing projects.

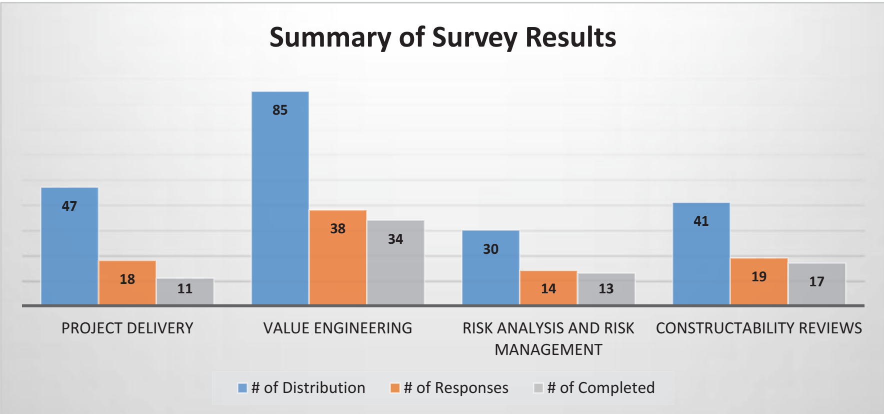
Other programs and practices have been developed and introduced to help the transportation agencies decision makers and the construction project's members to improve the project delivery process and outcome. These improvements include factors such as cost, performance, time, risk, reliability, flexibility, sustainability, competitiveness, etc. This chapter aims to survey current practices within public transportation agencies regarding their currently performing value engineering (VE), risk analysis (RA), and constructability review (CR) activities; how they are interrelated; and to what extent they are integrated and support each other. The survey will lead to investigate the effectiveness of these programs of measuring the success of outcomes relating to the delivery of transportation projects. We present a literature review that is relevant to policies, practices, procedures, and guidance from various state DOTs; analysis of the Federal Highway Administration (FHWA) program results; other transportation agencies; and distribution of surveys. VE, RA, and CR were studied separately during this phase in order to obtain the most detail in each category, although it is recognized that often these strategies are employed in conjunction with one another to produce successful results. Also, a formal project delivery (PD) survey was distributed to determine ways in which innovative methods improve transportation projects and to what extent VE, RA, or CR activities have conducted on projects using project delivery methods. A number of criteria and factors were identified during the research, as being relevant to the project delivery or project development process. These included cost, performance, time, reliability, flexibility, sustainability, competitiveness, etc. In the end of this phase, the research team arrived at a well-vetted list of outside industry methodologies, tools, and techniques that have strong potential to influence the value improving practices applied to transportation infrastructure projects.

Highlights of the research include:

- Over 215 individual pieces of literature were reviewed including technical reports, DOT guidance, academic papers, and research results.



- Four surveys were conducted covering VE, RA, CR, and Project Delivery that were sent to over 203 public officials.



- The FHWA annual VE reports for the years 2009–2013 were compiled and analyzed.

17.2 Literature Review

Project delivery methods define the relationships, roles, and responsibilities of project team members and sequences of activities required to complete a project [2]. Each project-delivery method can save time and money while delivering comparable quality to projects. However, many issues arise in the early stages of a project involving construction. Often the most challenging task, when large cost and complexity of construction is involved [3]. Anderson [4] evaluated the potential for alternative construction methods to accelerate project completion and what the impact would be. Tran [5] described that the selection of an appropriate delivery method is a complex decision due in large part to the risk and uncertainty at the time of the decision. The same authors indicated that the growing use of alternative delivery methods has led researchers and practitioners to search for structured approaches to choose project-delivery methods. The TRB, NRC, FHWA, AASHTO, and the individual states participating in the NCHRP have started in partnering and cooperating with universities and private consulting companies to develop other innovative techniques, tools, applications, or processes that reflect their own projects' circumstances and requirements. Some research focuses on current practices within public transportation agencies regarding how they currently perform VE, RA, and CR activities and to what level they are integrated and support each other; the effectiveness of these programs; and an evaluation of current methods of measuring the success of outcomes (i.e., cost savings, performance benefits, risk reduction, accelerated delivery, etc.). In the same subject, to understand the impact of these techniques on project delivery, Terry [6] indicated that the VE can help the owner and design-build team ensure the project satisfies the need and purpose in an effective and efficient manner, resolve issues and gain early consensus for project direction, and help the design-build team function even more effectively. VE is a function-oriented technique that has proven to be an effective management tool for achieving improved design, construction, and cost-effectiveness in various transportation program elements [7]. The federal-aid highway program emphasized in its value engineering report that over many years, VE has evolved into a management tool that can be used alone or with other management techniques to improve operations, project quality, and reduce project costs.

DOTs have realized substantial savings by using value engineering, these savings occur by restructuring operations and implementing cost-saving recommendations [8]. FHWA defines VE as a systematic process of project review and analysis during the concept and design phases by a multidisciplinary team of individuals involved in the project conducted to provide recommendations. The outcome of a VE study usually covers the recommendations of providing the required functions safely, reliably, efficiently, and at the lowest overall cost. Also, it covers improving the value and quality of the project, and reducing the time to complete the project [9]. NCHRP Synthesis 352 report refers to VE as a process that is more effective and influential on the performance, quality, and cost of a project when performed relatively early in the development of the project [10]. Furthermore, [10] VE can effectively be integrated with or into other technical management improvement approaches. In order to investigate the relation between the VE and CR programs, David [11] indicated that CR is not VE; there are significant differences between both of them such as timing and scope of service. Constructability review is most beneficial when performed prior to the establishment of defined scope, during early planning and design phases. David Ruby stressed that the VE is usually performed during the final stages of design development which limits the opportunity to make a significant impact on the project's cost or schedule [11]. The Idaho Department of Transportation's constructability review guidelines states that CR is a systematic process that ensures the feasibility of project construction. The CR process starts at the beginning of the project and continues throughout project development [12]. Several constructability reviews are incorporated into the project planning and development. Indiana Department of Transportation (INDOT) has endorsed constructability reviews to improve the total quality of construction bid package. The department works to ensure construction knowledge and experience in planning and design is effectively applied to achieve the project objectives [13]. The Idaho Department of Transportation incorporates constructability reviews into the design processes [12]. Project risk is an uncertain event that, if it occurs, has a negative or positive impact on a project's objectives, cost, schedule, or quality [14] [15]. Project management is described as a customizable effort corresponding with the size and complexity of the project under consideration. The risk management guideline of New Jersey Department of Transportation added that in addition to size and complexity, other factors to be considered for the level of efforts may include cost, location, delivery time frame, construction time frame, and so forth [15]. DOT executive leaders are encouraged to embrace risk management as part of their overall program delivery processes, and use the guidance in herein to examine their own programs and processes for risk management opportunities, as part of improving overall service to the public [16]. Regarding the integration between these programs (VE, RA, CR), the NCHRP SYNTHESIS 455 emphasized that integration can be achieved in a number of ways [17]. To support the statement, [17] [18] addressed the VE and CR need to be integrated with risk analysis (RA) and risk management (RM) process framework and applied during the project development phases.

