No More Muddling Through

Mastering Complex Projects in Engineering and Management

by

Rainer Züst and Peter Troxler

Springer

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Preface

Good engineers and professional managers use a systematic way of thinking. And they are in need of a methodology to guide demanding problem-solving processes in their everyday work. Systems Engineering offers such a methodology. It builds on traditional systems engineering methods from engineering sciences and combines them with modern, systemic management thinking, state-of-the-art problem solving approaches, and complete life-cycle management of products and systems.

In the 1950s and 60s new concepts were introduced to facilitate co-operation in multi-disciplinary teams with a view to developing an optimal complex technical system. A. D. Hall's 'A Methodology for Systems Engineering' (1962) was a landmark in the definition and exemplification of the new approach. At ETH in Zurich a comprehensive methodology named 'Systems Engineering' was then developed (Büchel (1969), Haberfellner et al. (1976), Haberfellner et al. (2002), Züst (2004)).

Competitive titles in the marketplace typically focus on the engineering of purely technical systems covering stages of design, systems engineering management, tools, and applications. They rarely discuss the complete life cycle, or, if they tend more to the soft issues side, lack the engineering and managerial problem solving approach.

The German equivalent of this book has been used extensively since 2000 in higher education at university level in both engineering and management master courses. International students and universities from across Europe keep requesting an English version of the publication, and the initial 50-page summary is not sufficient enough to cover this demand both in quality and in quantity.

This volume also contains three case studies from our collection published in 2002 (Züst R. Troxler P (2002). The cases tell real-life stories of how practitioners applied the methodology to their own projects in their particular circumstances. On purpose, these cases are more like stories than like textbook examples, so the reader can participate in the exciting struggle the authors faced when applying pure teaching to a practitioner's reality. These are not smoothly polished success stories, but real examples with all their ambiguities and contradictions. And yet they tell us how the considerate application of the SE methodology in the hand of a professional will lead to project success.

Rainer Züst
Zurich, spring 2006

Peter Troxler
Aberdeen, Rotterdam, Zurich, spring 2006

Foreword

Systems Engineering has in the past few years become a very popular discipline. Many products of our daily life grow in terms of added functions and often complexity. This concerns consumer goods such as cameras, televisions, automobiles, as much as socio-economic or environmental systems or communication networks. This sometimes only perceived growth in complexity is supported by the enormous capabilities of our modern information technologies and the associated software.

Systems Engineering today has grown from an exclusive technical design or process focus into a holistic or 'end-to-end' discipline. Today's System Engineers deal with technical optimisations, requirements analyses, implementation processes, economic issues, and after sales support matters. But they also analyse large network centric operations, generate complex architectures of systems of systems and evaluate enterprise structures and processes.

The principle value of Systems Engineering originates from its focus upon unbiased trans-disciplinary assessments of all parameters contributing to the design and production of better products. System trade-offs deal with technological, economic and sustainability factors and merge them into solutions, that meet market demands or customer requirements. Systems Engineering has become one of the strongest assets of enterprises since it delivers products that are well engineered and create market success and profitability. 'Modern' Systems Engineering is progressively more model based on and employs advanced tools and techniques of system simulation throughout the life cycle evolution.

This book is an excellent entry for novice system engineers, for people who want to familiarize themselves with the step-by-step systems engineering process and associated solution methods. It is written in a very practical manner and provides specific advice for practitioners. As President of the International Council of Systems Engineering (INCOSE) I welcome this book into the wider international systems library and wish its English version as much success as its German version has had in past years.

Prof. Dipl.-Ing. Heinz Stoewer, M.Sc.
President of “International Council on Systems Engineering (INCOSE)

1. INTRODUCTION

1.1 Origin and Development of Systems Engineering

In the 1950s extensive, complex, interdisciplinary and large-scale projects – such as landing on the moon – were launched. In the context of such projects, new materials, procedures and technical products were developed; in addition 'socio-technical' questions (human, legal, e.g.) had to be mastered. Diverse technical disciplines and experts were involved in solving these problems. Individuals or small groups could not manage such large-scale projects any more. Therefore a new method became necessary. Different concepts evolved how interdisciplinary project teams could work together and how complex systems could be developed efficiently.

In the context of the search for methods the book 'Methodology for system engineering', published by A. D. Hall in 1962, received special attention and distribution. Hall's methodical design was taken up and newly interpreted some years later by professor A. Buechel at the ETH Zurich at the beginning of the 1970s. It was then further developed into the independent method Systems Engineering at the Institute for Scientific Management (BWI) of the ETH Zurich by a group of authors (Haberfellner et al. (1976)).

Systems Engineering (SE) is a systematic way of thinking and a method to mange the problem solving processes in the context of challenging socio-technical questions. Primarily, the application of SE is recommended for projects with large object complexity and large size where it is difficult to efficiently develop, implement and control a sustainable solution due to the many parties involved.

Projects where a formal application of SE is recommended are for example:

- New transport systems: for example a new high-speed railway line with trains, line management (all parties involved taken into account), timetables and connections to further transport systems, tariff system and financing.

- Communication systems: for example a new satellite communication system.
- Computer systems: for example a computer architecture including networks and applications.

Large-scale installations of process engineering: for example for the production of genetically modified substances.

The formal application of SE methods is also recommended for certain projects of medium complexity and project size as for example

- Development and introduction of a new manufacturing strategy
- Structure and implementation of a new management system
- Concept for kerbside collection and recycling of recyclables

SE methods clearly are in competition to other general planning methods. In each situation it has to be examined whether SE methods, alternative methods or a combination should be applied.

The SE role in a project should guarantee the development of optimal products. We understand the term ‘product’ here in its broadest sense – as a ‘system of matter and action’. The economic, ecological and social implications of the product have to be taken into account in the system development (see also extended term of technology from G. Ropohl (1991)). Thus the SE function embodies the socio-technical expertise respectively the excellence of the system development and therefore the innovation potential of the company.

In contrast the project management role is responsible for the optimal project design and for its implementation (including the SE work, see figure 1.1). Project management governs the whole project while Systems Engineering primarily supports the development phases of a system.

The SE role is established at the level of company management as an independent, functional department in many larger companies, particularly in the area of air- and spacecraft, computer and large-scale industry in the U.S.A. and in other countries. This department is purposefully involved in projects to support the problem solving process.

In Switzerland, Systems Engineering was applied for the first time outside an engineering context when the Hürlimann commission, a Swiss planning commission, had to deal with the future planning of traffic and mobility in Switzerland. In the standard publication on Systems Engineering (Haberfellner et al., 11th Edition (2002)) the complex project of the planning of the airport of Munich at the beginning of the 1970s is described. In both examples, it becomes evident that a challenging planning task can be managed using Systems Engineering.

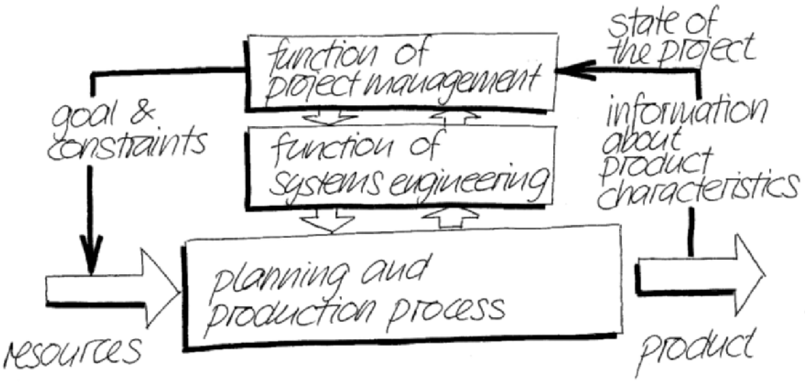


Figure 1.1. Project management and Systems Engineering functions (Züst, Schregenberger (2003)).

Over the years, the method of Systems Engineering was not only presented to industry leaders in workshops but also taught in several courses at the ETH Zurich and other universities, in particular at engineering departments.

Today, ecological aspects are also used in SE. Sustainability is an important postulate for SE projects, for example described in the project ECODESIGN (www.ecodesign.at) and the corresponding book (Wimmer, Züst (2001)).

The international movement for the promotion of Systems Engineering has been in existence for about fifteen years now. The 'International Council on Systems Engineering' (INCOSE, see also www.incose.org) is active worldwide to promotes systems engineering as a method for the development of challenging technical systems. Only recently INCOSE has started to investigate the role of systems engineering beyond its application to engineering projects.

This understanding of SE as a method to design socio-technical systems has been at the core of the Zurich school of SE since its beginning.

1.2 Structure and Content of Systems Engineering

Methodical problem solving is about gaining a complete picture of the problem from different points of view. Only then a defined initial condition can be transformed into an optimal target condition (figure 1.2).

This process, i.e.

- analysing and modelling material worlds,
- the definition and structuring of complex goal definitions,
- the heedful development of alternative solutions and
- the analysis and multi-dimensional evaluation of these solutions
- is called problem solving process in SE. It is supported by appropriate methods.

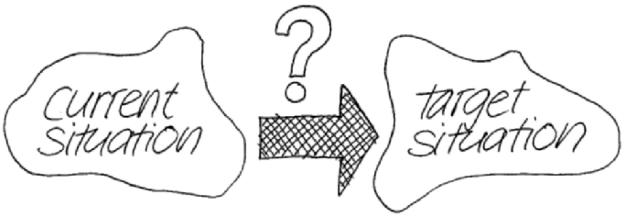


Figure 1.2. Problem solving as a transformation of an initial condition into a target condition.

Systems Engineering postulates a set of principles that have to be applied during system design (figure 1.3):

The successful application of Systems Engineering depends on certain conditions. These are focusing on specific fields of application (challenging questions), the institutional status of the SE role, methods of thinking in systems, and a set of problem solving heuristics.

Systems Engineering relies on two basic methodical concepts. These are:

- Life phase model (LPM): The life phase model describes the purpose and specific content of the individual life phase of a system.
- Problem solving cycle (PSC): The problem solving cycle contains several steps that are necessary in order to develop a solution to any sort of complex problem.

In the context of the Systems Engineering the interaction life phase model and problem soving cycle is of central importance.

Furthermore SE covers an interdisciplinary arsenal of qualitative and quantitative methods to solve specific problems.

This book also follows this structure of SE (as shown in figure. 1.3).

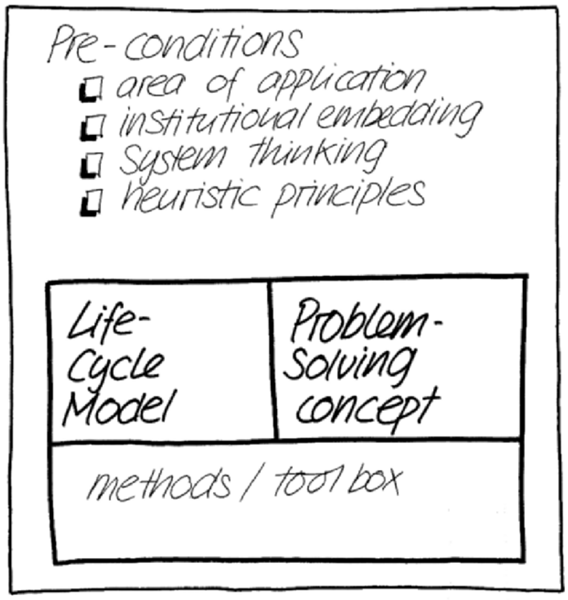


Figure 1.3. Structure and contents of Systems Engineering.

1.3 Content of the Book

The central focus of this book is on the most important, basic methods that have to be taken into account when designing a challenging system, and on their efficient and concrete application (see figure 1.3).

The book is devided into three parts (see figure 1.4.)

Main chapters	***Part of the book***
1. Introduction	
2. Requirements	Part 1
3. The life cycle model and the problem solution cycle and their interaction	***Systems Engineering Overview***
4. Interdisciplinary, universal toolbox	
5. Situation Analysis	Part 2
6. Goal Definition	***Problem Solving Cycle***
7. Search for Solutions	
8. Evaluation and Decision	
9. Application of SE	Part 3
Case A: Environmental Management System	***Cases***
Case B: Communication Network	
Case C: Strategic Positioning of a Product	

Figure 1.4. Content and structure of the book.

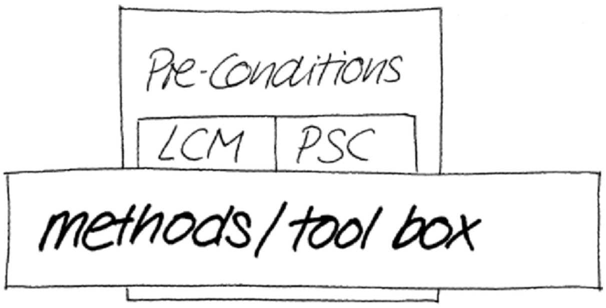
Part 1: Systems Engineering Overview: the methods of Systems Engineering as a whole. The description of the two basic concepts life phase model and problem solving cycle and their interaction.

Additionally we show which requirements are necessary for a successful application of SE and how management and engineering methods can be aligned with SE.

Part 2: Problem Solving Cycle: An important basic concept of SE is the problem solving cycle. This is described in detail in part two. This part focuses on the steps situation analysis, goal definition, search for solutions, evaluation and decision.

Part 3: Cases: Finally, three real planning examples are described. SE users talk about their experiences, about the difficulties and distress but also about the highlights and successes of the application of SE in their professional life. The main focus of the three cases is on the application of the problem solving cycle, the life phase model and their combined application.

2. PRE-CONDITIONS



Each general problem solving method such as the method of Systems Engineering (SE) is based upon specific conditions that are:

- the focus of its area of application,
- institutional embedding,
- the systems thinking approach,
- a set of heuristic principles.

2.1 Area of Application

Systems Engineering (SE) is a general method to solve complex and new design problems in the area of technology development. The application of SE is recommended when the problem is related to several areas of expertise and therefore a systematic consideration of different perspectives is required.

Terms:

‘Problem’ and ‘Problem solving’:

These explanations are selected from various definitions of the term ‘Problem’ in different specific fields: ‘A problem exists if an individual wants to achieve a certain objective but does not know how to achieve this objective’ (Süsswold (1956), p. 10). ‘We speak about problem solving when the means to achieve an objective are unknown or the known means have to be combined in a new way and also when no clear idea about the objective exists, (Dörner et al.(1982), p. 303).

‘Complexity’:

Among the numerous attempts to define the term ‘complexity’ we prefer this definition by G. Klaus: ‘Complexity is a character of a system defined by the type and number of relations existing between the elements, in contrast to the elaborateness of a system that is related to the number of different elements’ (Klaus, Liebscher (1979)).

A few reflections about the relation between revenue and expense are shown in figure 2.1 before getting into the formal application of SE.

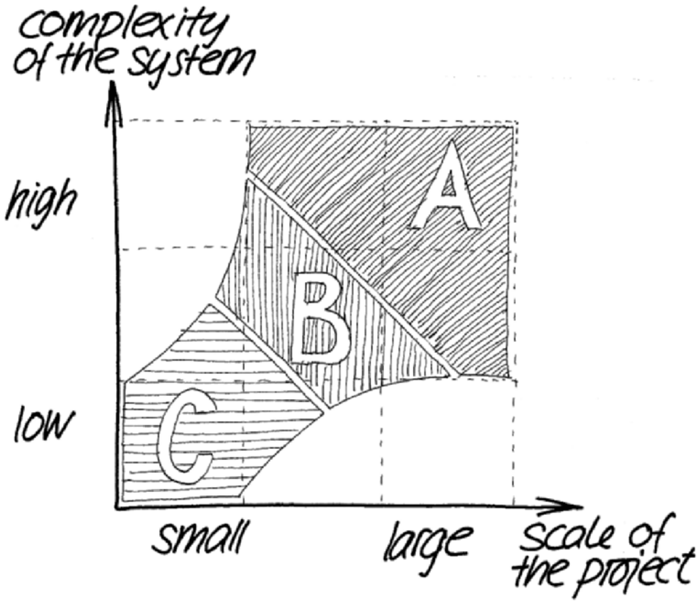


Figure 2.1. Qualitative characterisation of projects as a function of the scale of the project and the complexity of the system, to assess the appropriate application of SE methods.

Area A: Dominant Position of Systems Engineering

The formal application of Systems Engineering for the optimal system design was originally planned for area A shown in figure 2.1. It is made for very extensive and interdisciplinary projects using many resources. Examples include the development of new missiles, transport, telecommunication, or computer systems, weapons and process plants of all types. Since the 60's the formal application of SE in large scale and in complex projects has become accepted practice in many big companies and in government, mainly in the USA, Great Britain, Australia and Scandinavia.

Area B: Systems Engineering as an Option

A multitude of projects in industry, society and science are characterised by an average object complexity and project size. These projects are allocated to the area B in figure 2.1. Typically, interdisciplinary teams work on projects from a short period of time to a few months or several years. In these projects SE is one possible method to be used and competes with other general methods. In any case the question whether SE methods should be used or if other methods are more fruitful has to be answered.

> *Example:*
>
> *A company intends to develop a product generation that is taking current trends into consideration. For the first time the products will be sold on the international market. The plan has strategic importance for the company.*
>
> *In this situation challenging questions about optimal design, production, distribution, usage and service of products have to be addressed. The project team has to assess what economic, ecological and social implications the new product and market orientation will have. The team*
>
> *also to assess how organisation and management structures, the application of specific planning and decision processes and the allocation of resources must be adapted. The question is highly interdisciplinary, new, complex and relatively large scale for the company; additionally it has a strong technical character. In this case the use of SE methods will be useful.*

Cross Reference to Cases in Chapter 9

The combination of systems engineering with value analysis methods is described in case C 'Market success with systematic product planning':

The price and quality of a product are too high which presents a new and complex challenge for the company. Time pressure to find a solution is an additional element. Therefore potential solutions have to be identified in a fast and efficient way. The external consultant is an advanced user of Systems Engineering. He convinces the management to use Systems Engineering methods. The consultant succeeds in reaching the required project objectives by adapting Systems Engineering methods, especially the product life cycle model, and specifically by integrating value analysis as an additional methodological basis.

2.2 Institutional Embedding of the Systems Engineering Function

For the successful application of SE a clear decision in favour of the use of this problem solving process by the institution (company, professional body or community organisation) is necessary. A problem arising in the application of SE cannot be handled in normal day-to-day work. In particularly large projects, SE was and is applied by a specialised SE department (see also: www.incose.org).

2.3 Systems Thinking

In spring days become longer and solar radiation becomes more intensive. The climate and the growth conditions for plants change. We can only explain the growth of plants when we describe them in their complete geographical and biological system context.

In general language the term system is used in a multitude of contexts. Some examples are the solar system, traffic systems and political systems. When examined closely each system is a universe of organised smaller systems. When you begin with a rough structure of a specific system and then particularise its structure step by step, ultimately you aim to find basic modules. These modules are also called elements. Kosiol (1962) defines ‘a system ‘as the universe of elements with their relations between these elements and their ‘properties’.

In the mid 50s system theory were widely accepted in science. The following contributions have influenced the systems thinking approach, which is also fundamental in Systems Engineering:

- L. von Bertalanffy (Theory of Biological Systems), Bertalanffy (1968),
- N. Wiener (Cybernetic), Wiener (1948),
- W.R. Ashby (Information Theory), Ashby (1971),
- J. v. Neumann (Game Theory), Neumann (1961),
- J.W. Forrester (Modelling of global systems), Forrester (1961) and Forrester (1972),
- N. Luhmann (Theory of social systems), Luhmann (1984).

Example:

A company successfully develops, produces and distributes products. In a long-term perspective it has to secure its market leadership by appropriate measures. Therefore one project objective is to analyse the influencing factors of customer satisfaction and what effects customer satisfaction has for other areas. The project team presents the conclusions in a system model (figure 2.2)

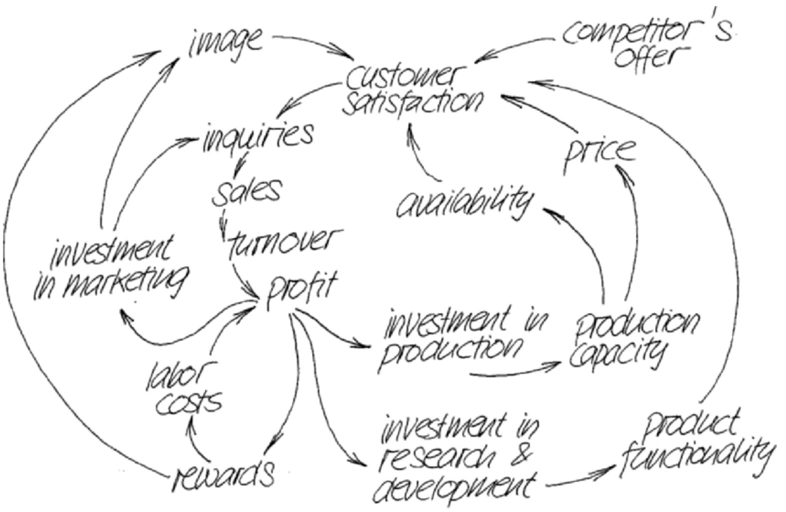


Figure 2.2. Systematic presentation of different factors for customer satisfaction and the effects on other system elements.

Thinking in systems is understood as a pronouncedly anti-reductionisy, holistic and context related way of thinking. Thinking in systems is basically interdisciplinary and can be helpful to solve many urging problems that go beyond the limits of traditional disciplines.

'The system theory approach shows a high degree of problem adequacy because the complex structure of the object to be analysed and designed remains accepted and preserved. Moreover the systemic approach leads to the strengthening of interdisciplinarity for the designers and to the integration of participating elements because the construction (or the design [remark of the author]) of systems has to be done according to the situation and the objectives.' (Mühlbradt (1996)). Thus system thinking is very important for the planning process.

If a system comprises interacting people, i.e. participants and persons affected, beside technical elements, this system is called a socio-technical system. Several points have to be emphasised:

- Manifold inter-relations exist within the system, particularly time-delayed feedback.
- The cause and effect relation between partial systems and the elements are partially non-linear and not constant.
- The system behaviour cannot be predicted intuitively. In fact counterintuitive behaviour is observed, which means that after an intervention, the system behaves completely differently to what was expected initially.

System thinking …

- is a general approach that helps understand a complex situation.
- is a special way of seeing the reality.
- is a basis of quantitative analysis of the behaviour of technical and socio-technical systems.
- emphasises the functional and process-oriented view.
- is interdisciplinary with regard to knowledge areas as well as to departments within an organisation.
- is a desired contrast to local, isolated and department-related thinking.

- is a means of integrating different perspectives.
- makes communication easier.

System thinking is a way of thinking which you can only learn trough a lot of practice.

2.4 Heuristic Principles

Heuristic principles are used to develop outcome-oriented action plans in problem solving processes when the way to reach the desired outcome is not fully obvious. It has been proven to help structure a planning process chronologically, to get closer to the solution step by step, and to think in alternatives. Thus it is guaranteed that an overall perspective can be preserved and alternative solutions can be examined and related to each other successively. System dynamics have to be accounted for as well.

In the framework of Systems Engineering the following heuristic principles are of high importance (according to Haberfellner et al. (2002)):

- Considering time-related changes
- Working from a general to a detailed perspective
- Thinking in alternatives/thinking in options

The above-mentioned three heuristic principles are described below.

Considering Time-Related Changes

Systems change during the course of developing a model. That is why the planning team must constantly handle new situations. There are two aspects to consider:

- anticipation of future changes in the environment and their integration into the planning process for example based on a trend analysis and
- re-evaluation of previously planned steps and intermediate decisions compared to new, relevant knowledge and their adaptation to results, if so needed.

Systems and their environment are subject to change over time. Identities, content and behaviour of system elements and their relation to each other can change. For example new knowledge in natural science leads to new emission limits for certain manufacturing plants. Such changes in legislation do not only influence the image of the company but also the future design of production equipment. The focus is on systematically accounting for new and generally higher requirements in a problem solving process.

Therefore a projection of the future must be included in a planning process. Future changes and trends have to be recorded. Additionally the knowledge level changes in a project. New results imply that the planned steps and decisions have to be re-examined critically and adapted if necessary. Below we describe both approaches in detail:

a) Recognise future changes in the system and environment and account for them in the planning process: Analyses of the past, the present and the future have to be integrated (figure 2.3) in the planning process.

   At first it should be examined how the actual situation evolved. Secondly the past has to be analysed. Thirdly it has to be clarified what future trends and changes are taking place in relevant areas of the system and the meta-system because a new solution has to be able to prevail in the future.

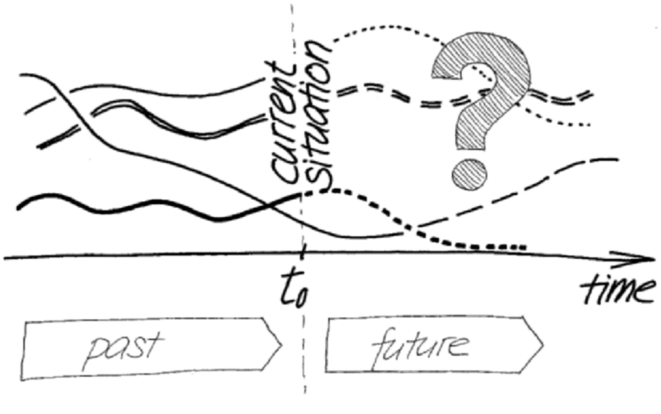


Figure 2.3. Reflections on the past, the present and the future.

b) Re-examine the planned steps and intermediate decisions when new results emerge: Accounting for changes over time should guarantee that agreed planning steps are re-examined whether they are relevant to the changes to the system and whether there are corrections needed. This requires that planning is iterative and cyclical. A pure sequential development of the project steps in the sense of a 'waterfall model' must be avoided.

Working from an General to a Detailed Perspective

A further element of successful planning is a meaningful and clear subdivision of the levels of consideration. In literature this procedure is called 'from general to detail' or 'the principle of hierarchies'. This principle says that it is generally useful to carry out a rough and comprehensive analysis in order to establish the general objectives for the whole system and a general solution framework right at the beginning. The degree of detail and specification is increased step-by-step in the process of forming the solution (figure 2.4).

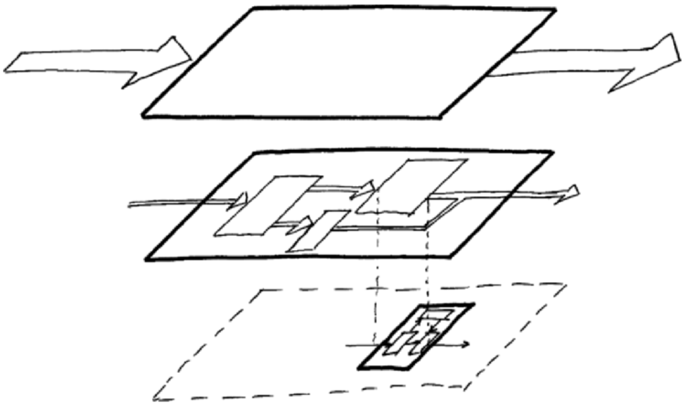


Figure 2.4. From general to detail.

The application of this heuristic principles aims at

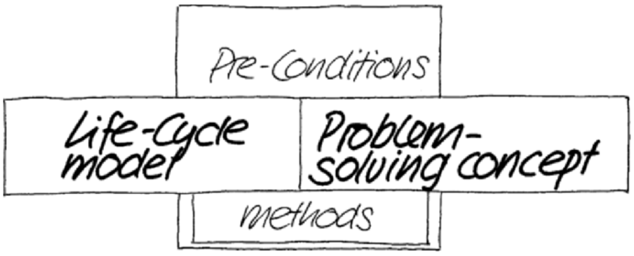
- focusing on essential system characteristics,
- optimising the solution by a step-by-step advancement and
- limiting the planning expenditure.

Thinking in Alternatives/Thinking in Options

As the saying goes, ‘one solution is no solution.’ Similarly in SE we try to cover the field of potential solutions as completely as possible in all individual planning phases. The main idea of ‘thinking in alternatives’ or also ‘thinking in options’ or ‘thinking in scenarios’ is of central importance when analysing situations and determining ideas and alternatives for solutions. Indeed, it is about recognising potential parameters and behaviour possibilities as well as about opening up a large spectrum of solutions for a project.

‘Thinking in alternatives’ is mainly required in the initial phase of planning. New and promising solutions should not emerge at the last moment only to question the previous steps in planning.

3. LIFE CYCLE MODEL, THE PROBLEM-SOLVING CYCLE AND THEIR INTERACTION



Systems Engineering is based on two basic methodical concepts, the Life Cycle Model and the Problem Solving Sycle. For Systems Engineering their purposeful interaction is central.

3.1 Life Cycle Model

The Life Cycle Model is a general description of the purpose and the specific criteria of the individual phases of the life of a technical system. For each phase it describes what results are to be expected, how the individual results are tested, and what further considerations have to be taken.

The lives of technical systems are divided into the four phases development, realisation/implementation, utilisation and disposal (figure 3.1).

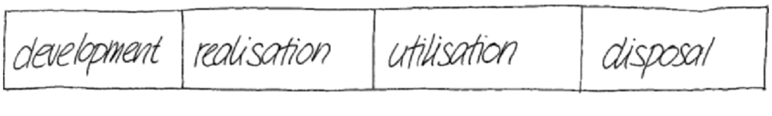


Figure 3.1. Life phases of a system.

Design processes in the fields of engineering and management are characterised by the fact that in the initial phase of a project, important decisions are to be taken despite of uncertain and incomplete information and evaluations (figure 3.2). The essential part of technical, economic, ecological and social consequences of any decisions are already determined during the development of new solutions in this early planning phase. They become effective only later in a different space-time context.

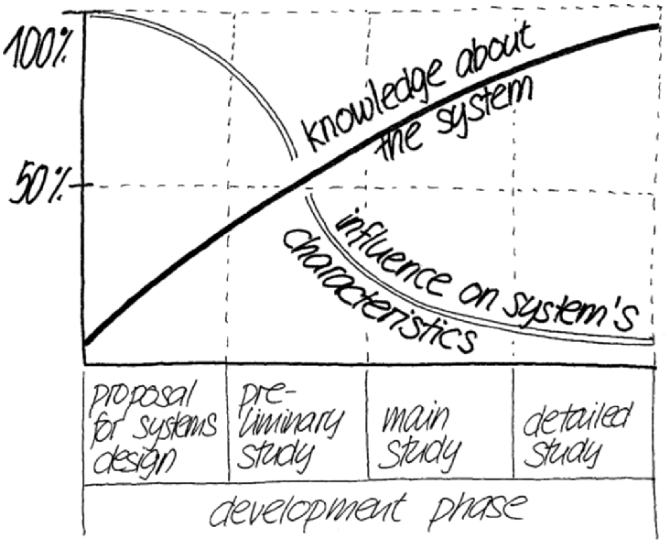


Figure 3.2. Influence of decisions on system characteristics and knowledge about the system (qualitative description) according to Haberfellner et al. (2002).

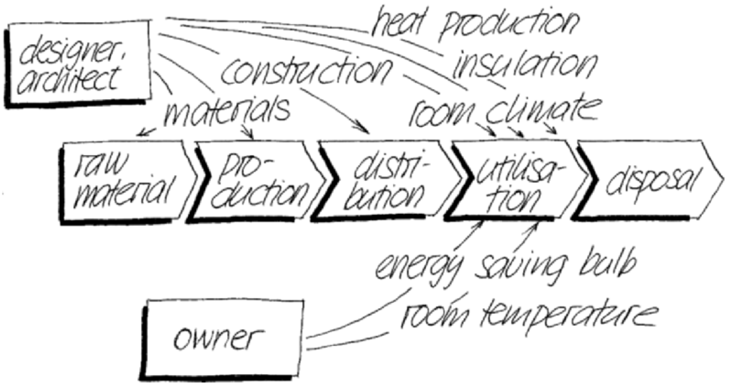


Figure 3.3. Influence of planning activities on individual product life phases in the example of energy consumption of a house.

Example:

An architect is planning a new building. He defines not only the form, but also the materials, the methods of construction, the type of heat generation as well as the type and scope of insulation (Figure 3.3).

Thus important properties of use are determined, e.g. in terms of energy consumption. The later users, in this case the residents only have little influence on the system characteristics through a change of their behaviour.

The individual life phases, their purpose and their specific criteria are described below.

3.1.1 Development Phase

In the development phase the system is designed step-by-step (figure 3.4).

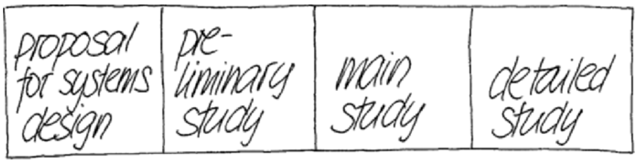


Figure 3.4. Subdivision of the development phase in four partial phases: proposal for system design, preliminary study, main study and detailed study.

Proposal for System Design

The proposal for system design is the first planning step in the development phase. It is the time span between the first detection of a problem to the decision to solve the problem. The impulse for the problem solving process either evolves out of

- criticism of a dissatisfying situation,
- a threat,
- the chance to use an opportunity or

- an attempt to stabilise a specific situation by influencing external parameters.

  Examples:

  - *'The administration has become too fat. The cost structure has worsened for the last few years!' This criticism emerged from a problematic situation.*
  - *'Our customers expect shorter delivery time and the proof of ecologically produced products in the near future. The present production equipment can not fulfil these future requirements.' The future changes in the business environment are recognised as a threat.*
  - *'The peripheral region is connected to the new international network of high-energy railways'. This new infrastructure is seen as a chance to improve the traffic situation in the periphery.*
  - *'Our company is the market leader. Its high quality products are in demand all over the world. The current product-market strategy is successful. This leading position should be protected in the long term.' The company aims to stabilise its leading role.*

The proposal for system design in regard to purpose and planning results is characterised as follows:

Purpose:	Sensitise decision-makers, develop problem awareness among decision-makers and clarify their willingness to act.
Result:	The result is evident as the decision of the deciding entity, the decision to either deal with the problem within the scope of a study or defer it.

The type and manner of the proposal have a crucial influence on the planning processes that follow. It is vital to scrutinise the proposal and possibly complete it after consultation with the client.

Cross Reference to Cases in Chapter 9

Case B describes a common solution approach. The attempt to design a communication network for regional and local authorities fails due to diverging interests of the people affected. A solution can only be developed after ensuring the systematic involvement of all the parties affected.

Haberfellner et al. (1976) does not consider the proposal for system design as a separate phase. Based on our experiences we consider the proposal to be so important that we explicitly want to mention it as a phase. Many characteristics of future solutions are more or less consciously defined during the practical work on the proposal, i.e. the phase between the initial impulse for the problem solving process and the decision to approach the problem in a managed way. So the problem definition already contains basic settings for the work in the project that follows.

Preliminary Study

The preliminary study encompasses a broad area of subjects. It has to be made clear which domains and relationships are relevant for the task. The problem-solving process in the preliminary study is characterised by the fact that important decisions must be made although there is not yet much information available.

The decision-makers have to close the preliminary study phase by making an important decision. Plans that are not promising should be discarded as early as possible. In order to concentrate efforts, better solutions should replace less promising undertakings.

The purpose and the planning results of the preliminary study are characterised below:

Purpose:	The preliminary study is a process of clarifying the problem formulation and the objectives. Possible solutions must be developed to a sufficient degree and checked for feasibility so that the decision-makers can evaluate them and make a decision.
Result:	The result of a preliminary study is a concept i.e. a conceptual framework for a solution that must be worked out in more detail in a main study.

In practice the terms ‘pre-project’ or ‘preliminary project’ and ‘framework concept’ are used for preliminary study and concept respectively. The preliminary study is of special importance given the fact that at the beginning of a preliminary study the type and scope of requirements for a new or changed system are not always clear. Often only a few symptoms of a dissatisfactory situation, a possible threat or a clue of an opportunity are known. Moreover only vague objectives exist. The symptoms must be examined in context with their cause and the possible ways of their removal before the task for the system development can be described clearly.

These requirements are closely linked to the question of system boundaries, i.e. the definition of the system and the meta-system, as well as to the relevant aspects to be considered. The system approach has the tendency to expand the scope of the task. This is not necessarily always purposeful and needed. However in most cases a better co-ordination of different partial systems can be achieved through a more comprehensive systems concept. However, this is likely to increase time and money spent considerably while in most cases resources are limited and deadlines are tight. As a consequence the system limits for the next phases have to be fixed very carefully in the preliminary study.

In many undertakings the first planning step is taken in a careless and incomplete way. In this first planning step the required concept has to be developed ensuring that a basis for the planning exists or at least an orientation for the planning team is available in later stages. Practitioners often tend to underestimate the relevance of this step.

The quality of a preliminary study can be tested with these questions (Züst (1997)):

- Has the problem been defined clearly enough?
- Who is affected by the project and who is involved?
- Is the relation between the system and its environment clear?
- Are the options for systems design known and defined clearly enough?
- Is the client in agreement with the information from the above question?
- Are the requirements for problem-solving (objectives and general framework) clear?

- Is there an adequate overview of all potential basic solutions?
- Can the suitability/effectiveness of these alternatives be evaluated?
- Is it possible to make a decision for or against a certain alternative based on this evaluation? Can the decision be justified logically and understandably?
- Are all critical factors known?

When the project is finally approved the risk of the project being abandoned later on decreases while it cannot be completely eliminated. Even during the main study and sometimes even after several detailed studies it can become evident that the system development has to be stopped and no realisation should take place because of a better understanding or because a solution is already available.

Cross Reference to Cases in Chapter 9

In case B ‘Regional Communication Network in the Public Sector’ the preliminary study is carried out first. The most suitable solution concept has to be selected. Analyses are carried out in the system environment as well as with the different project partners.

In case C the preliminary study is playing a central role. At first the project scope comprises only the considerable reduction of production cost. The external consultant convinces the management of the company to re-position the product in the preliminary study. The relatively broadly planned preliminary study forms a basis for the development and implementation of effective measures for improvement.

Main Study

On the basis of the selected concept the design of the overall system is defined in more detail in the main study. The concept has to be developed further so it allows a sound assessment of the functional efficiency, the usefulness and the profitability of the planned system. Here the term concept is to be understood in an extensive way. Based on the status in the development phase this may be a plan, a verbal description, a design drawing or similar item.

The area of consideration is refined in the main study. The focus lies on the system itself. The environment is important in the sense that all positive or negative effects on the design of the concept have to be taken into account. Critical partial systems that are either especially important or that include an assumption that could later lead to difficulties in the detailed studies have to be brought forward at this point in time.