17.3 Research Methodology

17.3.1 Purpose

This paper presents the survey results and discussion performed for VE, RA, and CR programs. The survey was distributed online to target professionals (project managers, project engineers, and project coordinators) who are currently working for DOTs and other transportation organizations throughout the USA. These professionals have experiences in the construction industry mostly in transportation projects. The goal of the survey to answer the prepared questions that designed for the three programs (VE, RA, and CR) as project delivery initiatives. In addition, the survey results will identify a clear picture emerged regarding the integrating and improving of these programs as best practices of project delivery being applied in transportation infrastructure projects in the USA.

17.3.2 Survey Strategy and Process

The survey questions were developed based on the research objective that targeted three best practices of project delivery related to the transportation construction projects. The authors started with a literature review of different academic papers and industry reports as a first step. The literature review focused on VE, RA, and CR programs in project delivery. Value management strategic (VMS), academic advisors at Portland State University (PSU), and project delivery experts were consulted to advise and validate the survey questions before and after the distribution stage (Fig. 17.1).

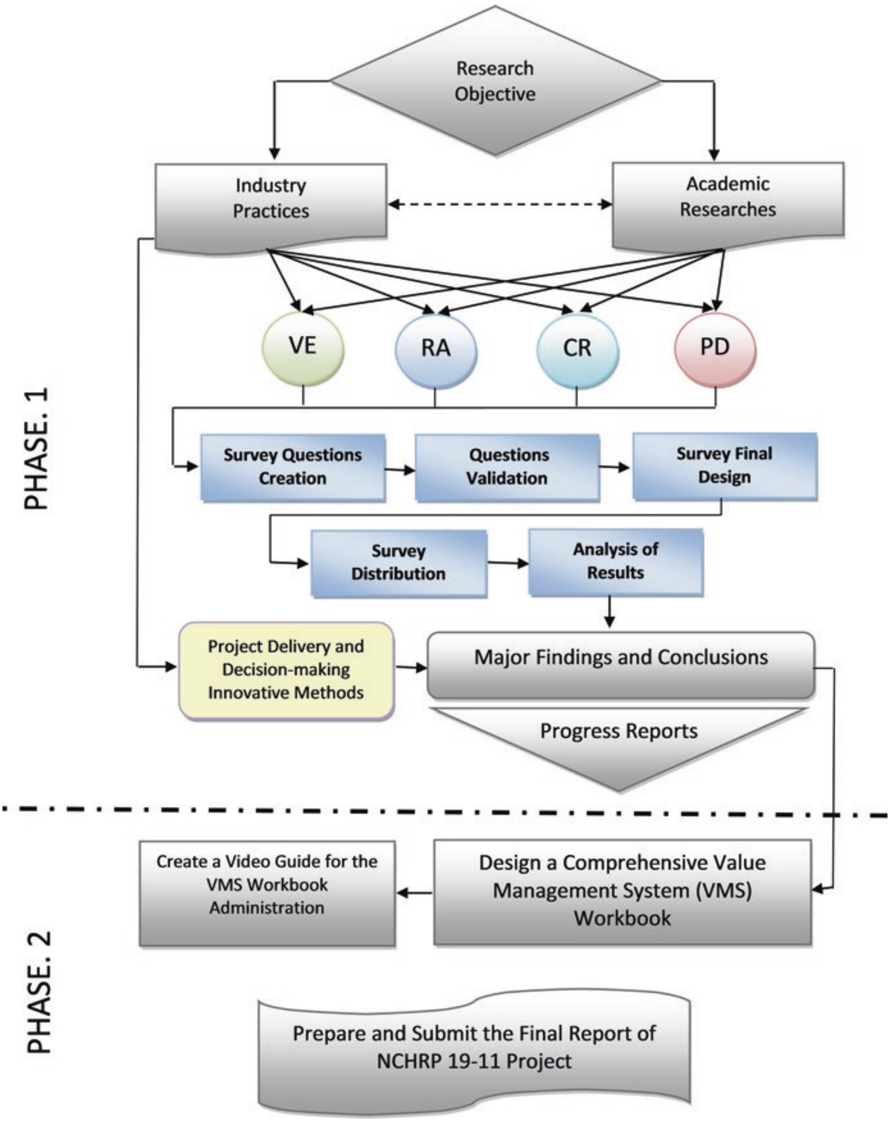


Fig. 17.1 Research framework

17.4 Data Collection

The list of respondents was developed to cover individuals in various state DOTs as well as state the Federal Highway Administration (FHWA) liaisons and individuals from other transportation agencies. In July 1st 2015, eighty-five emails sent to DOT coordinators to collect information from a knowledgeable group of professionals that would likely respond to the questionnaire. In the first round 20 out of 85 emails replied positively with the contact list of VE, RA, and CR professionals, each list included from 4 to 6 contacts. In August 1st 2015 a remainder email sent to who did not reply in the first round, the rate of responses had increased by 53% and the actual responses to our request by providing the contact list were 39% from a total of 85 email requests.

In August 13th 2015, three formal online surveys were distributed to VE, RA, and CR professionals. A total of 85 survey requests were sent out for the VE, 45 for the RA, and 31 for the CR. These surveys were conducted covering VE, RA, and CR questionnaires that were sent to over 156 public officials. Also, the progress of responses who have completed the survey were 40%, 42%, and 41% in VE, RA, and CR, respectively.

17.5 Results

17.5.1 Policy and Guidance

As shown in Fig. 17.2, the majority of respondents (82%) stated that their transportation agencies have a formal value engineering policy and the most recently updated policy was in June, 2015. For the risk analysis/assessment activity, approximately 70% of responding transportation agencies indicated that they had a formal risk analysis and/or risk management (RA/RM) policy. Those agencies that had a formal policy indicate that it was most commonly recently created between 2010 and now. Respondents of the constructability review survey indicated that more transportation organizations did not have a formal CR policy (59%) than those that did have a formal policy (41%). For those organizations that did have a formal CR policy most were recently updated between 2010 and 2012. Just on agency had updated the policy in March 2015.