More detailed analyses of and concepts for important partial systems can be carried out in form of well-defined partial studies within the framework of the main study, in some extraordinary cases even during the preliminary study. Even if the results of partial studies make it necessary to abandon the project, this procedure has the advantage that it causes no or very little extra planning expenditure.

The result of the main study is the overall concept, which allows the further development and realisation in a well-managed way.

Purpose and results of the main study are characterised below:

Purpose:	On the basis of a selected (abstract) solution principle (concept) the main study refines the design of the overall system. Detailed gathering of information in regard to the necessary refinements is central for the main study. Additional alternative system design concepts must be developed and evaluated in regard to their functional efficiency, usefulness and profitability in order to make investment decisions possible.
Result:	The result of the main study is the overall system design. The overall system design provides the framework for further development and realisation.

The quality of the main study can be tested with these questions (Züst (1997)):

- Is the recommended overall system design convincing and realisable regarding functional, economic, personnel and organisational aspects? Are the necessary means and the organisational prerequisites known?
- Is there an overview of conceivable alternatives?
- Are the critical components known?
- Are the people concerned sufficiently integrated, consulted or informed about the search for a solution?

- Is the situation ready for a decision? Can the decision be accepted and justified internally and externally?
- Are the priorities known for the detailed studies and for the realisation?

Cross Reference to Cases in Chapter 9

Case A describes how Volvo dealerships in Switzerland implemented the requirements for improved ecological management. Initially the environmental management system according to the international standard ISO 14001 is introduced. The first step explains which concept is the most suitable one for small businesses: the environmental label. In the main study a specific environmental label for repair shops is developed. This concept proves to be the best for ecological and economic reasons.

In case B 'Communication Network' the Life Cycle Model is applied and the project is implemented in a methodologically consistent way. The concept for the communication network is developed as a main study and tested especially in functional and economical aspects.

Detailed Studies

In detailed studies subsystems of the overall system are temporarily selected to investigate certain specific aspects. Detailed solutions for all partial problems respectively their components are developed. Additionally all relevant information for the implementation of the solution is provided.

In a detailed study the area of consideration is narrowed down as much as possible. Furthermore it has to be taken into account that individual detailed studies can extend over several system levels. Therefore the detailed design of the overall concept can be accomplished in several partial steps while adopting alternately an overall, holistic and a detailed, structure-oriented perspective.

Purpose and planning results of detailed studies are characterised below:

Purpose:	Development of detailed concepts based on detailed, sound, evaluated information and partial concept alternatives. Additionally all relevant information for realising the overall system design is provided.

Result:	The results of detailed studies describe detailed solutions for partial problems. These might also include recommendations regarding the disposal of existing systems or elements.

The quality of detailed studies in this phase can be tested with the these questions (Züst (1997)):

- Do the detailed concepts meet the requirements set forth in the overall system concept?
- Can the detailed concepts be integrated into the overall system design concept? Do they provide the functions they were conceived for? Do the detailed concepts have characteristics that are unfavourable in view of the overall concept?
- Are the detailed concepts concrete enough to be realised?

3.1.2 Realisation Phase

The realisation phase covers the period from the beginning of the realisation respectively of the production to the initial deployment of the system (figure 3.5).

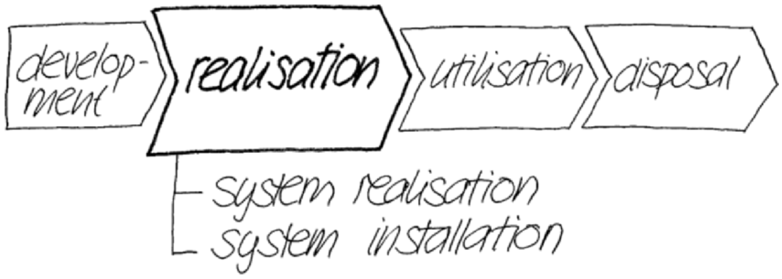


Figure 3.5. Position of the realisation phase in the Life Cycle Model.

System Realisation

The term system realisation signifies the realisation of a system. The system realisation can cover these tasks:

- production of equipment or machines

- in case of IT projects the programming including the documentation
- detailed preparation of organisational measures
    - User-oriented documentation, operating instructions
    - Definition of organisational requirements for users
    - Organisation of information flows
    - Definition of organisational rules for the case of malfunction or failure

Purpose and planning results of the system realisation are characterised below:

Purpose:	Acquisition or production of the individual components, systematic assembly of the system and preparation for system introduction.
Result:	A working system that is not yet deployed.

The creation or acquisition of further important hard- and software components, e.g. training materials, system documentation and user manuals is taking place in parallel to the production of the system itself.

System Installation

System installation means handing over the system to the user and explaining how it works and how to use it. With the appropriate preparation there is little risk in introducing simple systems as a whole while more complex systems are usually deployed according to a detailed implementation plan.

From the point of view of Systems Engineering, the system installation includes also final review of the Systems Engineering process and of the system. The achieved performance of the system, the accumulated expense, the development and the realisation has to be analysed critically.

Purpose and planning results of the system installation are characterised below:

Purpose:	Put the new system into operation and if need be dispose of the old system(s).

Result: The ready-to-use system is handed over to the system user.

After a successful handover of the system to the users the project is generally completed.

Cross Reference to Cases in Chapter 9

Case B describes the realisation phase. The decision favours an outsourcing alternative. The tender, the agreement with the supplier and the realisation are successful as a result of an elaborate 'Service Level Agreement'. The communication network can be deployed on time.

3.1.3 Utilisation Phase

System utilisation means the operation and administration of the system by the user. Service experience and wishes for changes are to be collected systematically and related to single system functions if possible. That way a basis is created for improvements of the system or for a new system design of analogue systems (figure 3.6).

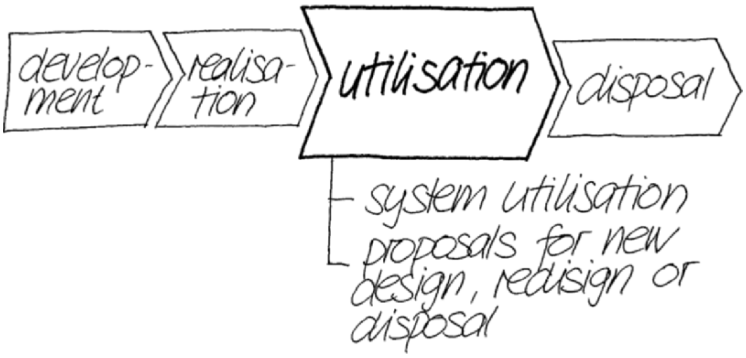


Figure 3.6. Position of the utilisation phase in the Life Cycle Model.

It can turn out to be necessary to install a suitable monitoring system for the utilisation phase. Certain parameters are to be defined and monitored continuously to help determine if the system is functioning properly or if there are deviations from the expected performance. Reasons for deviations can be attributed to either inadequate planning or to changes in use.

If the need arises for a re-design during systems utilisation that includes large changes or even a new design of the system this results in a proposal for a new preliminary study. For smaller changes there is no need to initiate a complete Systems Engineering process. Such adaptations can be done during systems utilisation and form part of this particular phase. To establish a procedure for adaptation requests helps collect faults purposefully and facilitates an orderly and co-ordinated re-design.

Purpose and planning results of the system utilisation are characterised below:

Purpose: Application and use of the system and monitoring of its performance while adapting its components if necessary. Raise decision-makers' problem awareness, readiness for re- or new design, and willingness to act.

Result: The system performs its foreseen function. In case of major problems the client might deicde to address the issue in the format of a new study at a certain point in time.

The decommissioning or disposal of an existing system is often related to a new design. To be able to carry out the disposal of as system seamlessly and without disruptions it needs to be planned properly. Considerations regarding the decommissioning have to be included in the design process of the new system.

3.1.4 Disposal Phase

The disposal phase covers the final disposal of a system. After the disposal phase the original system no longer exists. The professional disposal can be particularly problematic in cases of physical systems. For example, decommissioning obsolete production plants will possibly involve dealing with industrial waste deposits. It is advisable to divide the disposal phase into a planning and an implementation phase. In the planning phase the individual planning steps can be structured as in the development phase. Thus the incremental creation and elimination of alternatives in the planning of the system disposal is guaranteed. In the preliminary study for example solution principles for the disposal are developed. The most promising solution principles are mapped out in detail for the overall concept. Then the system can be (physically) decommissioned. The above procedure incorporates the heuristic principles ‘working from a general to a detailed perspective’ and ‘thinking in alternatives’ (figure 3.7).

Figure 3.7. Position of the disposal phase in the Life Cycle Model.

The original system no longer exists after the disposal phase. Individual components can be re-used in same or similar forms in other systems. For example production systems would be disassembled into individual machine components. Reusable system parts that have a certain value can be used in other applications. Parts and assembly groups that are interesting for recycling are recycled. What remains are often problematic materials that have to be treated separately at high costs. At best they are then ready for re-use or landfill.

Purpose and planning results of the disposal phase are characterised below:

Purpose:	Organised disposal of system
Result:	System is disposed of

The disposal phase should not only be the last task of the system life cycle, it should be part of the general system planning activities. Solutions for a possible system disposal should be considered during the development phase. There is ample literature on the topics of ‘Life-Cycle-Engineering’ or ‘Design for Environment’. For physical systems there are many methods and measures available for the planning and assessment of future dismantling, separating and reprocessing of systems and materials.

3.1.5 Activity Cycles within Individual Life Cycle Phases

A product is repaired many times during its utilisation phase (figure 3.8). Appropriate spare parts must be produced and integrated. Thus the lifespan of the product is prolonged. This task can be repeated periodically.

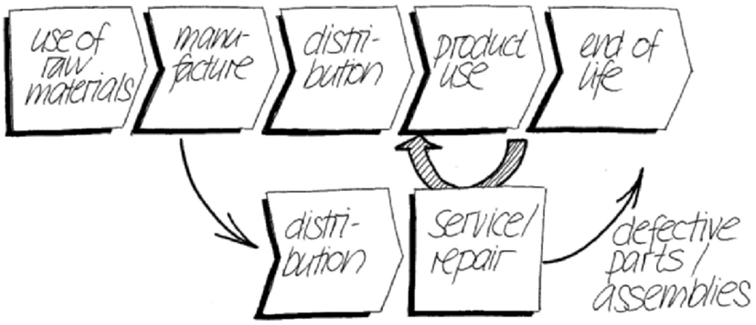


Figure 3.8. Cycles during a life phase with the example of a repair and service cycle (Wimmer und Züst (2002)).

A second possibility is to upgrade a system.

Example:

A company develops, produces and sells washing machines of high quality, good washing performance and long life span. The questions arise about how these machines can be adapted to trends or new performance requirements. The company decides to introduce a new generation of machines with modular structure. Thus it should be guaranteed that individual modules could be replaced by modern components when required (figure 3.9).

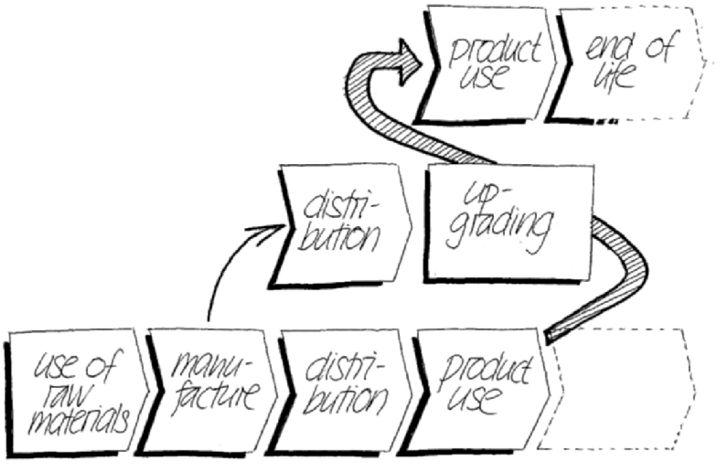


Figure 3.9. Example 'upgrades' (Wimmer und Züst (2002)).

> *The new modules are developed and produced at a later point in time. During the utilisation phase individual modules are replaced selectively and so the product is upgraded as a whole. Based on the original product a new product generation is created with other and extended functions.*

3.1.6 An Overview of the Life Cycle Model

The Life Cycle Model roughly divides projects and the creatin of a system into 'development', 'realisation' or 'production', 'utilisation' and 'disposal'. These main phases can be subdivided into individual partial phases (figure 3.10).

Proposal for systems design	Preliminary study	Main study	Detailed studies	Systems realisation	Systems installation	Systems utilisation	Proposals for new design, redesign or disposal	Disposal
Development phase				***Realisation phase***		***Utilisation phase***		***Disposal phase***

Figure 3.10. Division of the Life Cycle Phases in coarse and fine sections presented sequentially i.e. without showing the cycles that occur in its application.

Different specialised fields have established specific life cycle models. In addition many discipline specific technical terms are used for individual life phases.

In a business context it is not essential that all planning steps as displayed in figure 3.10 are carried out. If for example the solution principle is already known, the preliminary study can be skipped.

However the selected solution principle has to be assessed critically at the beginning of the main study. The same holds for the detailed studies.

3.2 Overview of the Problem-Solving Cycle

The Problem–Solving Cycle contains several steps and a whole spectrum of questions that are required to successfully turn an initial problem into an optimal solution (figure 3.11).

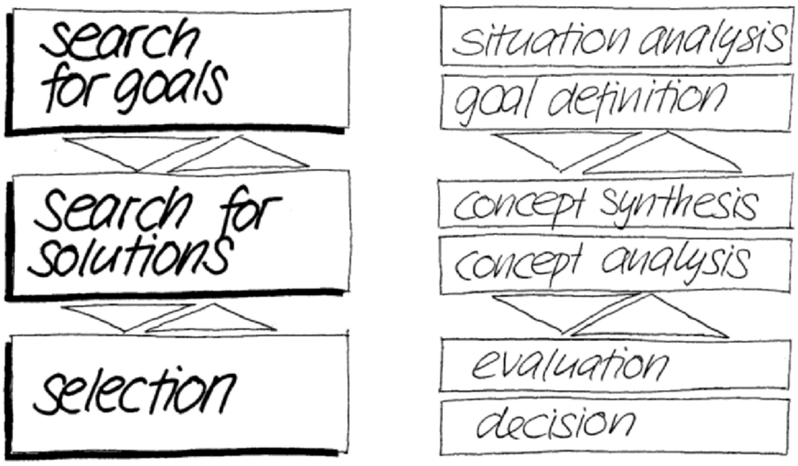


Figure 3.11. Problem-Solving Cycle as a recursive procedure of specific problem-solving steps.

The first step aims to clarify the given situation or problem. Values and preferences of the client or the decision-maker have to be defined explicitly. They are taken into account when searching for and selecting a solution. On the one hand, ‘goal definition’ is the basis for searching for solutions. On the other hand alternative solutions are assessed and selected relative to how they meet the defined goals. Solutions have to be designed and selected in a rational way and with regard to their consequences. Biased or preconceived notions of a desired solution or superficial answers to the symptoms instead of an analysis of the causes of the problem need to be avoided.

The problem-solving cycle is divided into three major and six minor steps respectively (figure 3.11):

- ***Search for objectives*** (Situation analysis and goal definition):
  What do we want to achieve?
- ***Search for solutions*** (Concept synthesis and concept analysis):
  What solution alternatives exist?
- ***Selection*** (Evaluation and decision):
  Which solution suits best?

The above description could leave the impression that the Problem-Solving Cycle is a linear development that has to be followed exactly in the way indicated. However, in practice, problem solving is much more cyclic; and it has to be cyclic since it often needs and relies on anticipating possible decisions in later steps. In many cases even multiple cycles are necessary (figure 3.12).

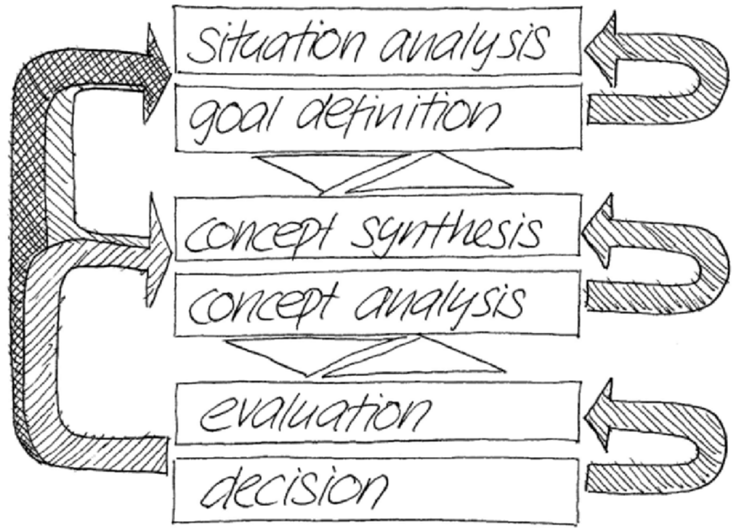


Figure 3.12. Cyclical processes of individual work steps within the Problem-Solving Cycle with major and minor cycles.

There is a difference in feedback from major and minor cycles (figure 3.12). The major cycles repeat previous steps or make theoretical assumptions of later steps. The minor cycles are feedback-loops within the major steps.

Cross Reference to Cases in Chapter 9

In real-world projects the Problem-Solving Cycle is used in multiple ways. Its application is described in chapter 9 in cases A and C. The individual steps are presented. Every step is based on the intermediate result of the previous step.

Part two of the book is dedicated to the detailed presentation of the Problem-Solving Cycle; the three chapters below only give a brief overview of the three major steps.

3.2.1 Search for Goals: Situation Analysis and Goal Definition

The search for goals consists of the situation analysis and the goal definition.

Four approaches that are closely related to each other are at the core of the situation analysis:

- A system-oriented view helps structure the problem area.
- A cause-oriented (diagnostic) view aims to understand the problem situation and its relevant context of cause-and-effect relations.
- A solution-oriented (therapeutic) view wich looks for possible solution and design alternatives. It is supported by the heuristic principle of ‘thinking in alternatives’.
- A fourth, future-oriented view is superimposed on these three views. It directs the perspective from the present to the future and addresses further potential developments.

The heuristic principles of ‘considering time-related changes’ and of ‘thinking in alternatives’ are essential to this first step. Additionally, the situation analysis defines the boundaries for the search for solutions.

The results of the situation analysis are the description of the structure of the system to be examined, the definition of its features, a list of already existing solutions, and a restatement of the problem (figure 3.13).