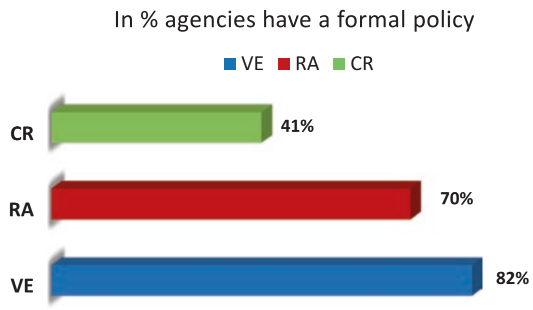


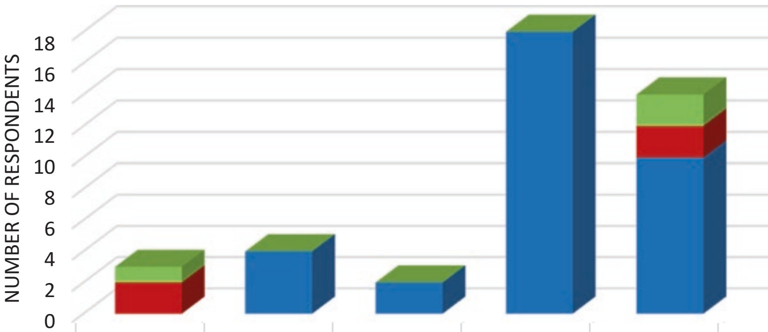
Fig. 17.2 Program policy

17.5.2 Thresholds

Figure 17.3 shows that there are different ($) dollar threshold for performing VE, RA, and CR in transportation projects among DOTs. The majority of respondents indicated that the project cost from $40 to $50 million is required to the VE program. Approximately 70% of responding transportation agencies indicated that they did not have an established dollar threshold for the performing of risk analysis or risk management activities; however, the 30% of agencies that did have a threshold indicated that it was commonly $10 million or less or that risk management is mandated on all projects regardless of dollar size. In the constructability review program, 82% of transportation organizations indicated that they do not have an established dollar threshold for conducting a constructability review. Those organizations that do have a formal constructability review policy indicated that criteria were that generally all projects must undergo a review. Other agencies indicated that costs in exceedance of $500 K were a threshold that triggers the need for a constructability review.

17.5.3 Program Facilitation

The survey results indicated in Fig. 17.4 that approximately 59% of all VE studies performed during the period were facilitated by consultants while 41% were performed in-house. About 70% of responding organizations internally conduct RA/RM activities. Another 23% of respondents rely on internal staff and external consultants and only 7% of organizations rely solely on external consultants.



	Lass than $ 10 M	$10-$25 M	$25-$40 M	$40-$50 M	Other
CR	1	0	0	0	2
RA	2	0	0	0	2
VE	0	4	2	18	10

Fig. 17.3 A dollar threshold for performing programs

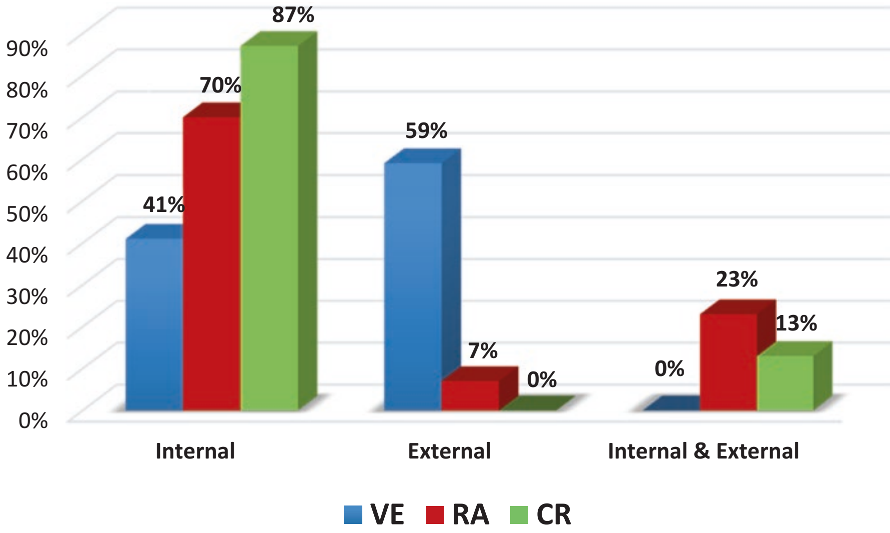


Fig. 17.4 The % of each program facilitation

Table 17.1 Number of respondents regarding the criteria to perform VE, RA, and CR studies

Criteria	VE	RA	CR
Project phasing challenges	20	5	13
Staging complexity	17	6	13
Right-of-way issues	13	7	5
Environmental challenges	15	6	6
Utility challenges	15	7	10
New/advanced technical challenges	21	5	5
External agency/stakeholder involvement	12	5	4
Building consensus with multiple stakeholders	13	5	3
Others	0	6	5

In the CR survey, respondents indicated that about 87% of transportation organizations that do conduct constructability review they were internal facilitated. The remaining 13% indicated that constructability reviews are both internally and externally facilitated.

17.5.4 Criteria

The respondents were asked about other criteria for selecting projects to perform value engineering (VE), risk analysis (RA), or constructability review (CR) study on transportation projects in their agencies or organization. Table 17.1 shows that most agencies implement other parameters that use to perform the required studies for each project selection individually. This is in line with the survey results, as the most use in the three programs (VE, RA, and CR) of transportation agencies are project phasing challenges, staging complexity, and utility challenges.

17.5.5 Timing

The respondents were asked about the timing of performing of each program during the project phases. As shown in Fig. 17.5, the majority of respondents (60%) indicated that they perform VE studies during preliminary design. Nearly half (45%) said that VE studies are being conducted during final engineering and about one quarter (28%) during project planning and/or feasibility. In the risk analysis survey, all respondents indicated that risk analysis is conducted during preliminary design. The usage declines the further along in project delivery agencies are as 75% of respondents use risk analysis in planning stage, 67% use risk analysis during final design, and 42% use risk analysis during construction. In the same subject the constructability review survey shows that the most respondents about 93% indicated that most constructability review are conducted on final design, while 7% of respondents indicated that the constructability review are conducted during the planning, and other 7% during the construction stage. Fifty-three percent of survey respondents indicated that the constructability review is conducted during environment studies or preliminary design.

17.5.6 Program Integration

The survey results indicate different levels of performing each activity (VE, RA, or CR) in combination with each other within transportation organizations and agencies. As shown in the Fig. 17.6 below, 8% of respondents indicated that risk analysis

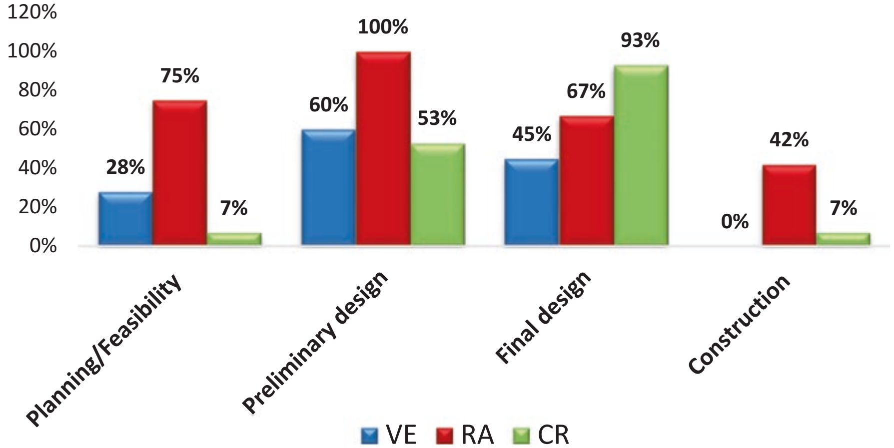


Fig. 17.5 Timing of conducting each program

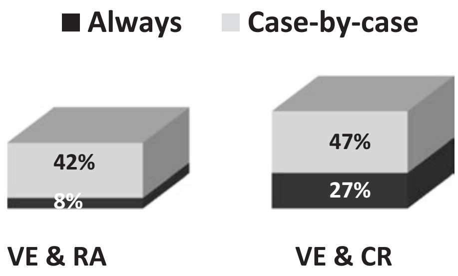


Fig. 17.6 Integration of VE with RA and CR initiatives

was always performed in conjunction with value engineering. Another 42% of respondents indicated that the risk analysis is sometimes performed with value engineering or that it is determined on a case-by-case basis. About 27% of the time the constructability reviews are performed with the value engineering, other 47% indicated that it is determined on a case-by-case.

17.5.7 Project Delivery Methods

The respondents were asked if they have conducted VE, RA, or CR on projects in their organizations using project delivery methods, if yes they asked which of the project delivery methods have been used by their organization. Most agencies have experience with design-build (DB) delivery method. Ninety percent respondents indicated that they are using design-build as a key method for transportation projects delivery. One-third (about 33%) have experience with construction manager/general contractor (CMGC). The Public-private partnerships (PPP) was indicated by 19% respondents, and 10% of them referred to design-build-operate-maintain (DBOM). The last method (design-build-finance-operate-maintain, DBFOM) was indicated by 5% respondents (Fig. 17.7).

The survey results in Fig. 17.8 shows that 100% of respondents indicated that risk analysis was conducted with design-bid-build (DBB), 92% was design-build (DB), 15% was early contractor involvement for DBB projects, 54% was construction manager/general contractor (CM/GM), and 31% was public-private partnerships (PPP). Respondents who conduct constructability review survey indicated that design-bid-build (DBB), design-build (DB), early contractor involvement for DBB projects, construction manager/general contractor (CM/GM), and public-private partnerships (PPP) were 89%, 83%, 3%, 10%, and 4%, respectively.

17.5.8 Training

The majority of respondents (about 56%) indicated that they do not regularly provide value engineering training (in-house or external). In risk analysis, the responding transportation agencies who conduct RA indicated that no risk analysis training

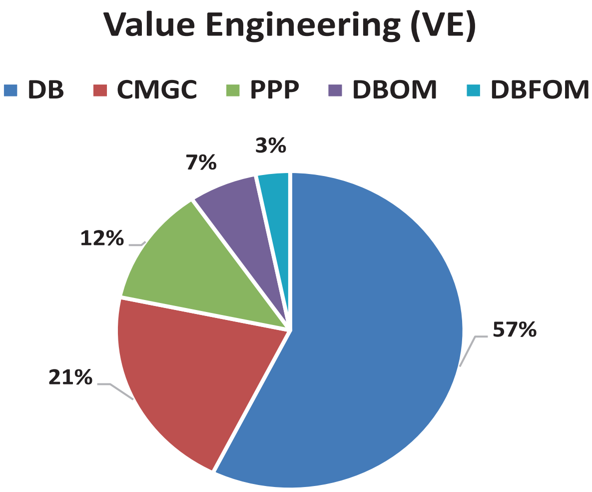


Fig. 17.7 The % of project delivery methods that conducted with VE in transportation projects

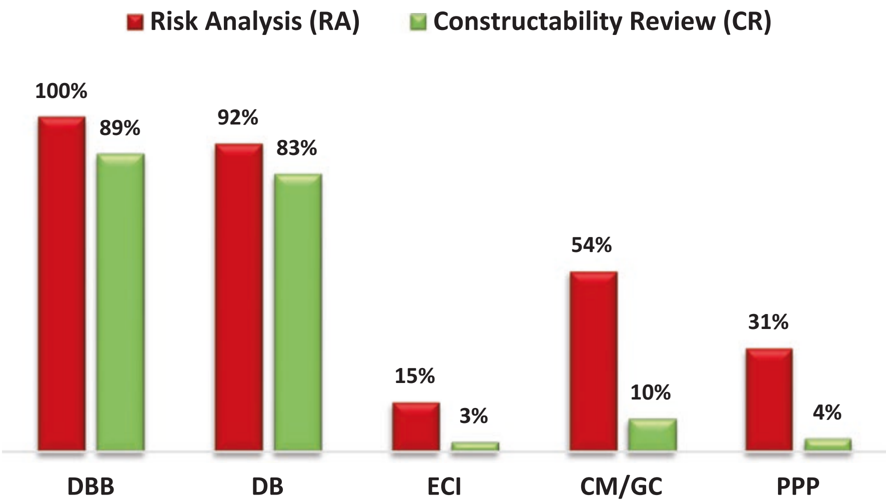


Fig. 17.8 The % of project delivery methods that conducted with each RA and CR in transportation projects

was provided within their agencies. Others indicated they sometimes provide training, never provide training, or provide training on a case-by-case basis (39%, 23%, and 38%, respectively). Respondents who conduct constructability review indicated that 7% they always provide training, 20% they sometimes do, 60% they never do, and 13% they provide training on a case-by-case basis (Fig. 17.9).

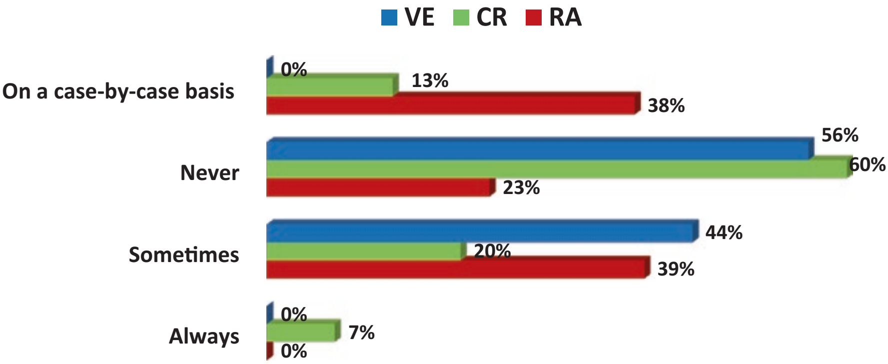


Fig. 17.9 The % of training conducted with the project delivery

17.6 Discussion

17.6.1 Value Engineering

Value engineering and value analysis is defined as an organized effort using multi-discipline teams that seek to improve project value through the analysis of functions by meeting or improving upon performance while reducing the total cost of ownership. VE seeks to find different ways to accomplish key project functions that cost less, improve performance, reduce schedule, and minimize risk. It is often confused with cost reduction exercises but is fundamentally different in theory and application.