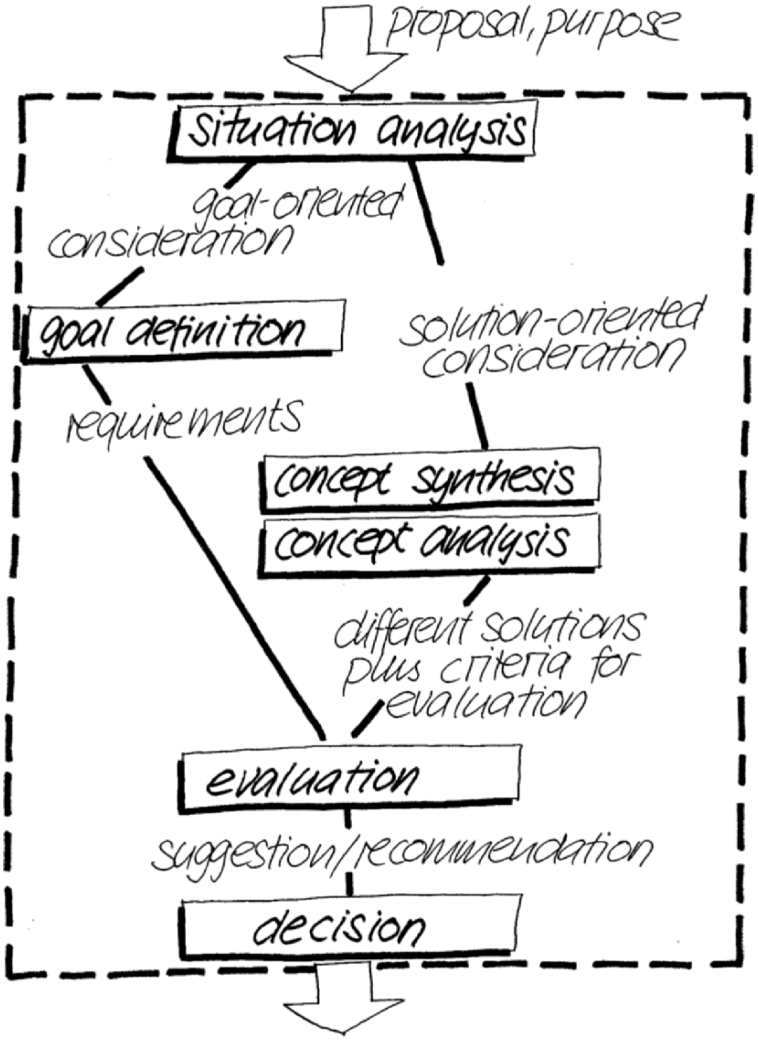


Figure 3.13. Problem-Solving Cycle with the corresponding information flow (Haberfellner et al. (1976), with adaptations).

The goal definition that follows the situation analysis (figure 3.13) requires systematic reflection on how to phrase the goals. Goals should be phrased neutrally, completely, specifically, understandably and realistically. Goals identified as mandatory are subsequently used to discern between feasible and impossible solutions.

The result of the goal definition is a well-phrased, significant and structured catalogue of requirements.

3.2.2 Search for Solutions: Concept Synthesis and Concept Analysis

The search for solutions consists of the concept synthesis and the concept analysis.

In the concept synthesis, solution alternatives are developed. The heuristic principle of 'thinking in alternatives' is put into effect. The description of the solutions should be detailed enough to allow to compare the alternatives. The individual solutions might need to be aligned to or integrated into an overarching concept.

In the concept analysis, each solution is scrutinized:

- Does the solution meet the mandatory goals (requirements)?
- Are the individual solutions complete?
- Are individual solutions functional?
- Does the solution cover all essential parts?
- Do effectiveness and (projected) performance of the solution meet the expectations?

Additionally the consequences of a specific solution have to be assessed as part of the concept analysis.

The result of the search for solutions is a list of alternative solutions that are evaluated in the next step.

3.2.3 Selection: Evaluation and Decision

The selection is the last step in the Problem-Solving Cycle and comprises evaluation and decision.

An evaluation of alternatives is only required when the optimal solution is not directly apparent. The evaluation criteria are derived from the catalogue of requirements, which is a result of the search for goals, and from additional criteria that may result from the search for solutions. These criteria allow the application of suitable evaluation methods. The evaluation results in a ranking of the alternative solutions, recommendations for a decision, and an appraisal of any future steps to be taken. Now the decision-makers can be made their decision.

3.2.4 Concluding Remarks on the Problem-Solving Cycle

The Problem-Solving Cycle describes a sequence of steps that logically build on each other. The work is done cyclically and simultaneously if possible. The results of a Problem-Solving Cycle form the basis for subsequent planning or realisation phases.

The steps of the Problem-Solving Cycle are described in further detail in part two, chapters 5 to 8.

3.3 Interaction of the Problem-Solving Cycle and the Life Cycle Model

In every phase of the Life Cycle Model usually a large amount of tasks and sub-tasks have to be handled. This requires a co-ordination of the corresponding problems and their Problem–Solving Cycles that have to be processed in parallel, ideally by different teams. This co-ordination is marked in figure 3.14 with a double arrow.

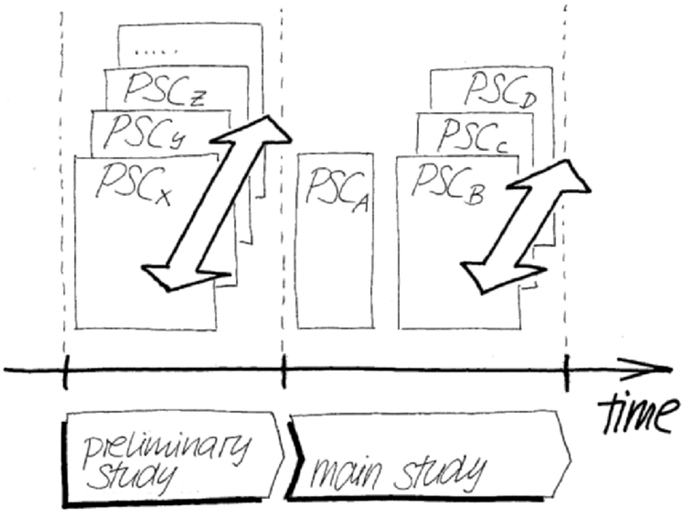


Figure 3.14. Co-ordinated parallel processing of tasks in different phases of the Life Cycle Model.

Example:

The existing airport in a large city has three problems. It produces a lot of noise, it has too little capacity, and there is no room for further housing development in the area. So the city plans to build a new airport (figure 3.15).

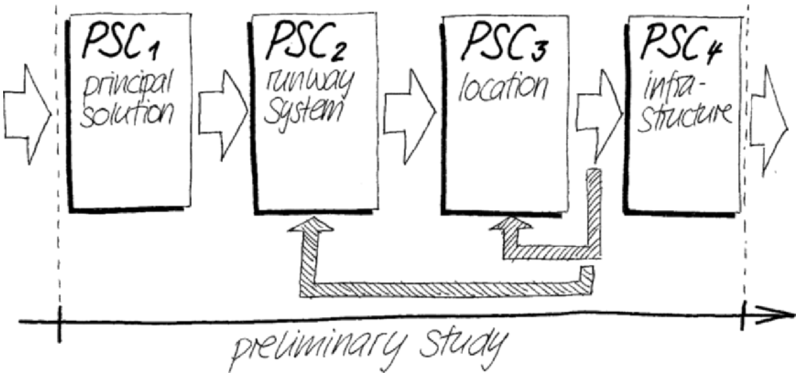


Figure 3.15. Parallel problem processing.

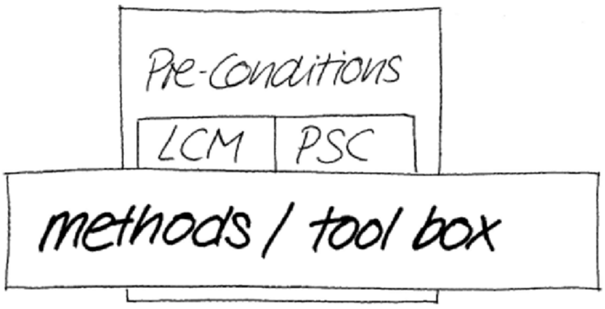
The project leader decides to address four questions in the preliminary study (Figure 3.15):

- *What is the basic solution concept (leave the location as it is; expand old location; search for new location)?*
- *What is the runway system (number and order of runways)?*
- *What new locations are possible?*
- *What is the 'infrastructure' of the airport?*

The Problem-Solving Cycles corresponding to the four planning questions are closely related and have to be dealt with in parallel.

The interaction between the Life Cycle Model as macro strategy and the Problem–Solving Cycle as micro strategy is central to Systems Engineering.

4. METHODS – INTERDISCIPLINARY UNIVERSAL TOOL BOX



Systems Engineering is using a wide range of disciplinary and interdisciplinary methods and tools within the concrete problem-solving process.

4.1 Search for Methods

There are an immense number of methods in each area of expertise. A method recommends a course of action to achieve a defined objective. By definition methods are abstractly formulated. They do not relate to a specific case but refer to a certain type of problem situations and desired transformations. Schregenberger (1982) distinguishes three categories:

1. Algorithms that are logically and reliably leading to achieve an objective, for example mathematical operations.
2. Techniques that practically and reliably leading to achieve an objective, for example static calculation methods.
3. Heuristics as rules of thumb that are likely but not reliably leading to achieve an objective (see also Dörner and Tisdale (1993)).

In practice it is difficult to find the ‘right’ or ‘correct’ methods in early phases of planning and decision-making processes, particularly when there is little knowledge about the problem. Basically there are two possibilities to find appropriate methods, literature research and asking experts. Technical literature contains collections of methods that are regularly used in the area of system design. For example Haberfellner et al. (2002) list more than 100 methods that are frequently used in everyday planning life. For more specific problems it's worthwhile to ask an expert because each field of expertise has its own methods. The advantage of asking an expert is that the application of the method can also be discussed so misinterpretation and application errors can be avoided.

The collection of methods applicable to interdisciplinary problems is extremely large. New methods are constantly being developed and applied in practice. During the problem solution process methods have to be evaluated continuously to find the most efficient method for the actual planning activity.

In the last 30 years different collections of interdisciplinary methods to deal with certain problem categories and problem solving steps were published. Below we list some examples:

- Chestnut (1967): Emphasis on the modelling and simulation of systems
- Geschka (1983): So-called 'creative' methods to the solution search
- INCOSE's collection of methods (see: www.incose.org)

Every selection of methods is subjective. Nevertheless the above authors try to offer a representative selection of frequently used interdisciplinary methods in the context of Systems Engineering. Some particularly important methods are discussed in the next few chapters.

4.2 Selecting a Suitable Method

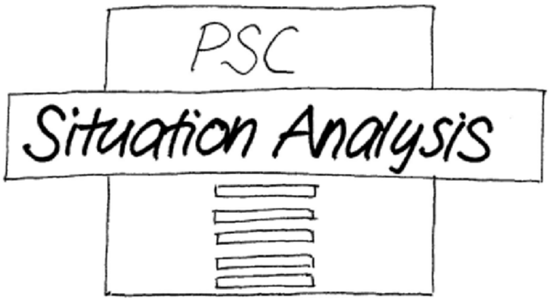
In the context of problem solving the question arises again and again what methods are suitable for a certain planning step. Schregenberger (1997) and Züst (1997) suggest considering the questions below when evaluating suitable methods:

- What is the purpose of the method? Who is the author? What aspects of the problem can the method cover (degree of abstraction)?
- What are the context-related constraints for the application of the method (for example society or cultural context)?

What conditions apply to their application and does the current application meet these conditions?

- Can the method be used for the problem in consideration? What restrictions have to be made, if any at all?
- What limiting factors do exist if this method is applied? How will they affect the result?
- What significance do the results have? What uncertainties does the method contain?
- How much does it cost to apply the method? Is this expenditure justified?
- What measures support the application of the method?
- Does the data exist which the method requires? How can it be established? What uncertainties are included in the data? Are expenditure and return well balanced?

5. SITUATION ANALYSIS



The situation analysis is the first step in the Problem-Solving Cycle (PSC). It is the systematic assessment of a situation. The results of the situation analysis are used to formulate goals and to search for solutions.

The situation analysis comprises of a systematic analysis, of a description of intervention possibilities and measures, and of establishing the information needed for the next steps. The situation analysis is divided into:

- task analysis,
- analysis of the current state,
- analysis of the future and
- summary of the problem and identification of actions to be taken.

At the same time ideas for solutions are collected and documented so they can be used in the concept synthesis step of the Problem-Solving Cycle.

Depending on the problem the different steps of the situation analysis can gain different importance. Therefore the general procedure outlined below will have to be adapted to the specific problem or situation. The individual steps of the situation analysis are described below.

5.1 Task Analysis

In any project the initial question is ‘what is the task?’ and not ‘what is the problem?’ The task analysis has to examine the client’s motives and expectations (figure 5.1).

Special attention must be paid to any partners and participants in the project. Only through making enquiries a holistic view of the initial situation can be found. In particular it has to be established whether the problems specified by the client are only symptoms of a more comprehensive problem. This could lead to an extension of task.

- *analyze and question the task,*
- *identify important aspects of the existing system,*
- *establish the origin of the task,*
- *describe the system to be examined verbally,*
- *determine the degrees of freedom of the task,*
- *determine important influencing variables and constraints,*
- *clarify unclear terms,*
- *identify important aspects for the next steps,*
- *identify interfaces to other projects and plans,*
- *describe expected benefit,*
- *identify existing requirements,*
- *determine type and form of expected results,*
- *define project boundaries,*
- *designate project managers and project team,*
- *describe milestones,*
- *define the type of intermediate and final decisions,*
- *fix dates and deadlines,*
- *calculate expenditure in money and working days,*
- *designate the members of the project committee and of the decision-making body respectively,*
- *name contact persons outside the project team,*
- *collect information about similar projects already implemented.*

Figure 5.1. Steps of the task analysis.

The need for a task analysis is illustrated in the following example:

> *An engineer is tasked to investigate in a two-month preliminary study what the relevant environmental impacts of the production plant X are and how they could be reduced systematically. At first it remains unknown to the engineer where this task originated from. There could be various reasons for this study:*
>
> - *The production plant X does not fulfil certain environmental regulations. The plant therefore risks to be closed down. In this context improvements to the products and processes had to be developed that could be realized rapidly. Additionally it would probably be appropriate to include the relevant authorities in the problem solution process.*
> - *The ISO 14001 standard 'environmental management systems' (see: ISO 14001 (2004), ISO 14004 (1996)) and its implementation in the company is regarded as key to future success. Therefore the engineer has to examine in the preliminary study which measures are required for the introduction and certification of an environmental management system. For this purpose the important environmental aspects of activities, products and services have to be identified, and the process for a constant improvement of the environmental performance has to be started.*
> - *There could be an obligation to take back the products as waste and the associated disposal costs could be extremely high. Probably the product itself and the logistics for taking back the product were designed improperly. Future products would have to be improved to allow subsequent take-back, disposal or recycling. Optimal ways to dispose of used products have to be defined.*

The example shows clearly the importance of the task analysis for a systematic problem solving process. Depending on the reason behind it, the project will take a different course. Therefore it is crucial to establish the motives and reasons for carrying out a particular project. It might even be necessary to investigate additional aspects. In practice task analysis often does not get enough attention. Yet, a task analysis helps define content and objectives of a study and refine them where appropriate. A careful task analysis saves trouble later.

5.2 Analysing the Current State

After the task analysis a critical evaluation of the current state is desirable. It usually comprises of these steps:

- demarcate the system from its environment,
- analyse the system and the relevant areas of the environment,
- identify strengths and weaknesses of the system
- analyse cause-and-effect relationships

The individual steps of the current state analysis are described below. Because the system demarcation has a crucial influence on the problem solving process this step is covered more extensively.

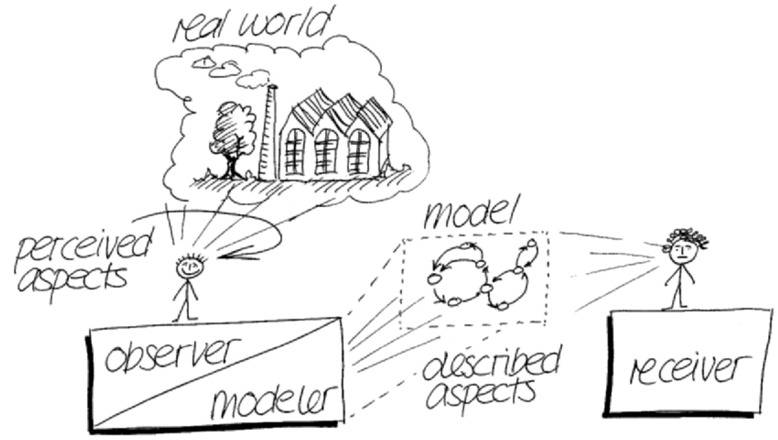


Figure 5.2. Relations between subject (observer, modeler), material world and model (according to ISOTC 184/SC5/WG1 (1994)).

5.2.1 Demarcate the System from Its Environment

Facts, or ‘the reality’, can be seen from a structural, functional or effect-oriented perspective and they can be modelled as a system. ‘Models are abstractions and simplifications of the reality and therefore only point out partial aspects. Therefore it is important that the models are appropriate to the situation and the problem definition. That implies that for all considerations, the questions of appropriateness and problem relevance have to be raised.’(Haberfellner et al. (2002)).

Models are the basis of all forms of communication with oneself and others (figure 5.2). In principle human beings think in models.

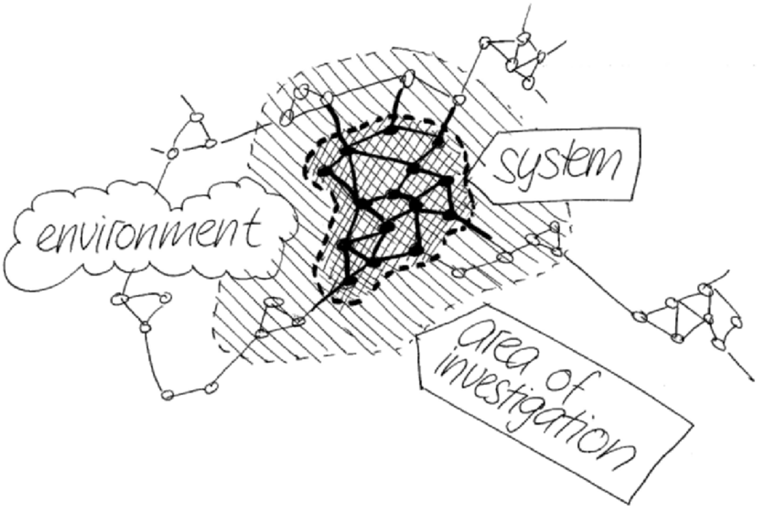


Figure 5.3. System, environment and area of investigation.

Demarcating the system is defining the boundaries of that part of the material world that needs to be considered, and establishing how its structures and functions – in accordance with the task – can be changed or stabilized. Three important terms have to be distinguished (figure 5.3):

- ***System:*** The ‘system’ comprises the area where in the context of the given tasks, interventions and changes are possible and where they have to take place.
- ***Environment:*** The real world outside the defined system.

- ***Area of investigation:*** The examined area covers the system and the areas of the system environment that have important relations to the defined system and are therefore relevant for the task (figure 5.3).

Cross Reference to Cases in Chapter 9

The system demarcation and the analysis of the influencing variables are closely related to each other. Case A in chapter 9 shows which areas of the environment are related to the system and which external elements affect the system.

In practice it is not unusual that the system demarcation is not done systematically even though this would specify a substantial part of the scope of the project and thus also restrict or extend the range of potential solutions. Therefore it proved to be useful to answer these questions:

- Where are interventions and changes possible? What degree of freedom exists? In which areas are changes conceivable?
- What functions does the system have to control? What structures are present?
- What authority does the client have? Does it correspond to the system boundaries?
- Does an extended system demarcation have to be considered?
- What influencing variables affect the system? Which ones are relevant for the task?
- In what areas do changes in the system design change the environmental effects? What quality do they have? Which ones are relevant?

An example should illustrate the above list of questions:

> *A local authority has to improve their system of kerbside waste collection and kerbside recycling. Figure 5.4 shows the system demarcation specified by the planning team.*
>
> *The system covers areas where the local authority can make improvements to the management of the flow of materials. They can for example review and extend the local waste regulations, they can change the way they communicate waste and recycling issues in order to educate the*

public, or they can change the financial regime of waste collection through fees and incentives. They cannot directly interfere with households and individuals. However, they can influence individuals and their behaviour by a suitable system design.

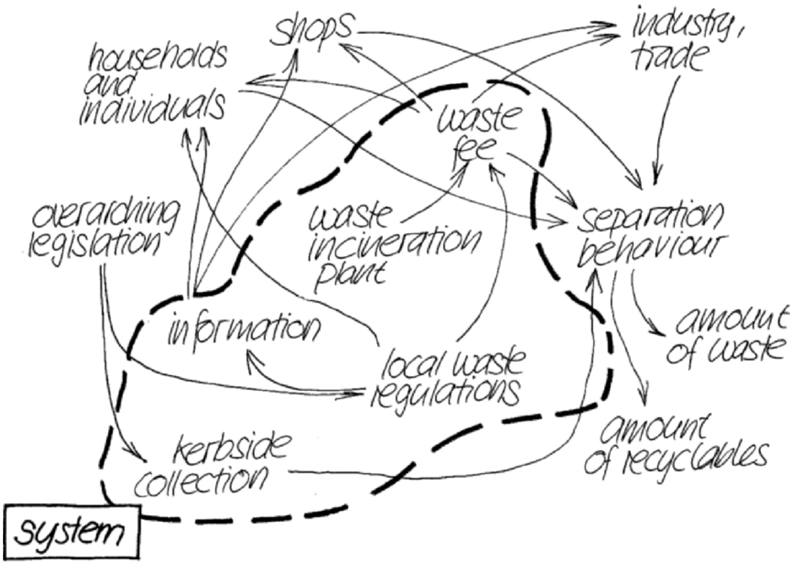


Figure 5.4. The system of kerbside waste collection and kerbside recycling of a local authority (according to Caduff and Frei (1992)).

The environment refers to everything that is outside the defined system. Relevant areas that have relations with the system are for example the different sources of waste or overarching legislation. They might influence the introduction of new waste collection fees but they cannot be changed since they are outside the scope of reorganising kerbside waste collection.

But it is also important to realize which intervention possibilities realistically exist for the system designer given the time, personnel and financial constraints.

The system demarcation and particularly the definition of the intervention area determine what can be changed in the project. Thus the solution space is fixed at the beginning of the project. If the system boundaries are too narrow, possible solutions might be excluded from the beginning – intentionally or unintentionally. An example might illustrate this:

> *A local wastewater treatment plant does not meet the current legal requirements any longer. Therefore a refurbishment is required. The local authority tasks its head engineer to develop an adequate concept. Depending on the system demarcation different solutions can be developed:*
>
> - ***narrow demarcation:*** *The engineer is only in charge of the technical system, i.e. the local wastewater treatment plant. The solution space will only contain technical improvements to the existing plant.*
> - ***wide demarcation****: The engineer checks the whole sewer and wastewater treatment system including the relevant regulations and fees of the local authority. Apart from the technical improvements, he also has to study the sewage regulations or the possibility to adopt or change of local sewer fees. Here the system goes far beyond the wastewater treatment unit. The behaviour of the public, for example depending on regulations and fees, becomes part of the study.*
> - ***very wide demarcation****: A common wastewater treatment unit shared by several smaller local authorities would be a possible solution because many small plants have the disadvantage that they can not be operated efficiently due to economic and ecological reasons. Here the system demarcation covers the sewerage and wastewater treatment systems of several local authorities. It would have to be established if this system demarcation would lead to realistic solutions at all.*

It is often advisable to demarcate the system together with the client. In practice it is important that relevant areas in the environment and their dynamics are recognized. The example in figure 5.4 shows for example that the changed waste separation behaviour of households or the tightened waste regulations have to be taken into account in the planning process.

There are no commonly accepted rules for system demarcation; however some rules of thumb may give some general guidance:

1. System boundaries are usually set similar to geographic/ regional boundaries. Possibly these do not coincide with the area of activity of the system.
2. Since neither problems are sharply defined nor effects of possible interventions are clearly foreseeable at the beginning of a system design, demarcation should be wide initially. Within each planning step the demarcation has to be reviewed critically.
3. The heuristic principles of the 'black box', of 'adopting different points of view' and of 'creating a hierarchy' can improve the process of the system demarcation substantially. They are therefore briefly described below.

Black Box:

A system is treated as black box. Either its structure is not (yet) known or it can be abstracted because it is not essential for the evaluation or the design. A black box can possibly contain a highly complex structure. If a system is treated as a black box, all statements concerning its structure, i.e. the elements and their relations to each other, are still open (figure 5.5).

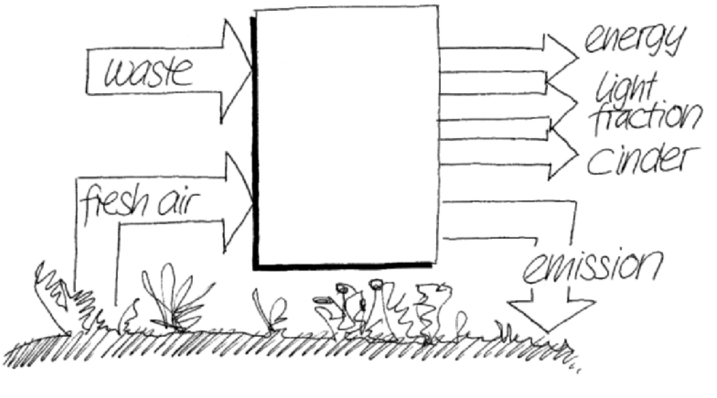


Figure 5.5. Example of a black box view of a waste incineration plant.

The main advantage of the black box method is that its application brings a considerable reduction of complexity right at the first step. At the same time it directs the view to the system and avoids preoccupation with details.

Adopting Different Points of View:

When analysing systems it helps to examine a system from various aspects, or ‘points of view’ (figure 5.6). Subsequently these points of view can be combined in a suitable way to build a whole picture.

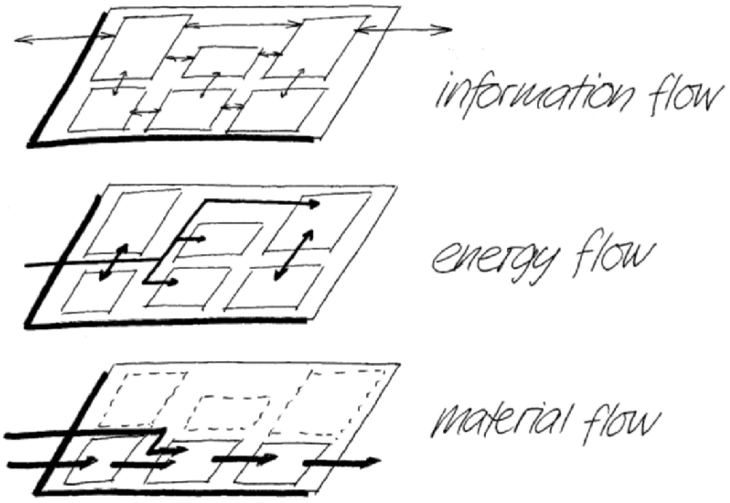


Figure 5.6. Example of a point of view approach.

The same elements and possibly the same relations can play different roles when seen from different points of view.

System Hierarchy:

The system to be designed is initially considered as a black box on the highest system level S(0) (see figure 5.7) and then the resolution is gradually refined. In case of a certain resolution (-i) the system shows a characteristic structure S(-i).

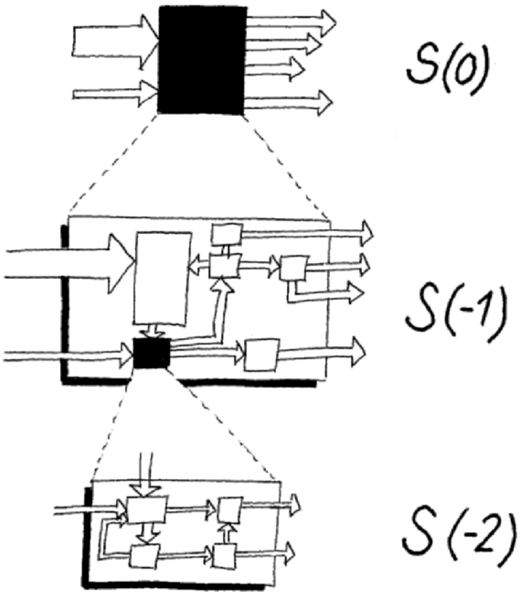


Figure 5.7. Example of a system hierarchy, gradually increasing the resolution and thus the differentiation of its internal structure.

5.2.2 Analysing the System and Relevant Areas of the Environment

The second step of the current state analysis after the system demarcation is the systematic analysis of the system and the relevant areas of the environment. The system and the relevant areas of the environment are to be analysed regarding their structure and their functions. These analyses, i.e. gathering the related information, require suitable surveys (interviews and questionnaires), observations (participating observation, work process analysis, activity sampling) and desk research.

An interview always carries the risk that the persons interviewed deliberately or inadvertently bias their statements. Developing an interview questionnaire is not unproblematic. The effort for the preparation of the questions and for the evaluation of the answers should not be underestimated. The interviewer should therefore follow adequate rules (figure 5.8).

Guidelines for of Interviewing:

- develop a catalogue of keywords
- if ever possible conduct the interviews in a familiar environment
- be friendly and show good manners
- describe the objective of the interview and set a time-frame
- keep the duration of the Interview to max. 1 hour; if necessary continue at a later point in time
- create a relaxed atmosphere in the introduction phase
- in case of a longer interview intentionally mix in soft phases, e.g. issues not connected to the problem
- do not take a position during the interview
- end the interview with a positive final note to create a basis for future talks

Questions:

- motivate readiness to provide information by general questions
- ask short and simply worded questions; a question should not refer to several issues at the same time, ask matter-of-fact questions first
- do not raise suggestive questions; the interview should provide new information and should not confirm the opinion
- ask provocative questions only in exceptional cases, remember an interview is not an interrogation
- treat information confidentially and do not repeat opinions from other interviews
- ask control questions: are the declarations of the interviewee free from contradictions? Do their statements confirm other's?
- approximate quantities
- do not rush the interviewees and listen attentively

Figure 5.8. Guidelines for an interview.

Dealing with the information from an interview:

- Record the interview directly using recording equipment (e.g. mp3-recorder) and transcribe it verbally. You need explicit approval of the interviewee, get the approval when you fix the appointment for the interview.
- Note down keywords immediately after the answer (arrange this with the interviewee).
- Evaluate the answers directly during the interview by filling in a prepared form or classification diagram (field assessment)
- Document the interview from memory (not advisable)

Figure 5.8 (cont.). Guidelines for an interview.

In 'participating observations' the observer tries to detect the problem by getting involved and taking part in the situation. An observer whose task is to find out the weaknesses of an in-plant transportation system could for example work in the department for a few days.

Business process analyses are well suited for observation and documentation of a detailed sequence of activities. The results yield qualitative, structural information and are typically represented graphically. They can be supplemented with quantitative data from full-time or sampling observations (e.g. time studies or activity sampling).

Apart from surveys and observations it is also useful to analyse secondary data (desk research). Desk research can draw from a variety of sources of information:

- list of projects and their budget
- annual report including evaluation of the management of the company
- documentation and records of control data and corrective actions (monitoring data)
- literature research (technical literature, journals, Internet, …), …
- …

The result of these analyses is information about the structure, the functions and the impact of the system as well as its interaction with the relevant areas of the environment. These insights are systematically evaluated in a next step.

5.2.3 Identifying Strengths and Weaknesses of the System

Recognizing strengths and weaknesses requires knowledge about desired operations and conditions. In the operational context this information is usually available. It often already exists before the start of the study. Sources for this kind of information are vision, mission and strategy statements of the company, constraints identified in past investigations or defined at higher-order problem levels, insights from empirical investigations, theoretical considerations and intuitive expectations.

> *Example:*
>
> *In a preliminary study a company checked if they met the requirements of the ISO 14001 standard 'environmental management systems' (ISO 14001 (1996)) and they investigated what measures were needed and suitable to achieve certification within the next twelve months. General objectives in regard to a qualified environmental management system are specified bindingly in the standard itself and in the ISO 14004 standard 'environmental management system – general manual about principles, systems and auxiliary instruments '(ISO 14004 (1996)). This was the result of the analysis of the current state:*
>
> 1. *The production plant has motivated employees.*
> 2. *The employees are neither sufficiently educated in nor aware of environmental issues.*
> 3. *The company has an effective recycling procedure in place. Recyclables are collected separately and shipped for recycling.*
> 4. *Completely missing are any preventive environmental procedures which are required for the design of activities, products and services.*

The results of the current state analysis can now be summarized in a table (figure 5.9).

	Evaluation					Comments
	–	-	+/-	+	++	
Motivated employees					**X**	Employees are motivated above-average
Knowledge about environmental requirements of their own activities	**X**					No specific environmental knowledge
Internal collection system of recyclables					**X**	All production waste is collected separately
Preventive environmental protection, especially in regard to the own products	**X**					Not existing

Figure 5.9. Example of an analysis of strengths and weaknesses of a production system relative to the requirements of ISO 14001.

An analysis of the strengths and weaknesses is well suited to deliver a better understanding of the results of the analysis of the current state, for example in the context of an intermediate presentation to the project team and the client.

To determine the strengths and weaknesses it is necessary to have some ideas of an ideal state. These ideas will be reflected in the later steps of the Problem-Solving Cycle, particularly the goal definition. So the analysis of the current state forms the basis of the problem solving cycle.

5.2.4 Cause Analysis

The cause analysis concludes the analysis of the current state. When searching for the causes and effects in complex systems preconceived notions of linear cause-and-effect relationships are not valid.

Example:

A manufacturing company has high manufacturing and disposal costs. A project manager is tasked to develop proposals for more cost-effective manufacturing and an improved disposal system.

After only a short time it becomes evident that how the company uses its production facilities and how its organisation is structured prevent a more economical manufacturing strategy. A first solution could combine segmentation of the production with new production equipment. A reason for the high disposal costs could be that there is no strategy for taking back products.

The project manager continues the analysis. He is intrigued by various questions: Why does the company have to collect, dismantle and dispose of the products itself? Why can't this happen in direct proximity to the customers' premises? Why is there a need for new production equipment when manufacturing costs are already high? What are the actual causes for the high costs?

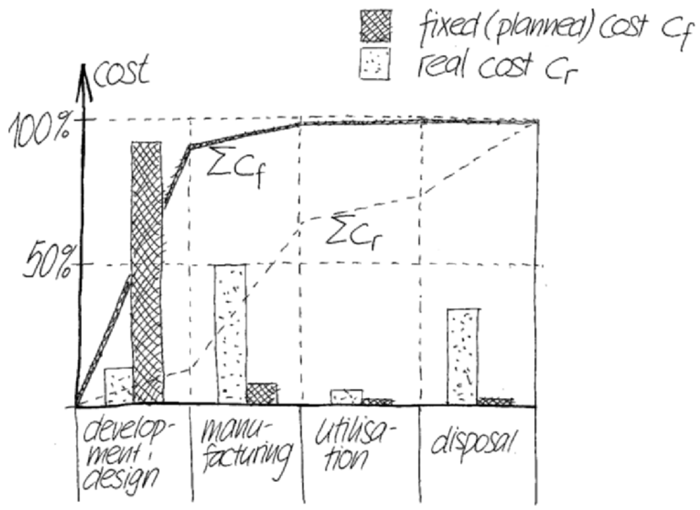


Figure 5.11. Pre-determined and accrued product costs (Züst and Wagner (1992)): Extensive planning and decision-making in the development phase determine the further product life to a large extent – and thus also its costs.

Investigating these questions, the project manager finds that the actual causes are outside the control of manufacturing since ninety to ninety-five per cent of the entire product life costs have already been determined during the development of the products (figure 5.11).

To lower the costs effectively, product development has to be included in the project. Therefore the system boundaries have to be extended accordingly. This is a change to the objective of the project that has to be agreed with the client, and the project manager has to be given the authority to work on the extended project. Extending the system boundaries also requires planning decisions to be revisited and changed if necessary.

It usually makes sense to present the results of the cause analysis together with the strengths and weaknesses. The presentation of the strengths and weaknesses is thus supplemented by additional information on underlying causes (figure 5.12).

	Evaluation					Comments	Cause
	−	−	+/−	+	++		
Motivated employees					**X**	Employees are motivated above-average	Payment by results
Knowledge about environmental requirements of their own activities	**X**					No specific environmental knowledge	No training measures in the framework of the environmental management system
Internal collection system of recyclables					**X**	All production waste is collected separately	Realised measures in the framework of the environmental management system
Preventive environmental protection, especially in regard to the own products	**X**					Not existing	Ecodesign is not yet a question in the framework of the environmental management system

Figure 5.12. Strengths and weaknesses of a production system complemented with the respective causes.

5.3 Analysis of the Future

‘It is the business of the future to be dangerous’ (proverb). In the planning process it is important to recognise opportunities and threats emerging from changes in the underlying system or from trends in the environment. Identifying opportunities and threats is particularly relevant as it informs the goal definition and the search for solutions.

Future developments and their impact on the existing and the future system have to be evaluated carefully (figure 5.13).

The analysis of the future consists of three parts:

- predict the behaviour of the relevant areas of the environment
- predict the behaviour of the system without additional interventions
- summarise the results as an analysis of opportunities and threats

Below these three parts of the analysis of the future are described.

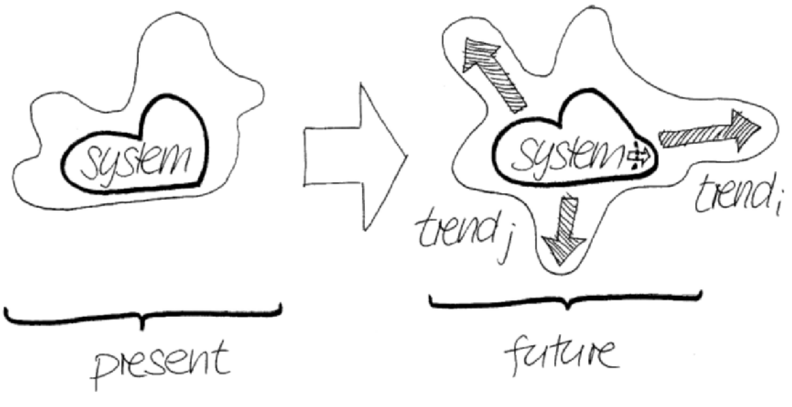


Figure 5.13. Analysis of the future: Changes happen within the system as well as in the environment.

5.3.1 Predicting the Behaviour of the Relevant Areas of the Environment

As part of the analysis of the future the planner intends to assess future developments and trends in the environment. Forecasts and scenarios are often derived from past or present developments, facts and figures since certain changes do not occur erratically or chaotically, but gradually or periodically.