The survey shows most agencies have a VE policy. In some state department of transportation (DOTs) value engineering studies are guided by a specific process based largely on the American Association of State Highway and Transportation Officials (AASHTO's) guidelines for value engineering [19]. It is possible for department policy to be changed when a new method is introduced through a value engineering study. For example, an accepted recommendation that suggests the use of a proprietary retaining wall system in lieu of a cast-in-place retaining wall would require a change in policy if the DOT has an existing policy in place that prohibits the use of proprietary retaining walls.

As shown in the survey results VE programs are mostly applied with the design function. The majority of respondents indicated that they perform value eengineering studies during preliminary design. About half of them said that value engineering studies are being conducted during final engineering and some said during project planning or feasibility stage. NCHRP SYNTHESIS 352 [20] stated that the $25 million cost threshold trigger for federal-aid projects serves as both motivation and as a limitation for some state transportation agencies (STAs). Some modest-size transportation agencies with projects falling below the $25 million threshold rarely do value engineering, whereas some larger transportation agencies rarely consider value engineering programs on state-funded or lower-cost federal-aid projects. So, the current policy for National Highway System (NHS) projects requires value engineering studies for each project located on where the estimated total project cost is $50 million or more that utilizes federal-aid highway or transit funding. While $40 million or more that utilizes federal-aid highway funding for each bridge project located on the NHS. The estimated total cost for purposes of the thresholds identified by the NHS and shown in the survey, is based on the best estimate of the cost to construct the project. The survey results verify the above statement and it was noticed that the majority of value engineering programs have adapted the more recent, higher federal dollar value thresholds.

Value engineering (VE) is typically performed as an isolated activity within the project delivery process. Most respondents' refer to the lack of formal feedback and lessons learned that are captured and shared during the project delivery process. This issue might be improved if the value engineering program integrated into the project delivery process rather than being thought of as a stand-alone activity. Value engineering (VE) studies may be performed either in-house by an ad hoc or permanent value engineering team or may be performed through contracts with engineering firms experienced in value engineering [21]. The respondents indicated an even split between consultant-led and in-house value engineering studies and the use of internal vs. external technical team members. The basic value engineering (VE) analysis is being executed coordinating with risk assessment workshops such as cost risk assessment (CRA) or cost estimate validation process (CEVP). Value engineering (VE) analysis should be closely coordinated with other project development activities as well as with risk assessment workshops such as CRA or CEVP [22]. The survey indicated that some agencies are using innovative VE techniques, primarily through the incorporation of some form of risk analysis and/or the use of value measurement systems. Clearly, exploring ways to incorporate these more sophisticated methods into VE studies should be further explored. Project development manual, Appendix 9 [19] stressed that the department offers a minimum of one VE training course every two years. Training is necessary to maintain effective VE programs and the corporate enthusiasm to allocate resources to VE. However, training initiatives are typically influenced more by the overall funding of transportation programs [23]. Training is recommended for anyone associated with transportation projects [24]. However, the majority of respondents in the survey emphasized that they do not regularly provide value engineering training.

17.6.2 Risk Analysis/Management

Risk management is comprised of several key steps including risk planning, risk identification, risk analysis, risk response planning, and risk monitoring and control. Risk workshops are conducted using multidiscipline teams to identify project-related threats and opportunities; assess their probabilities and impacts to cost and schedule; and identify actions to appropriately manage risks. The majority of respondents indicated that they have policy for applying the risk analysis or risk management in transportation projects. The risk analysis/management process is applied for effective management of project risks during entire project life cycle (from problem screening through the completion of construction) [15]. The same survey indicated that the use of RA/RM techniques was more prevalent than CR in support of project delivery. However, other results indicated that use of RA tools and techniques are becoming more common in the delivery of transportation projects. Most agencies do not have an established dollar threshold for performing RA and commonly include it as part of project delivery activities. RA efforts are mostly conducted using a combination of internal and external consultant staff. Some respondents' comments referred to the justification of using the RA by internal or external staff or both of them together that RA is dependent on the competencies in term of personal capabilities. The majority of states are developing internal personnel, but some of them do not have experienced internal staff and are using external consultants. The need for RA is most commonly determined on a case-by-case basis, the survey results indicated that 42% of respondents said RA is used in combined with VE efforts in the transportation projects. Most of them indicated a single RA effort is the most common application of RA on any given project, with a smaller percentage performing continuous risk management activities throughout the project delivery lifecycle. Most agencies do not spend time on RA/RM efforts. In terms of integrating effective practices and innovative methods for project delivery, the integration of RA/RM and VE has been proven; however, CR has generally not been integrated with RA/RM efforts [25]. In the California Department of Transportation (Caltrans), project risk management process is intended to be applied during the entire project life cycle – from project inception to completion of construction. Caltrans emphasize the scalable risk management approach (i.e., level 1, 2, and 3). Therefore, the time for some particular risk management tools is different. Generally, simpler projects may use simple qualitative analysis, whereas larger more complex projects may use more robust/quantitative analysis techniques such as simulation. The respondents considered RA/RM as an ongoing and integrated component of project management and needs to be performed through the project life cycle. No specific project RA training is using within transportation agencies. The majority of the responding transportation agencies indicated that no RA training was provided within their agencies.

17.6.3 Constructability Review

Constructability reviews typically focus on managing construction related risks at two levels. The first is identifying and mitigating issues related to the constructability and biddability of projects. The second is performing a thorough review of construction bid documents (e.g., plans and specifications) to identify errors, omissions, and discrepancies that could lead to quality defects and/or construction change order and claims.

As mentioned in the survey data analysis section, most of transportation organizations did not have a formal CR policy. However, those they did not have a formal CR policy they have started to establish and updated the CR policy within their organizations. Most CR policies were recently updated between 2010 and 2012. These updates covered project requirements to perform CR on large, complex, or issue-ridden projects. For example; [26] the Idaho Department of Transportation incorporates constructability review into the existing design review process as outlined in the design manual. For determining the level of constructability review required, projects are categorized as level one, two, or three. Simple state and federal projects are considered level one. Complex projects are typically considered level two. Complex projects with new, innovative, expensive or complex design features may be considered level three. Project will be designated as level three at the discretion of the District.

In spite of this, 82% of respondents indicated that their DOT does not establish a dollar threshold for conducting constructability reviews for transportation projects. However, those organizations that do have a dollar threshold policy indicated that generally all projects must undergo a review. Other agencies indicated that project costs in exceedance of $500,000 were the threshold that triggers the need for a constructability review. The North Carolina Department of Transportation uses a 5-year work plan to conduct constructability reviews on the department projects. These projects have a combined-estimate greater than $10 million regardless of its location in the design life cycle [27]. The rate of 87 respondents is reflected that great majority of agencies conducting Constructability Review have internal staff with specific experience comparing with the very minimal training that provide to them. Caltrans has some initiatives to integrate alternative project delivery methods on all major projects on the State highway system that exceed the Minor A limit as defined by the California Transportation Commission. These integrations do not include other programs such as value engineering or risk analysis [28]. In this survey the respondents indicated that there are little or no specific connections or references are made between the state's CR program to other design and project review processes such as VE and RA. Finally, as noticed from the survey, most constructability reviews are conducted on the final plans, specifications, and estimates (PS&E), although a significant portion of reviews were also indicated to be conducted during preliminary design. For example, the Georgia Department of Transportation has updated their constructability review policy to perform CRs after concept report approval during the preliminary design phase, near 30% plan completion [29].

17.7 Conclusions and Recommendations

Virtually all of the various methods, techniques, and processes that were analyzed as part of this research essentially improve project delivery performance by facilitating team communication in some way, shape, or form. Through the surveys and review of DOT guidance related to value engineering, risk analysis, and constructability review, a very clear picture emerged regarding the practice of these project improving practices within public transportation agencies.

They are performed as separate, distinct processes that occur at specified points in time, assuming they occur at all. A random sampling of VE reports indicated that 15% of them either directly incorporated or immediately followed a risk analysis activity. The survey results further support this: 8% of survey respondents indicated that risk analysis was always performed in conjunction with value engineering. Constructability reviews are performed in conjunction with value engineering only 27% of the time. Constructability reviews are performed in conjunction with risk analysis only 31% of the time.

They are most often performed due to internal or external policies or requirements. The notable exception is constructability reviews of which the surveys indicated that 59% of respondents stated there was no formal policy for their agency. They are activities that are performed by individuals outside the project delivery team, ostensibly to maintain the objectivity of the processes. They result in findings that recommend changes to a project that must be implemented by the project delivery team. There is little regular formal training. The survey results indicate: 58% indicated that they never provide VE training. Twenty-three percent indicated they never provide RA training while 38% indicated they provide some training on a case-by-case basis. Sixty percent indicated they never provide CR training. One of the most interesting findings revealed itself in the analysis of the FHWA annual VE reports from 2009–2013. In addition, the research team reviewed over 40 VE reports from 18 different DOTs. From this information, there was a very clear pattern between states that had predominately consultant led VE studies versus in-house led VE studies.

The four most active VE programs that were predominately in-house fell below the national average while five out of six of the most active consultant led programs performed better than the average. The number of VE proposals is an indication of the quantity of recommendations generated during the effort (22% higher); the number accepted is an indication of the quality of the recommendations (48% higher); and the acceptance rate is an indication of the efficiency of the VE effort (21% higher). The key differences between the consultant and in-house programs were: Consultant led studies were typically 5-days in duration while in-house led studies were only one day. Consultant led studies were led by individuals with SAVE International credentials while in-house led studies were not. Consultant led studies demonstrated much higher levels of the correct applications of VE techniques while in-house led studies did not.

Clearly, the benefits of communication and collaboration are of great benefit to projects. These are further enhanced by providing more time in a structured environment using good techniques. Imagine what the benefits could be if multiple methods, such as value engineering, risk analysis, and constructability, were integrated, used good technique by trained participants, and were conducted throughout the project delivery process?

Most agencies have experience with design-build delivery methods. Some (about one-third) have experience with CMGC and public-private partnerships. Basically, all of them are very familiar with design-bid-build. The research indicates that this trend is growing, and the many states now consider, and utilize, multiple different alternative delivery methods. Clearly, there is a need for aligning the three primary techniques in this research project (i.e., value engineering, risk analysis, and constructability review) for use with these methods such that they maximize their effectiveness.

In Phase 2 the research team focused on developing and refining the guidance on specific methods and techniques; how best they should be applied individually or in conjunction with each other; recommendations on methods for accurately measuring outcomes; developing electronic templates, and supporting a video guide showed how to successfully implementation of the integrated value management process. The developed process incorporates value engineering, risk analysis, and constructability review along with decision analysis and delivery selection tools. This integrated process aims to enhance communication, collaboration, and innovation for project delivery teams. The new integrated process is developed as a comprehensive process that will assist project delivery teams in maximizing the value of their projects and it is called an integrated value management system. The IVMP consists of the following tools: project setup, stakeholder analysis, decision analysis, delivery method selection, risk analysis, constructability review, and value engineering. (The screenshots from this system are provided in the appendix.)

Acknowledgments

- The authors would like to thank the TRB and NCHRP for their support in our research endeavors. Extended thanks also go out to all the state DOTs and other local transportation organizations who participated in the survey process. Finally, we are very grateful to NCHRP 19-11 research team (PSU & VMS) for all the help, the survey would not have been possible without their support and guidance.
- An earlier version of this research has been presented and published in the PICMET (Portland International Center for Management of Engineering & Technology) Conference Proceedings 2016 [30].