In the following four forecast methods are briefly characterized:

> ***Survey:*** A survey gathers information about knowledge, opinions, desires or intentions of a certain group of people (consumers, citizens, the electorate, the sales force ...). Typical survey instruments are standardized interviews or questionnaires. A repeated survey of the same group of people is called a panel survey.
>
> ***Scenario writing*:** Scenario writing describes several future developments and the consequences of likely future events. The objective is mainly to point out those turning points where fundamental decisions have to be made. Generally, scenario writing comprises of a best, a worst and an average scenario alternative.
>
> ***Delphi method:*** A group of experts, who do not have to have any contact with each other, are asked for their opinion about certain topics in several consecutive rounds. The results from one round – average answer and extreme single opinions – are made available to the participants in the next round. Thus the opinions converge and can be consolidated to representative statements. The Delphi method is a structured group survey where no direct communication of the participants takes place. Therefore problems with group dynamics are substantially smaller than with an open panel discussion.
>
> ***Extrapolation of time series:*** Time series have the form of $y = f(t)$. The time t is the independent variable and y is the dependent variable, i.e. the parameter to be predicted. This method of extrapolating trends uses only data of the dependent variable. It is based on the assumption that trends can be derived from past developments and that they can be projected to the future using simple extrapolation tecniques. Predictions based on such a basic concept essentially rely on

the historical analysis of the process and the assumption that future developments will be analogous to the past.

The more uncertain prognoses are, the more crucial it is for the system designer to agree with the client the important key assumptions and fundamentals as well as the objectives for building the new system. The undisputed advantage of quantifiability of mathematical prognosis procedures should not tempt us to be limited to such procedures.

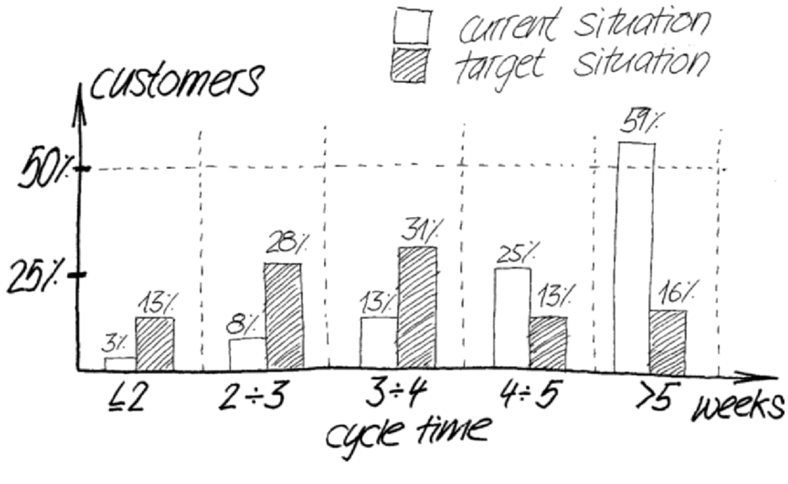


Figure 5.14. Present cycle times and future requirements from the customer's view (time horizon of five years), (Roessle (1995)).

Example:

Predicting customer behaviour is an interesting task in e.g. the supply industry's analysis of the future. For this purpose an extensive customer opinion poll has been accomplished to establish the customers' future expectations of cycle time.

Figure 5.14 shows the findings of the customer opinion poll. It shows clearly that cycle time is an important future success factor for the supply industry. The more flexible an enterprise is, the better it can handle short-term orders,

> *which tend to be better paid for. In the future a company in this supply industry can only survive if it can reduce its cycle times drastically. This statement is extremely important for the goal definition and the following search for solutions.*

5.3.2 Predicting the Behaviour of the Existing Systems

The next step of the analysis of the future refers to the system itself. It is about the future behaviour of the system. Prognoses are necessary here as well. They will be accomplished in the same way as described in the chapter above.

Information about the future behaviour of the existing system has to be compared to the predicted behaviour of the relevant areas of the environment in the next planning step.

5.3.3 Analysis of Opportunities and Threats

Using an analysis of opportunities and threats, the impacts a changing environment has on the system can be studied in a clear way. How exactly opportunities and threats can be determined is illustrated below using the example of the supply industry again.

> *Example:*
>
> *If a supply company maintains their long cycle times and the customers suddenly require much shorter cycle times this becomes a dangerous situation (figure 5.15).*
>
> *If pre-qualification, e.g. based on quality certificates, becomes more common in the future, having such a‘quality is an opportunity (figure 5.15).*

The presentation of opportunities and threats can be supplemented – just like the presentation of pros and cons – by a further column in the table with the appropriate underlying causes.

So for example anticipating future market requirements, long cycle times could represent a threat. The reason for this could be the manufacturing strategy (figure 5.15). Possible actions are derived from these considerations.

	Possible future changes in the environment	Evaluation					Arguments for the evaluation	Underlying causes
		−	−	+/−	+	++		
Cycle time	Customers require short delivery time, e.g. max. 5 weeks	**X**					Current cycle times with around 8-10 weeks clearly too long	Manu-acturing strategy
Pre-qualification	Customer expects quality and environmental certificates (ISO 9001, ISO 14001)					**X**	Quality and environmental management system already exist	Management systems implemented and certified
…….	……..				**X**			………

Figure 5.15. Excerpt from the analysis of opportunities and threats for a company in the supply industry.

5.3.4 Systematic Evaluation of the Analysis of Strengths, Weaknesses, Opportunities and Threats

The results of the analyses of strengths and weaknesses and of opportunities and threats can be processed in different ways. Below we present two possibilities.

Portfolio Analysis:

A portfolio analysis is one way to jointly present the analysis of the current state and the analysis of the future. In the early 50s the basics for the portfolio method were developed for and applied to the optimisation of investments on the stock market. Stock certificates with high risk and expected high returns were balanced with stock certificates with low risk and expected low return.

Twenty years later the Boston Consulting Group developed the portfolio matrix as a two-dimensional representation o this analysis (figure 5.16). The vertical axis stands for the success factors of the environment as for example market growth. The horizontal axis stands for the company related evaluation, e.g. market share.

The portfolio matrix, as shown in figure 5.16, contains insights found in the analysis of the current state and of the future. The portfolio matrix was further developed in the last 30 years and is used today in different variations and professional areas.

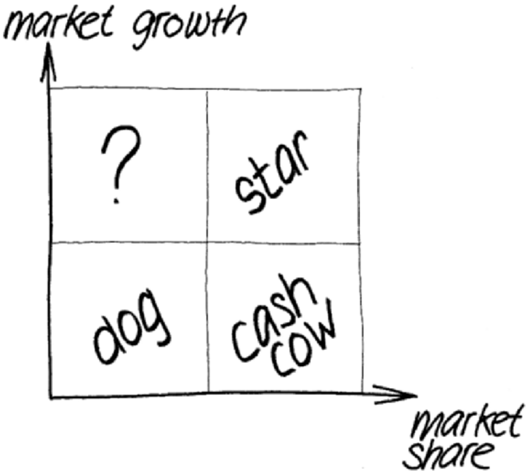


Figure 5.16. Portfolio matrix of the different products of a company: The vertical axis shows the market growth (possible future developments) and the horizontal axis represents the relative market share (own strength).

SWOT Analysis:

The so-called SWOT analysis is another possibility to evaluate results and evaluations from present and future-oriented views. SWOT stands for Strengths, Weaknesses, Opportunities and Threats.

In an SWOT analysis the strengths and weaknesses as well as the opportunities and threats are listed in a matrix vertically and horizontally, respectively (figure 5.17).

Based on a SWOT analysis you can examine how the individual strengths and weaknesses of the system interact with the opportunities and threats of the future. Strengths and weaknesses and opportunities and threats that have the same cause most likely need similar or the same actions.

The four fields in figure 5.17 also represent the following basic strategies (clockwise from top left):

- build on strengths and use opportunities
- build on strengths and minimize threats
- repair weaknesses and minimize threats
- repair weaknesses and use opportunities

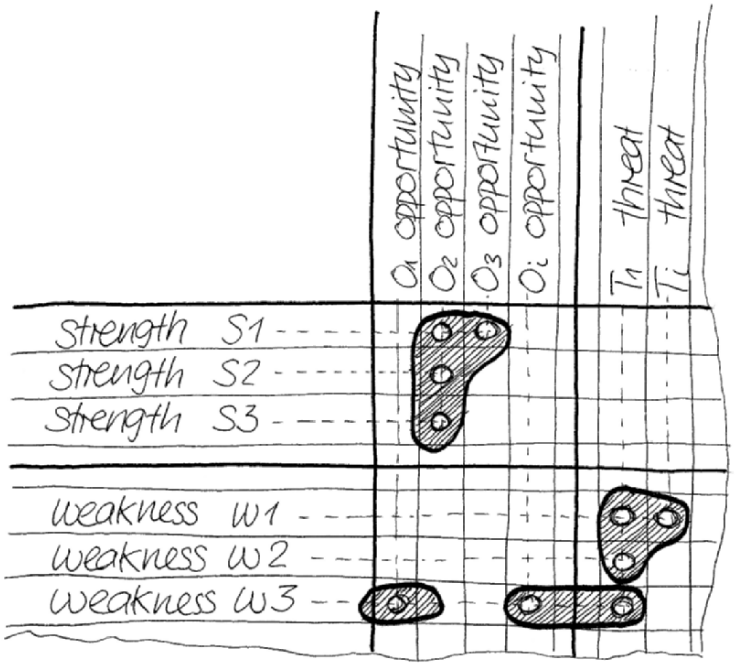


Figure 5.17. SWOT-Analysis with areas of actions.

Example:

A present weakness of the supply industry is their handling of orders. Business processes need to be addressed. The analysis of the future reveals that the cycle time is too

> *long. Again, business processes could be the reason. In a next step common reasons for strengths and weaknesses and opportunities and threats have to be identified. These are marked in figure 5.17 by a small circle.*
>
> *Clusters of circles indicate where common causes might exist and where therefore action could be focused. Such clusters are marked by a hatched area in figure 5.17. At one glance it now becomes evident where to look for new solutions.*

Using the SWOT analysis, different causes for strengths and weaknesses and opportunities and threats can be structured clearly and systematically, especially in regard to their need for action.

5.4 Summary of the Problem and Identification of Actions to be Taken

It has proven to be appropriate to conclude the situation analysis with a summary of the problem definition. The aim is to compile the most important results of the situation analysis briefly and clearly.

The summary of the problem definition and the identification of actions to be taken will include amongst others the following points:

- definition of the problem to be solved on the basis of the analyses of strengths/weaknesses and opportunities/threats, including the analysis of underlying causes and if necessary supplemented by a portfolio or SWOT analysis;
- description of the expected characteristics of the solution;
- determination of the framework and special constraints for a solution;
- degrees of freedom for the search for solutions which follows as the next step.

Based on the situation analysis, possibilities to intervene and the degrees of freedom have to be described and defined more precisely. In particular it has to be pointed out where a need for action exists and which areas have to be excluded from being changed. Methodically this step could be supported by a SWOT analysis. The range of potential solutions can already be limited within the situation analysis if there is supporting evidence.

Summarizing the problem needs to guarantee that an appropriate basis of information for the next planning steps is developed. It is important not to get carried away with collecting as much information as possible. The motto should be: ‘as much and as detailed as necessary’

- to understand the problems and determine the need for action,
- to define the objectives and
- to start the concept synthesis with the first possible solutions’.

It does not make sense to collect all information that is needed to search for and select a solution already in the context of the situation analysis, particularly for new problems. The risk is too big that unnecessary data is collected. On the other hand, continuously adding information ad-hoc whenever a partial problem appears is not efficient either. Collecting the right amount of information requires anticipating the need for information to a certain degree.

5.5 Summary Remarks on the Situation Analysis

The situation analysis aims to:

- Holisticly understand the problem and establish a sufficiently large frame of reference,
- define the intervention possibilities and the degrees of freedom for new concepts and measures
- create a basis of information for the next steps, in particular for the goal definition and the search for solutions.

The situation analysis

- is related to the past, the present and to the future, as it studies the current situation and future trends
- is open in regard to objectives, solutions and applicable measures and
- is the basis for all the following steps in the procedure.

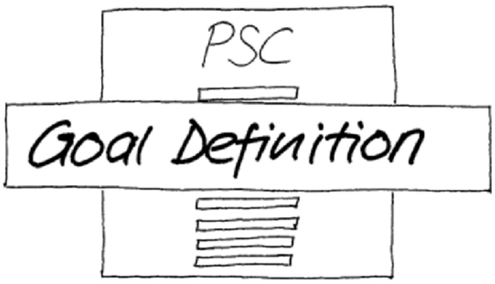
The steps of the situation analysis, which have to be implemented cyclically, are in detail:

- the task analysis
- the analysis of the current state of conditions and behaviour of the system comprising of
  - setting the boundaries of the system,
  - analysing of the existing system and the relevant areas of the environment,
  - analysing strengths and weaknesses (see figure 5.12) and
  - analysis of underlying causes
- analysis of the future, comprising of
  - prognoses of the behaviour of the relevant areas of the environment,
  - prognoses of the behaviour of the unchanged system and
  - analysis of opportunities and threats (see figure 5.15), including an analysis of underlying causes, and ideally a SWOT analysis
- solution-oriented considerations carried out in parallel to the analyses of the current state and of the future
- a concise summary of the results of the situation analysis and of the need for action.

The results of the situation analysis are:

- a description of the boundaries of the system (system and relevant areas of the environment),
- a description of the structure of the system to be examined,
- a structured discussion of the interactions of the system and the relevant areas of the environment,
- analyses of strengths, weaknesses, opportunities and threats (figure 5.12 and figure 5.15), including analyses of underlying causes,
- the important key assumptions and fundamentals
- a compilation of solutions that exist already,
- a summary of the most important information from the situation analysis as well as a description of the need for action.

6. GOAL DEFINITION



In the context of the goal definition process it has to be defined what to reach and what to avoid by the new solution itself and while on the way to the solution. The results of the goal definition are used in the search for solutions as well as in the selection steps of the problem-solving cycle.

6.1 Introduction to the Goal Definition

The search for solutions is only manageable if it is known what to look for. By defining a concrete objective as a requirement for a solution, an aspect of the future is determined consciously. Objectives should be guiding the way in the planning process, particularly for the search for solutions. Objectives should not be 'invented' later solely for the purpose to make an evaluation possible. Not the formal catalogue of requirements is important, but the collecting and the weighing of the objectives that have to be reached. By defining objectives rationally and systematically, Systems Engineering aims to avoid biases in the search for solutions.

Listing objectives in writing has several purposes:

- Firstly, as objectives resulting from the situation analysis might still be unclear, they are completed, specified, clarified and systematically structured and documented in the form of a catalogue of mandatory requirements.
- Secondly, these objectives build a much needed framework to guide the search for solutions.

- Thirdly they become an information basis – that might even be agreed in writing with the client or the decision maker – for the systematic evaluation of different options for a solution.

Example:

From the situation analysis a company concludes that the new manufacturing equipment for a certain engine type XY has to be in operation within one year. Therefore the following objective is defined:

The new manufacturing equipment for the engine XY providing a minimal daily production capacity of 1.100 pieces has to be in operation within 12 months at the location of the existing equipment.

The process of the goal definition is divided into three steps

- Drafting a structured catalogue of objectives
- Systematic analysis and creation of an amended catalogue of objectives
- Client agrees the catalogue of objectives

The results of these three-step procedure steps are gradually made more specific in a cyclic manner until the client accepts the catalogue of objectives. Below the individual steps of the goal definition are described.

6.2 Drafting a Structured Catalogue of Objectives

In a first step a structured catalogue of objectives has to be created. For this purpose ideas for objectives are collected, arranged and examined roughly. The result of this step is the basic structure of the catalogue of objectives.

6.2.1 Collecting Ideas for Objectives

At the beginning of a goal definition there are notions of or ideas for objectives. They originate from the client or from the situation analysis, for example from statements made by participants or affected parties, or from the analysis of strengths, weaknesses, opportunities and threats. It is advisable to constantly write down all ideas for objectives to collect raw material for the catalogue of objectives.

The goal definition transforms these ideas for objectives into properly defined objectives. A properly defined objective names the entity it relates to, the characteristics of the entity, the target characteristics in measurable terms, and an indication when and where the objective has to be achieved.

Entity: What are the objectives related to?

The entity is the system to be designed.

Example:

A new manufacturing strategy is to be developed and introduced in a mechanical manufacturing workshop. The entity is the 'manufacturing strategy'.

Characteristics: What is to be achieved?

The characteristics of the entity – also called the content of the objective – can be system conditions, functions, activities or effects.

In case of complex circumstances the catalogue of objectives consists of different characteristics that are usually of different importance. So it becomes necessary to prioritise the different characteristics in the goal definition process. This prioritization of characteristics is described in a later section.

Example:

A possible 'characteristic' for the entity 'manufacturing strategy' is the cycle time.

Measurable targets: How much should be reached?

Measurable targets quantify the characteristics of an entity. This helps to compare different solutions later in the planning process

Example:

A customer opinion poll showed that an acceptable cycle time is five weeks at most. Therefore the measurable target for the characteristic 'cycle time' is 'maximum five weeks'. If the cycle time is lower than or equivalent to five weeks,

> *this objective is achieved. If, however, the client wants a cycle time that is as short as possible, e.g. a cycle time of clearly less than five weeks, alternative solutions have to be developed that focus on a minimum cycle time.*

Time: When should the objective to be reached?

Since the availability of a solution or of parts of it can be of crucial importance in a practical context, the catalogue of objectives has also to specify the time aspect. The question is: when, until when or as of when does the solution or parts of it have to be available?

Time specifications are also used for project management.

> *Example:*
>
> *The analysis of the future in the example of the supply industry showed that the customers expect shorter cycle times in the immediate future. Therefore the new manufacturing strategy has to be introduced 'within 12 months'. This time specification limits the range of potential solutions.*

Place: Where should it become effective?

A further aspect could be to name a location.

> *Example:*
>
> *The new manufacturing strategy has to be implemented at a certain manufacturing plant.*

When collecting ideas for objectives it makes sense to constantly keep the five objective attributes 'entity', 'characteristic', 'measurable target', 'time' and 'place' in mind. Thus the quality of the collected ideas increases. So if the client only makes statements about the characteristics, the objective can be made more specific by asking further questions about targets, time and place.

Collecting ideas results in an unstructured collection of objectives. It is not evident which objectives concern the system and which objectives concern the processes, how the objectives are (hierarchically) interrelated and which priorities the individual objectives have.

6.2.2 Systematic Structuring

The ideas for objectives have now to be assigned to the system or the process, structured accordingly, and prioritised.

Distinction between system and process objectives

System objectives are statements about future conditions, important characteristics and behaviours of a system in its realization, use and disposal phases.

> *Example:*
>
> *A manufacturer has to guarantee continuous supply of its products. A longer production shut-down is therefore not possible. The system objective that makes a statement about the realization phase of the new solution expresses that:*
>
> *'The introduction of the new manufacturing strategy must not affect the availability of the manufacturing workshop.'*

Process objectives, also called project-planning objectives, describe essential characteristics of how to reach the objectives of the system. Process objectives have a direct relation to the project management.

> *Example:*
>
> *The management are burdened with strategy and budget considerations in the last months of the year. Additional activities have to be avoided. Therefore a project-planning objective states: Organisational changes should not take place in the fourth quarter, if possible.*

System and process objectives must be compatible.

Grouping of objectives into categories

In order to structure the catalogue of objectives, it is appropriate to group homogeneous objective characteristics into categories. Thus a breakdown into 'economic objectives', 'performance objectives', 'personnel and social objectives' and 'ecological objectives' might make sense.

> *Example:*
>
> *'The lead times for the whole manufacturing process may amount to maximally five weeks. Production of rotationally symmetric parts of a diameter of up to 32 mm has to be possible, with diameters up to 60 mm as an option. Surface treatment has to be done in house.'*
>
> *These objectives state requirements for the function of the new production system. They can be categorised as 'functional objectives'.*

The individual categories can be broken down further. For example, the economic objectives can be further divided into 'profitability objectives' and 'investment objectives'.

> *Example:*
>
> *'The introduction of the new production strategy may cause investments of 100`000 Euros at most.' 'The pay-back period must be less than 2 years.' The first objective refers to the capital allocation strategy of the company; the second objective is related to risk management requirements.*

In business management literature occasionally a distinction is made between 'material goals' and 'formal goals'. Material goals relate to the market performance of the company. Economic performance goals, expressed in terms of earnings, profitability and more, are called formal goals.

The choice of categories is specific to the problem or system.

Prioritisation of the objectives:

Prioritising the individual objectives is the next step of the goal definition. Objectives are classed as mandatory, supplementary, and best-case objectives:

- Mandatory objectives have to be met (marked with an 'M' in figure 6.1.)
- Supplementary objectives are important as well ('nice to have' objectives, marked with a 'S' in figure 6.1.),
- Best-case objectives, their fulfilment is desired, but not necessary ('gold plating' marked with a 'G' in figure 6.1.).

Example:

In connection with the establishment and introduction of a new production strategy different objectives are defined. These are prioritised as follows:

- *'The cycle time has to be less than five weeks.' Because this specification has to be kept, this objective is a mandatory objective.*
- *'The investment may not exceed the amount of €100.000.' This restriction is important, but could be increased in case of a higher profitability of a solution proposal, if necessary.*
- *'The manufacturing of parts with a diameter of more than 32 mm should be possible.'*

The individual objectives can be written down in a structured catalogue of objectives (figure 6.1).

Objective classes	Objective characteristics	Scale of objective	Objective priority
Performance objectives	▪ cycle time ▪ diameter of the parts ▪ diameter of the parts ▪	5 weeks diameter < 32 mm diameter >32 mm	M S G
Economic objectives	▪ investment ▪ profitability	<100.000 Sfr. >20% cost reduction in production	S S
Personnel and social objectives	▪ with existing employees ▪		S ....
Ecological objectives	▪ no use of CHC in production ▪	....	S

Figure 6.1. Example of a structured catalogue of objectives with objective categories and priorities.

Example:

Explicit ecological and social objectives become increasingly important when organisations are striving for sustainable development. So for example, it is expected that a new generation of refrigerators performs environmentally better than the old generations. When designing the new generation of refrigerators, the planning team faces the challenge to specify understandable objectives that are based on the analysis of the environmental impact of the new products. Ecological and social objectives can also be described by performance objectives. For example, the environmental analysis of a new refrigerator might establish that while environmental effects are accumulated by material and energy consumption in production, distribution, use and repair, and disposal of the product, the utilisation phase is most relevant. Energy consumption in the utilisation phase is determined by the cooling system (power demand, consumption of cooling lubricant) and by the operation of the appliance (e.g. frequent opening of the refrigerator, incorrect closing). Instead of demanding a reduction of the environmental impacts of for example 33%, an ecological objective could request to 'reduce cooling demand during utilisation by at least 20%' or to 'allow loss of only 1% of cooling lubricant during 10 years of intensive use'. These would be performance objectives. The ECODESIGN PILOT (Wimmer and Züst (2002) includes guidance to redefine ecological objectives as performance objectives.

In the goal definition process, the catalogue of objectives has, so far, not been analysed systematically. It might well be that the objectives are neither measurable nor expressed in a solution-neutral way. In the next planning step a systematic analysis of the catalogue of objectives has to be carried out.

6.3 Systematic Analysis and Revision of a Catalogue of Objectives

The structured catalogue of objectives is systematically analyzed in the next step. A number of formal requirements apply to the individual objectives and to the catalogue of objectives as a whole:

Formal requirements for the individual objectives:

- solution neutral
- operational, measurable

Formal requirements for the objective catalogue:

- complete
- balanced

Formal requirements for the relations between individual objectives:

- consistent
- free of redundancy

The individual requirements are described below.

6.3.1 Formal Requirements for the Individual Objectives

Objectives have to be solution neutral:

Objectives have to be worded as neutrally as possible with regard to specific measures and solutions. For example following objective is not solution neutral: ‘the production strategy has to be improved by manufacturing segmentation.’ In this case, the solution is already specified by the objective. A proper study of alternatives, based on the principle ‘thinking in alternatives’, is not possible any more. Thus, an objective should rather state the effects that solutions should bring.

Whether a certain objective is solution neutral or not is also a question of the problem level. The remarks above refer particularly to a pre-study or to the main study. In the detailed studies more specific solution requirements can emerge that resulted from the conception and selection process. In a pre- and a main study, specific solutions should only be requested, if they are justified due to detailed experiences with the problem.

Objectives have to be operational and measurable:

Objectives are operational

- if all participants understand them and thus the objectives can serve as a basis for everybody’s own thinking and acting,

- if they are specific to the problem and do not only state general principles,
- if performance objectives are clearly described and
- if benchmark measures and corresponding measuring methods are known and applicable to determine if an objective has been fulfilled.

At the beginning of the goal definition, objectives are frequently defined vaguely. However they have to be analyzed and specified so they are useful for the search for solutions.

> *Example:*
>
> *'The layout of the new manufacturing workshop must be flexible with regard to future changes.' This objective is not operational because it is not evident how the flexibility can be determined and evaluated. Based on prior knowledge of the situation, it might be possible to specify the amount of space required to accommodate this flexibility. The objective could then read: 'The manufacturing workshop requires a spare surface of at least 300* m^2*.' Thus it would be clear for the planning team in which direction layout planning would have to proceed and which scope would have to be reached within the individual solution alternatives.*

It is not always possible to find a measurable parameter to describe a certain characteristic of an objective with sufficient precision. It is, for example, difficult to find a measurable parameter for the objective 'make the layout adaptable flexibly in regard to future changes'. Sometimes it is possible to substitute other parameters instead. A substitution for 'flexible layout design' could be to specify the amount of spare space needed, or to allow extra costs for fixed foundations and infrastructure.

In practice, it is typically difficult to define operational parameters. However, it is highly discouraged to skip the step of making the catalogue of objectives operational. It is preferable to accept an evaluation of alternatives that might be less accurate with respect to one single criterion than to risk neglecting a whole set of objectives. If required the influence of problematic criteria could be established by carrying out a sensitivity analysis. If their influence is considerable, they need to be defined more precisely by more parameters or indicators.

6.3.2 Formal Requirements for the Catalogue of Objectives

The catalogue of objectives has to be complete:

The definition of objectives has to include all properties and effects of a system that could be met by different design alternatives for which there might exist preferences. This demand for completeness should not mislead to develop a catalogue of objectives that is too fine, which could be more confusing than helpful for the search for solutions.

The catalogue of objectives has to be balanced:

During the search for solutions a large number of relatively unimportant objectives can block the view for the essential ones. The effort for evaluating a solution will be rather large but not more reliable, whatsoever.

The catalogue of objectives has to avoid a bias of the project towards one-sided group interests. Apart from its ethical value this demand also has a very pragmatic relevance; it should improve the acceptance of solutions.

6.3.3 Formal Requirements for the Relations between Individual Objectives

Between the individual objectives there can occur several types of relations as described below:

Conflicting objectives:	Conflicting objectives might not be evident immediately. However, a known conflict between objectives has to be eliminated.
Competiting objectives:	In case of competing objectives, one objective prevents another mandatory or supplementary objective from being achieved. Competing objectives are quite common.
Indifferent objectives:	Indifferent objectives have no connections between themselves. Indifferent objectives are an occasional feature in a catalogue of objectives.

Supporting objectives:	Supporting objectives exist if the achievement of one objective is benefiting the achievement of another objective. This happens quite often.

> *Example:*
>
> *When buying a new car, some restrictions for price and performance might have been set. An alleviated form could read: 'The investment for a new car must not exceed 35'000 €.' This is a mandatory objective. 'The performance has to be maximised.' This is worded as a supplementary objective.*

Seemingly supporting objectives could also be redundant; i.e. both objectives would demand the same. Redundant objectives don't pose a serious problem for the search of solutions. Still the catalogue of objectives is extended unnecessarily. However, redundant objectives potentially affect the evaluation of solution alternatives unfavourably. Therefore redundancies have to be eliminated previously.

To describe conflicting, competing, indifferent, supporting and redundant objectives in a complex system of objectives, the matrix of relations between objectives (figure 6.2) is well suited.

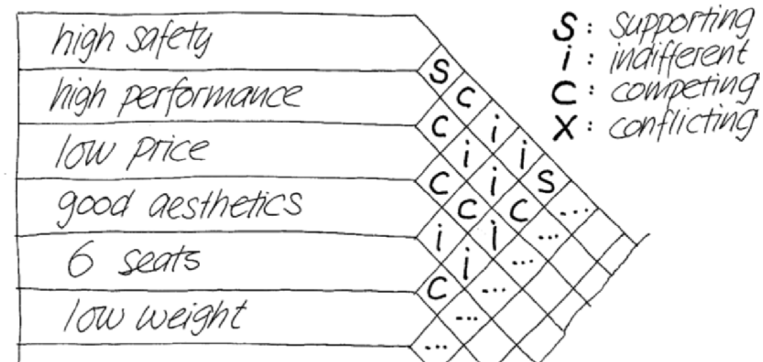


Figure 6.2. Matrix of relations between objectives for the example of buying a new car.

6.3.4 Implementation of a Systematic Analysis

The structured catalogue of objectives has now been analysed systematically. The individual objectives and their mutual relations have to be examined for formal aspects. This task can be facilitated using the questions below:

Are objectives solution neutral, operational and measurable?

- Are all objectives solution neutral? Do they not already suggest measures?
- Do the objectives refer to the right problem levels?
- Are all objectives worded so it can be determined to what degree any solution will meet the objectives? Are all objectives understandable?
- Are mandatory objectives restricting the solution space inadequately?
- Is the search for solutions possible based on these Objectives?
- Are parameters or indicators known for all the objectives in order to be able to determine to what degree any solution will meet the objectives?

Is the catalogue of objectives balanced and complete?

- Are all aspects represented in the catalogue of objectives according to their approximate relevance?
- Are all sub-objectives helpful and necessary for the search for solutions?
- Are the interests of all participants and affected parties considered appropriately?

Questions about the relationships between individual objectives:

- Are there conflicts between individual objectives?

Cross Reference to Cases in Chapter 9

Case A describes a further example of a catalogue of objectives. This catalogue of objectives specifically relies upon the principles and recommendations described above.

6.3.5 Revision of the Catalogue of Objectives by the Project Team

Conflicting interests must not be left undiscovered until a late stage such as the selection of a solution. A conflict at such a late stage frequently leads to unsatisfactory compromises. Accepting a compromise over conflicting objectives as part of the goal definition, however, produces a sustainable basis for the search of solutions. This allows a coherent design of a new solution. A later compromise over a solution typically changes certain characteristics of that solution retroactively, in order to satisfy interests of certain groups; this leads to sub-optimal concepts.

Within a company, decision authority is clearly defined and mechanisms exist to define objectives and to make decisions. For projects that have serious staffing consequences, for instance, it is mostly not advisable to have the formal decision maker decide on conflicts of interests, as the example below shows.

> *Example:*
>
> *At the beginning of the goal definition process the planning team is faced with two conflicting objectives. The management demands: 'The production costs must be reduced by 20 % within one year.' However the workers' representatives have the opinion: 'that the number of jobs has to be sustained.' In this form the second objective is not acceptable for the management. A clash of interest exists. If a compromise could be found to restate the second objective as: 'Minimisation of the number of dismissals and avoidance of cases of hardship', the conflicting opinions could be duly considered.*

For the revision of the catalogue of objectives the procedure below is suggested:

- The objectives as stated by all groups of interests are collected in an initial objective catalogue of objectives.
- The catalogue of objectives is revised with regard to redundancy by negotiations.
- The remaining partial objectives are examined for conflicts. Conflicts are settled by negotiations between the groups of interests.

- Basically, all objectives that then remain form the initial catalogue of objectives form the revised catalogue in the sense of the compromise.

This procedure does not necessarily lead to success. Basically there are two reasons for that:

- Parties are not ready to accept a rational decision.
- Due to emotional reasons specific aspects of solution alternatives dominate the discussions.

The Problem-Solving Cycle aims to gradually develop and eliminate alternative solutions. In the case of complex a project, the Problem-Solving Cycle is therefore applied subsequently several times. So, the search for solutions becomes a cyclic process of preliminary studies, main and detailed studies. The catalogues of objectives, developed during the individual planning steps, are dependent on each other. The catalogue of objectives of the preliminary study, for example, has to be revised in the main study. If objectives are no longer practicable at the time of the main study, they have to be identified as such – also to the client. Such a procedure is used frequently.

Within the problem solving cycle there are reasons for a retroactive adjustment or completion of objectives that have already been decided upon. Some examples:

- Objectives can turn out to be too limiting or unrealistic during the search for solutions.
- In case of long-term projects, changes in the relative importance of values held by participants and affected parties are possible.
- The basic assumptions for a project can change over time.

Such changes have to be identified before the final evaluation of alternative solutions.

For the goal definition, catalogues of objectives from earlier projects with similar content could be used. However, reusing such a catalogue of objectives has to be challenged critically, even more than when reusing a situation analysis, since their objectives strongly depend on the current intentions of the decision makers and on the current situation.

6.4 Summary Remarks on the Goal Definition

The goal definition builds on the results of the situation analysis. A meaningful search for alternative solutions is only possible if these alternatives can be systematically derived from the requirements.

The goal definition has the purpose

- to collect and complete the ideas for objectives from all participants,
- to systematically structure these ideas,
- to examine if they fulfil formal requirements, and finally
- to document the catalogue of objectives in a formally binding form.

The objectives are a guide for the search for solutions. They contain expectations set for the system to be designed. Effects to be avoided have to be documented as well.

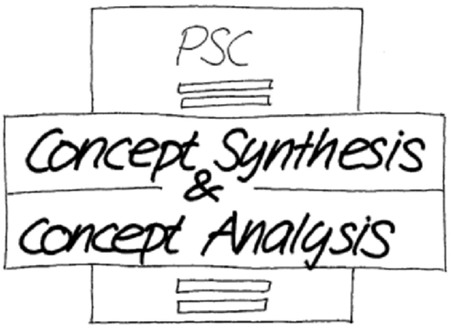
The procedure of the goal definition can be divided into different planning steps that are passed cyclically:

- First draft of a structured catalogue of objectives, including ideas from all stakeholders
    - intuitive collection of ideas for objectives
    - systematically structuring of the objectives in particular according to objective categories and objective priorities
- Systematic analysis and provision of a revised catalogue of objectives
    - examine if the individual objectives are solution neutral, operational and measurable
    - examine if the catalogue of objectives is balanced and complete as a whole
    - examine if the catalogue of objectives is free from conflicts and redundancy between individual objectives

- Approval of the catalogue of objectives.

The result of the goal definition is a structured catalogue of objectives. This catalogue of objectives is further used in the concept synthesis, concept analysis and selection.

7. THE SEARCH FOR SOLUTIONS: CONCEPT SYNTHESIS AND CONCEPT ANALYSIS



In the context of the search for solutions, alternative solutions are developed and checked if they are in line with the main objectives.

The term ‘concept’ in the context of systems engineering stands for the ‘blueprint’ for a new solution. ‘Concept synthesis’ is the first step in the search for solutions. It consists of the development of alternative solutions of various levels of detail and concretion. In the second step, ‘concept analysis’, alternative solutions are evaluated and possibly eliminated or reassigned to a further revision and improvement based on existing mandatory and supplementary objectives. The result of this two-stage process is a list of valid alternative solutions.

7.1 Creativity as Driving Force for the Search for Solutions

The search for solutions always goes beyond the first ideas. Its purpose is to develop a comprehensive spectrum of solutions that is sufficiently documented for further processing and for evaluation. The creativity of the persons participating is crucial in finding new ideas. The creative potential of different people is diverse and can be stimulated by creativity techniques. Psychological barriers to creativity in individuals and groups have to be overcome.

In order to reduce the barriers to creativity the principles below proved as useful in practice:

- Detach yourselves from normal everyday life (no telephone calls, no day-to-day business, change the working environment, …),
- Consciously avoid criticism.
- Integrate people with different educational backgrounds and experiences and promote divergent thinking (try to move away from conventional ideas for solutions).

In problem solving, people tend to examine new ideas immediately whether they are suitable, and if not to discard those ideas at once. Team-based creativity techniques try to counteract this tendency.

Ideas for solutions emerge, as shown in figure 7.1, in different situations, surprisingly only 24% at work.

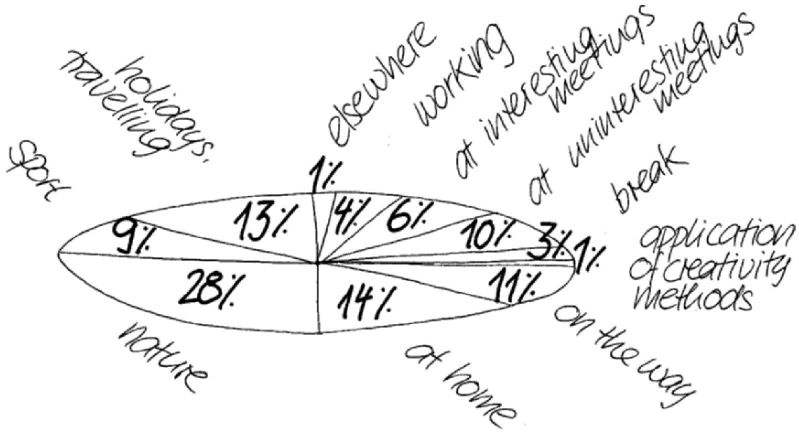


Figure 7.1. ‘Where Do new ideas arise?’ A study in 116 companies and business units showed that out of 100 ideas only 24 occurred at work (Berth and Kienbaum (1993)).

Therefore it is even more important to create a climate that supports the development of ideas in a company. From Figure 7.1, the impression might arise that the use of creativity methods is insignificant for the development of new ideas for solutions. This is not the case in practice. New ideas can be further developed in such a way, for example by building analogies and varying ideas systematically. Additionally comparisons with other professional fields can be done. An example for that is bionics: natural solutions are transferred to artificial systems.

7.2 The Interaction between Concept Synthesis and Concept Analysis

It is desirable to generate a large variety of alternatives; however, this variety can and should not be sustained throughout all the following steps, mainly because of costs. Alternatives that do not fulfil mandatory objectives are not considered further. Moreover, alternatives that fulfil supplementary objectives only poorly can be eliminated. These two phases, generation of ideas and elimination of ideas, are implemented separately:

The purpose of the concept synthesis is

- to find diverse solution ideas and alternatives and
- to further develop and concretise them.

The concept analysis aims at

- identifying unsuited solutions or individual deficiencies
- selecting and improving ideas and solutions and
- narrowing down the spectrum of alternatives in the process of the analysis

The interaction between concept synthesis and concept analysis is cyclic, in a typically Systems Engineering way. The principles ‘thinking in alternatives’ and ‘from general to detail’ are combined once again.

In the first step of a synthesis-analysis-cycle, a wide and comprehensive range of solutions is developed with only a shallow description of details. This first step aims at completely covering the field of possible solutions. The following, general analysis, also called intuitive analysis as in figure 7.2, guarantees that obvious deficiencies can be identified in an early stage. Solutions can be either justifiably discarded or purposefully improved. The result of this first, general cycle of synthesis and analysis is a selection of possible solutions. In the next, more detailed cycle these solutions are developed further, concretised and formally analysed (figure 7.2). The result is a list of suitable solutions. This two-stage procedure is described in detail below.