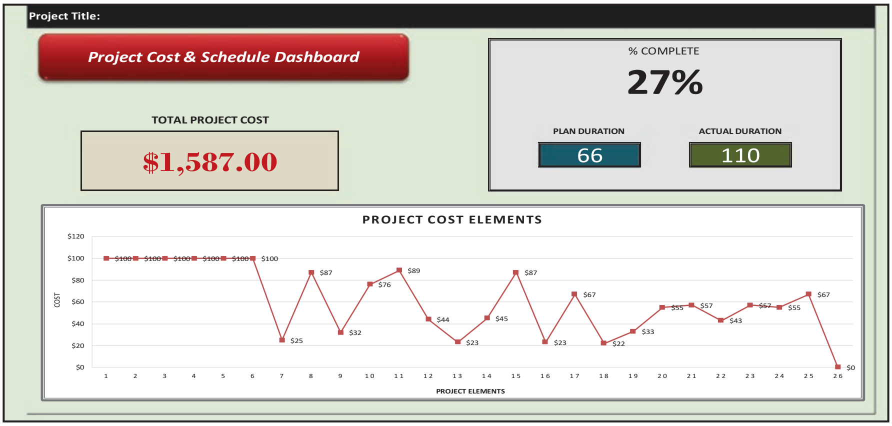
Appendix

Innovative Methodologies Guide

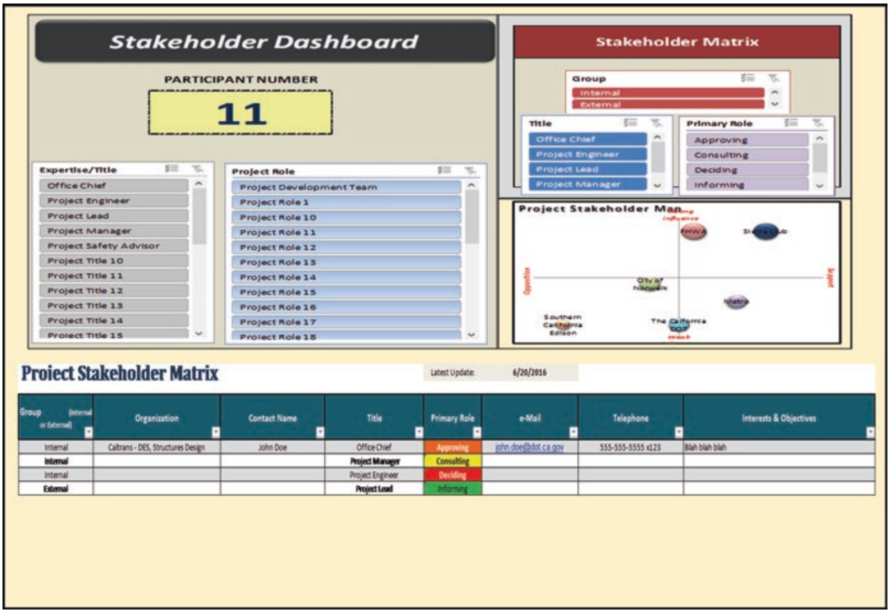
Based on the research and survey outcome which considered several corresponding and feedback from the NCHRP panel at the Phase 1, the research team developed a “strawman” MS Excel template as shown below that included the various activities, tools, and techniques discussed in this paper. The intent includes several MS Excel workbooks that aim to support DOT project teams in managing the value of their projects by applying VE, RA, and CR in an orchestrated way. The developed process is called an integrated value management System (IVMS) which consists of the following tools:

- Project setup
- Stakeholder analysis
- Decision analysis
- Delivery method selection
- Risk analysis
- Constructability review

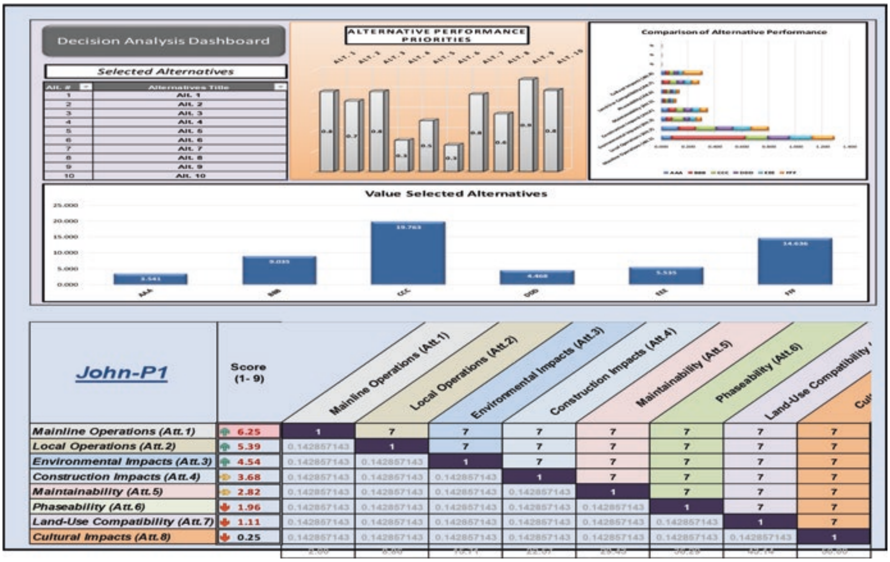
Project Setup



Stakeholder Analysis



Decision Analysis



Delivery Method Selection

Project Delivery Methods (definition & scales)

CMGC

Click **Previous** **Next**

To add additional attributes, please enter on bottom of list in Column B and enter a consideration in Column C.

#	Attribute	Considerations	Weight	Rating Definition	Rating	Total Score
1	**Project Complexity & Innovation**	• Highly innovative process through 3 party collaboration • Allows for agency control of a designer/contractor process for developing innovative solutions • Allows for an independent selection of the best qualified designer and best qualified contractor • VE inherent in process and enhanced constructability • Risk of innovation can be better defined and minimized and allocated • Can take to market for bidding as contingency • Can develop means and methods to the strengths of a single contractor partner throughout preconstruction • Process depends on designer/CM relationship • No contractual relationship between designer/CM	66%	Rating Defination (Why Fair?)	0.4	0.26
2	**Project Delivery Schedule**	• Ability to start construction before entire design, ROW, etc. is complete (i.e., phased design) • More efficient procurement of long-lead items • Early identification and resolution of design and construction issues (e.g., utility, ROW, earthwork) • Can provide a shorter procurement schedule than DB • Team involvement for schedule optimization • Continuous constructability review and VE • Maintenance of Traffic improves with contractor inputs • Contractor input for phasing, constructability and traffic control may reduce overall schedule • Potential for not reaching CAP and substantially delaying schedule	55%	Rating Defination (Why Very Good?)	0.8	0.44
3	**Project Cost Considerations**	• Agency/designer/contractor collaboration to reduce project risk can result in lowest project costs • Early contractor involvement can result in cost savings through VE and constructability • Cost will be known earlier when compared to DBB • Integrated design/construction process can provide a cost efficient strategies to project goals • Can provide a cost efficient response to meet project goals • Non-competitive negotiated CAP introduces price risk • Difficulty in CAP negotiation introduces some risk that CAP will not be successfully executed requiring aborting the CMGC process • Paying for contractors involvement in the design phase could potentially increase total cost • Use of Independent Cost Estimating (ICE) expertise to obtain competitive pricing during CAP	34%	Rating Defination (Why Excellent?)	1	0.34

Risk Analysis

Risk Assessment															
Un-Managed State (Pre-Response)								Managed State (Post-Response)							
Probability	Performance		Cost		Schedule		Total Severity	Probability	Performance		Cost		Schedule		Total Severity
	Impact	Severity	Impact	Severity	Impact	Severity			Impact	Severity	Impact	Severity	Impact	Severity	
		0		0		0	0.000			0		0		0	0.000
		0		0		0	0.000			0		0		0	0.000
		0		0		0	0.000			0		0		0	0.000
		0		0		0	0.000			0		0		0	0.000
		0		0		0	0.000			0		0		0	0.000

Constructability Review

Constructability Review Issues
Resolution Status

Project (insert reference):

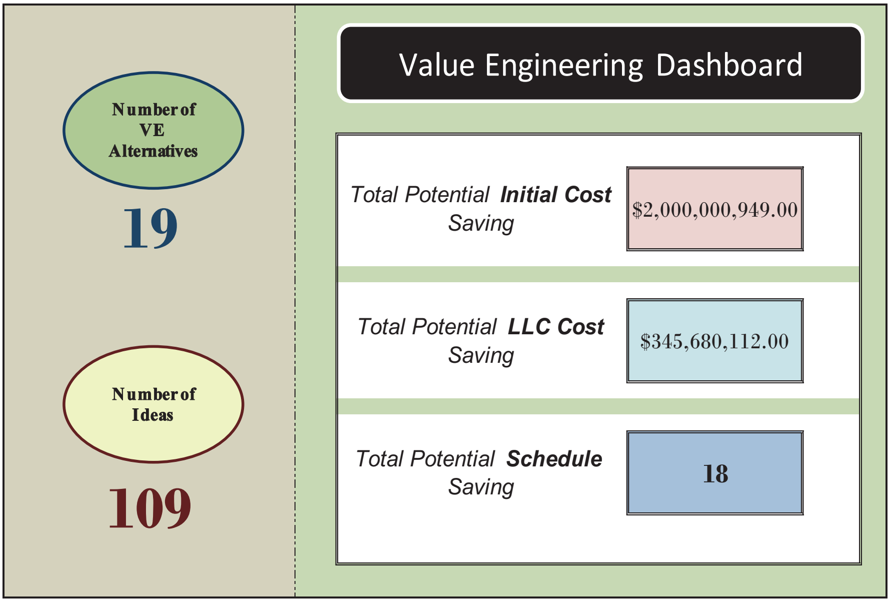
No.	Issue Category	Severity	Status	Risk?	Response Actions
1	Construction	Medium	Resolved	Yes	
2	Design	0	Resolved	Yes	
3	0	Low	Open	0	
4	0	High	Open	0	
5	0	Medium	Open	0	

Constructability Checklist

Project Name:

Constructability Review Category	Suggested Timing for Review				0 = Fail ✗ 1 = Pass ✓
Environmental	**Required?**	**<35%**	**65%**	**95%**	**Last Checked By**
Is an environmental reevaluation required or needed?	YES	✗	✗		
Have environmental construction windows been identified?	NO				
Are design noise levels affected by minor design changes?	YES	✓			

Value Engineering



References

1. Mendez, V. (2010). *Every day counts: Innovation initiative* (pp. 1–2). Washington, D.C.: Federal Highway Administration.
2. Walewski, J., Gibson, G.E. Jr., & Jasper, J.. Project delivery methods and contracting approaches available for implementation by the Texas Department of Transportation, Report No. FHWA/TX-0-2129-1, Center for Transportation Research, Austin, Tex., 2001, 116 pp.
3. Understanding Project Delivery for the Design and Construction of Public Buildings, AIA Minnesota, A socitey of the American Institute Architects. https://www.aia-mn.org/wp-content/uploads/project_delivery.pdf
4. Anderson, S. D., & Damnjanovic, I. (2008). *NCHRP Synthesis 379: Selection and evaluation of alternative contracting methods to Accelerate Project Completion*. Washington, D.C.: Transportation Research Board of the National Academies. 68 pp.
5. Tran, D., & Molenaar, K. (2015). Risk-Based Project Delivery Selection Model for Highway Design and Construction. *Journal of Construction Engineering Management*.
6. Terry Hays, R. (2006). Value engineering on design-build transportation projects, Achieving Value . www.value-eng.org
7. Value Engineering, Manual of Instruction, Utah Department of Transportation (2015).
8. Value Engineering in the Federal-Aid Highway Program, Federal Highway Administration, U.S. Department of Transportation. (2007).
9. Value Engineering, Federal Highway Administration, U.S. Department of Transportation, Washington, D.C. www.fhwa.dot.gov/ve/
10. Wilson, D.C. (2005). NCHRP Synthesis 352: Value Engineering Applications in Transportation, Transportation Research Board of the National Academies, Washington, D.C. .
11. David Ruby, Constructability Maximizing Simplicity, STRUCTURE magazine. (2006). www.structuremag.org/wp-content/uploads/2014/09/SF-Constructability-Part-I-June-061.pdf
12. Constructability Review Guidelines, Idaho Transportation Department (ITD). (2011).
13. Constructability Guide Book, Indiana Department of Transportation (INDOT). (2010). www.in.gov/indot/files/ConstructabilityReviewProcess.pdf
14. Construction Manager/General Contractor (CMGC) Manual, Colorado Department of Transportation (CDOT). (2014).
15. Risk Management Guideline, New Jersey Department of Transportation (NJDOT). (2015). www.state.nj.us/transportation/capital/pd/documents/RiskManagementGuideline.pdf
16. Guide for Managing NEPA-Related and Other Risks in Project Delivery. (2011). *Volume* (Vol. 1). Washington: DC.
17. Alternative Technical Concepts for Contract Delivery Methods, NCHRP SYNTHESIS 455, 2014. www.TRB.org
18. Guide for managing NEPA-Related and Other Risks in Project Delivery. (2011). *NCHRP, V.*, 1. http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_W183v1.pdf.
19. Value Engineering in Design, Project Development Manual, Appendix 9, New York State Department of Transportation (NYSDOT), 2015.
20. Value Engineering Applications in Transportation, NCHRP SYNTHESIS 352, A Synthesis of Highway Practice, Transportation Research Board, 2005.
21. Value Engineering, Chapter 2-E, Federal Lands Highway Manual, FLH, 2012.
22. Value Engineering, Chapter 310, Design Manual, Washington State Department of Transportation (WSDOT), 2013.
23. Value Engineering Applications in Transportation, a Synthesis of Highway Practice, NCHRP – Synthesis 352, 2005.
24. Value Engineering Program for Transportation Projects Policy, Oregon Department of Transportation (ODOT), 2014.
25. Project Risk Management Handbook, California DOT (Caltrans). (2012). www.dot.ca.gov/hq/projmgmt/documents/prmhb/PRM_Handbook.pdf

26. Constructability Review Guidelines, Idaho Department of Transportation. (2011). http://www.idaho.gov/manuals/
27. Value Management Program Policy and Guidelines, North Carolina Department of Transportation. (2015). https://connect.ncdot.gov/resources/Products/Documents/VMP%20Guidelines%205%200%20Value%20Management.pdf
28. Constructability Reviews, California Department of Transportation. (2010). http://www.dot.ca.gov/hq/oppd/design/PD-05.pdf
29. Plan Development Process, Georgia Department of Transportation. (2015). http://www.dot.ga.gov/PartnerSmart/DesignManuals/PDP/PDP.pdf
30. Khalifa, R., & Stewart, R. (2016). Survey of Value Assessment Programs within Transportation Construction Projects in U.S, PICMET (Portland International Center for Management of Engineering & Technology), Portland State University, U.S. .