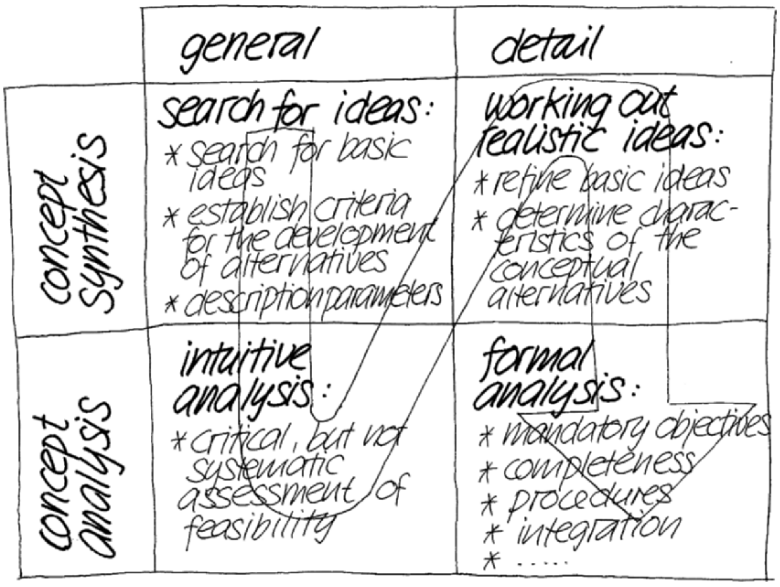


Figure 7.2. Activities of concept synthesis and concept analysis (Nagel and Haberfellner (1982)).

7.3 Concept Synthesis

The contents of the general and detailed concept synthesis are described below (figure 7.3).

7.3.1 General Concept Synthesis: Search for Ideas

At the beginning of the search for ideas it is advisable to write down some fundamental solutions (see figure 7.2). Such fundamental solutions are not to be seen as rigid guidelines, but rather as working hypotheses. They must result from professional expertise and knowledge about the situation, but must not obstruct the further search for ideas.

In the early phase of the search for solutions, methods and techniques are applied that promote the creative potential of people, embodied in their emotional and intuitive intelligence. These techniques are particularly used in teams in order to break the routine of traditional ways of thinking and interaction between team members. They try to tap into to the intuition of people and in particular their ability to think laterally. The most important and best-known method is brainstorming.

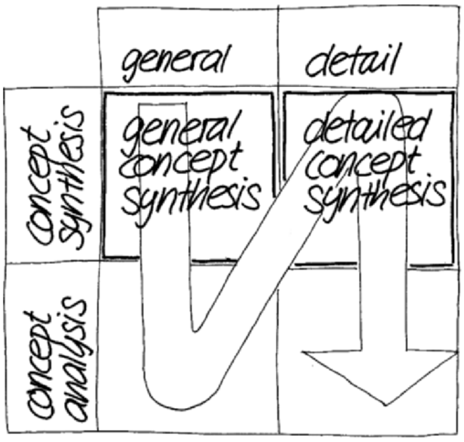


Figure 7.3. General and detailed concept synthesis.

Example 'Brainstorming':

Brainstorming aims at reducing creative blockages and at the same time at promoting the generation of ideas by mutual stimulation. Brainstorming can already be used in the situation analysis for finding possible future developments or in the goal definition for the development of ideas for objectives. The main application of brainstorming is in the search for solutions.

Formally, a brainstorming session is a meeting specifically set up for this purpose, i.e. with no other agenda items. In order to make the meeting as successful as possible, some important basic rules have to be considered:

- The chair of the meeting or the facilitator asks the participants to spontaneously express ideas about the topic of the meeting.
- From experience the optimal group size for a brainstorming session is around 6 to 8, at most 12 to 15 participants.
- The chair or facilitator tries to stimulate a lively exchange of ideas and an orderly discussion.

- The facilitator or the keeper of the minutes writes down all statements and keywords, visible for everyone. Tools used are for example black- or whiteboards, projectors or flipcharts.
- The names of who made the statements are not written down.
- The ‘principle of the postponed judgement’ is strictly adhered to at the meeting. No one is allowed to particularly praise or criticize ideas or proposals during the meeting.
- It is explicitly encouraged to change, improve or combine ideas of other participants.
- Important are the quantity and variety of the suggestions.
- The meeting ends after 20 to 30 minutes.

During the brainstorming session any evaluation or criticism is forbidden. Killer phrases prevent effective brainstorming, just like prematurely praising a contribution (‘Thank you for your outstanding proposal – may I suggest that any further collection of ideas would only be a waste of time and would cause unnecessary trouble...’).

Eliminating criticism and praise during the meeting results in a collection of ideas about diverse problem areas and of different usability. The principle most frequently violated is the ‘principle of the postponed judgement’.

Evaluating, structuring and assessing the proposed solutions is not part of the meeting. This is done in a second step. Enlisting additional specialists who did not attend the conference can support this second step. Both a classification based on problem areas and an evaluation have to be made. The questions below have to be answered:

- Does the idea belong to the problem area treated?
- Does the idea fit the step presently discussed?
- Is the idea useful?

Basic solutions for the problem are found at the end of the search for ideas. These solutions neither get detailed nor are they examined if they meet the objectives.

7.3.2 Detailed Concept Synthesis: Elaboration of Realistic Solutions

The basic solutions are now refined and enriched in a further step of synthesis (figure 7.3). The ideas, which are usually abstract, should be concretised by systematically varying the parameters of solution, generating different, alternative solutions. The terms 'alternative solutions', 'solution alternatives' and 'options' are interchangeable and used as synonyms in literature.

Often methods are used to systematically create alternatives. They aim at covering the space of possible solutions completely. Examples are the 'morphological chart' and the 'morphological matrix'. The term 'morphology' originates from Greek and means something like system or design theory. Both methods support structured, schematic design.

Example 'Morphological Chart'

When applying the morphological chart all the important parameters that characterise a solution are specified. Then, different values are searched for each parameter.

> *Example:*
>
> *In the context of a product development project the question arises how the connection between the housing and the base plate can generally be realised. The parameter is the type of the connection. Possible values are form-, force- and material-fit connections or a combination of them (figure 7.4).*

<table>
<tr><th>Parameter</th><th colspan="7">Values of parameters</th></tr>
<tr><td>Type of connection</td><td colspan="2">force-fit</td><td colspan="2">form-fit</td><td colspan="2">material-fit</td><td>combination</td></tr>
<tr><td>Material</td><td>metal</td><td colspan="2">aluminum</td><td colspan="2">brass</td><td>synthetic</td><td>combination</td></tr>
<tr><td>......</td><td colspan="2">....</td><td colspan="2">....</td><td colspan="2">....</td><td>....</td></tr>
</table>

Figure 7.4. Possible values for the type of connection and for the material of the housing.

The reasonable and correct definition of the parameters and their appropriate values is a task that is important and difficult at the same time. Conventional solutions or new ideas could be the starting point. During the definition of the parameters it has to be taken into account:

- that the parameters are as independent of each other as possible,
- that the number of parameters is as small as possible, that they represent the most important characteristics of the new system and
- that the values of each parameter point out important differences.

A force-fit connection, as shown in figure 7.4, can be realised with different kinds and numbers of bolted connections. Additional combinations are possible. The housing could also be connected by a combined form- and force-fit. A plug-in fastener with an additional fixation would also be possible. A morphological chart should also provide for ‘combinations’, as this next example illustrates.

Example:

New options for the transport of people and goods are to be developed. Important parameters – ‘relation of power unit and passenger compartment’, ‘steering mechanism’, ‘power unit and ‘energy source’ – are identfied. Appropriate values are established for each parameter (figure 7.5).

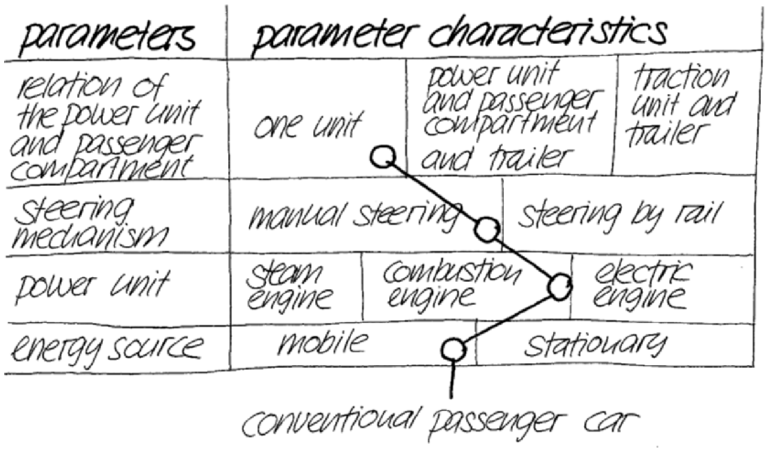


Figure 7.5. Example of a morphological chart: The example of a conventional passenger vehicle is shown.

> *As shown in figure 7.5 a line describes one solution alterative. Each possible combination leads to a new solution alternative. The maximum number of different alternatives is reached by multiplying the number of values for each parameter. In the present example there are 36 solution alternatives. If a morphological chart is believed to incorporate all potential solutions (as shown in figure 7.5), it is called a total solution space.*

Even if solutions found in a morphological chart don't seem to be possible after only a short reflection, the 'principle of the postponed judgement' also applies here. Only later it is decided whether a solution is useful or not. Experienc shows that unconventional solutions are often the key to success.

In a next step the pattern is analyzed. Values or combinations of different parameters are examined whether they make sense and if these combinations are feasible. A morphological matrix effectively supports this planning step.

Example 'Morphological Matrix'

It can be appropriate to transform the morphological chart into a morphological matrix. In the morphological matrix each solution represented by a line in the morphologic chart becomes a matrix field (figure 7.6).

Combinations, which were rated unrealistic or impossible, do not reappear in the morphologic matrix any more. In this sense the morphologic matrix is working with information that has been further developed from the morphologic chart.

As shown in figure 7.6 for instance, the combination 'steam engine' and 'fixed energy source' is not considered any more because this combination obviously does not make sense.

It is characteristic for the morphological matrix that combinations of values of different parameters are used as labels for the rows and columns. At the intersections of rows and columns, abstract solutions are found. These have to be detailed later.

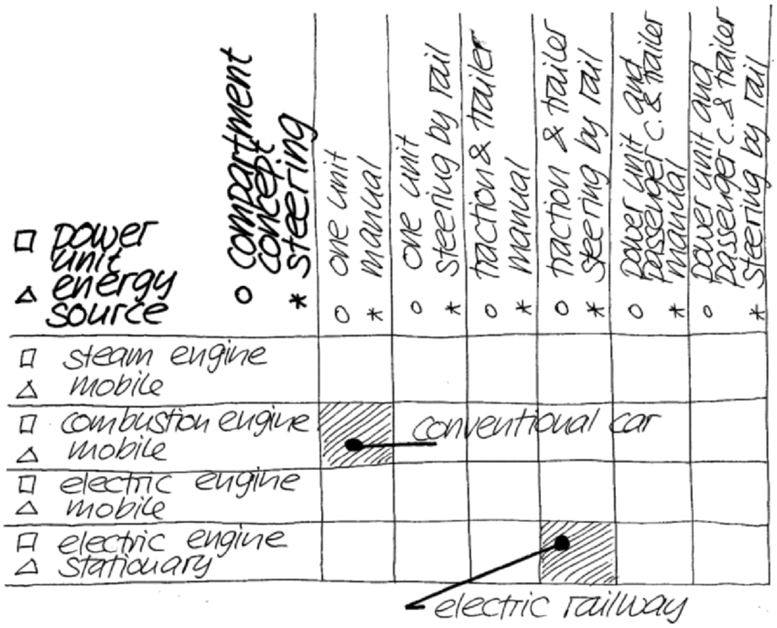


Figure 7.6. Morphological matrix: shown is the conventional car and the electric railway with locomotive and wagons.

The process of developing solution ideas and solution alternatives using the morphological chart and the morphological matrix could consist of these steps:

a) Collect ideas

- collect as many different and specific ideas as possible: the basis can be well-known solutions or ideas from a brainstorming session
- identify essential differences in their characteristics
- define the most important parameters of the solutions

b) Structure and detail ideas

- create the morphological chart
- if the morphological chart becomes too large, less important parameters have to be separate

combine values of different parameters into pairs, eliminate unsuitable combinations of values

- create morphological matrix if necessary
- reduce the number of (abstract) solutions by comparison
- general evaluation of alternatives in their abstract form with the aim to identify the most promising solutions, possibly with additional sub-alternatives
- detail the alternatives

For more information on the application of these methods see the list of secondary literature in the appendix.

The morphological chart and the morphological matrix already incorporate some degree of analysis. This analysis, however, is restricted to assessing whether combinations or single values make sense; is not an evaluation whether a proposed solution actually would meet any objectives.

7.4 Concept Analysis

7.4.1 Aspects of a Systematic Concept Analysis

Concept synthesis and concept analysis have to be separated as strictly as possible to avoid a hasty elimination of solutions.

The concept analysis is a formal, systematic analysis of solutions to eliminate unsuitable ideas that don’t meet mandatory or supplementary objectives as required in the catalogue of objectives. Alternatives that are not eliminated in this step are evaluated in the next step of the process, the selection (see below, chapter 8).

In principle, the concept analysis is about examining ‘validity’ of the individual solutions. For this purpose, the solutions have to be analysed under different aspects. This analysis covers at least the following aspects:

- fitness for purpose (normal situation, exception, malfunction), functions and processes
- integration into the meta-system

- usability and maintenance
- ease of implementation
- necessary preconditions
- comparability of alternatives

Below, these aspects of evaluation are described briefly.

Analysis of the Functions and Processes

The fitness for purpose can be logically and systematically analysed on the basis of draft documents. Additionally, there is the possibility to conduct test investigations or adequate simulations.

Usually it is not sufficient to examine the fitness for purpose in regard to the intended operating conditions of technical systems only. In the analysis, exceptional system conditions such as possible disturbances and malfunctions have to be considered. Thus, effects have to be assessed that have not been considered yet.

The performance of the system has to be appraised and evaluated with regard to the objectives. In particular, all alternatives have to be checked if they meet all mandatory and supplementary objectives. If a solution does not meet mandatory objectives it has to be improved or eliminated.

Finally, for any solution, i.e. for any proposed system and its future operation, its positive and negative consequences have to be established in terms of its financial, personnel, organizational, and ecological impact. If there are negative consequences, it is of particular interest to find measures to alleviate or even to avoid these negative impacts.

Analysis of the Integration into the Meta-System

The integration of a solution into the relevant areas of the meta-system and thus the interactions between the proposed system and the meta-system have to be examined.

Chapter 5, above, situation analysis, already presented methods supporting this evaluation, particularly the ‘analysis of strengths and weaknesses’ and the ‘analysis of opportunities and threats’. Any proposed system can be analysed in the same way and compared to the current condition. Thus, it becomes possible to point out the improvement potential of a solution in a simple way.

Analysis of Usability and Maintenance

In the phase of analysis the planner has to try to put himself in the place of a participant, user or other affected party in order to review a solution from their point of view and in later phases of life of the proposed system. Possibly the views of users, maintenance personnel etc. have already been checked and evaluated in the context of the situation analysis.

Analysis of the Ease of Implementation

During the implementation or realization of a new concept, participants and affected parties might have to face changes and adaptations might have to be made to the meta-system. Special attention has to be paid to the transition from an old to a new system.

Difficulties, which might occur during the system introduction, have to be anticipated in order to take preventive measures. In the case of organisational change these preventive measures could include breaking up the implementation into several stages, each achieving a temporary but fully functional intermediate solution.

The detailed descriptions of the ease of implementation, of usability and maintenance can be used as additional criteria for the evaluation of the solutions.

Analysis of the Necessary Preconditions

The preconditions for a proposed system to work have to be set out very clearly. In particular those preconditions have to be highlighted which lead a solution to fail if they are not met. Special attention has to be paid to these preconditions during the further development and the realisation of the system.

Analysis of the Comparability of Alternatives

In practice, alternative solutions are often not immediately comparable. Particularly during the intuitive search for solutions, ideas might appear that deal with the problem on different levels. These ideas are called ‘false alternatives’.

> *Example:*
>
> *A reorganisation project has the objective to reduce the costs and the cycle times in a manufacturing workshop. Solutions for the manufacturing strategy are found. In addition alternatives concerning the product design process are developed. Only marginal design modifications could have a large improvement potential. If these design ideas have to be pursued further, the system boundaries have to be extended.*

Finally, the solutions have to be examined whether they are complete and whether they are described to a similar degree of detail. Solution alternatives are only comparable if they show a similar degree of detail and completeness.

Cross Reference to Cases in Chapter 9

In case A the individual alternatives are systematically analysed whether they are suited. Unsuitable alternatives are eliminated based on the mandatory and supplementary objectives.

7.4.2 General Concept Analysis: Intuitive Analysis

After the concept synthesis, the individual solutions are to be examined based on different criteria. Similar to the two-step synthesis, the analysis consists of two steps (figure 7.7).

In the first step of the analysis the solutions are examined critically but neither a systematic nor a complete analysis is carried out whether they fulfil the mandatory and supplementary objectives. The general analysis is primarily a first critical assessment of the suitability of a solution, but not a systematic examination. If, however, solutions are detected to not fulfil mandatory or supplementary objectives they must be adapted or eliminated if necessary. Any reason for eliminating a solution must be documented.

The results of this first step of analysis are solutions that have to be refined in a further step of synthesis and that are then systematically analyzed.

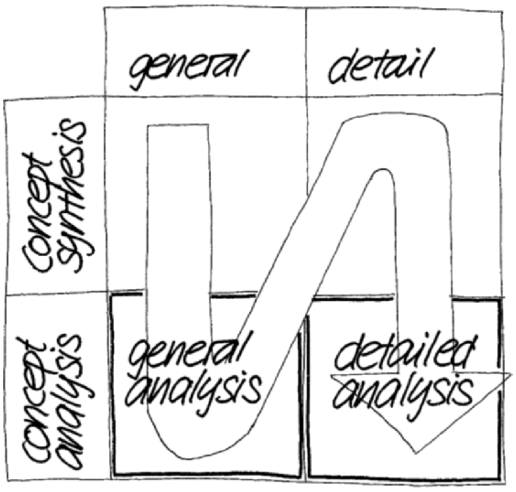


Figure 7.7. General and detailed concept analysis.

7.4.3 Detailed Concept Analysis

The solutions that are now available in a detailed form have to be analysed systematically whether they fulfil all the objectives (figure 7.7); this is the detailed analysis. The catalogue of mandatory and supplementary objectives forms the basis for this planning step.

For a detailed analysis it can become necessary to use simulations. Two examples:

- High risk: power failures and other disturbances in critical production departments cannot be tested in reality.
- High expenditure: not all inventory strategies can be tested in reality.

In these cases simulation models are developed to assess system performance.

Example:

A city plans to introduce a volume-dependent waste fee, the so-called 'rubbish bag tax'.The purpose is to distribute the raising waste costs based on the cost-by-cause principle. In addition, recyclables as for example paper, glass, iron *and aluminium, increasingly are collected and recycled separately. This new recycling and waste collection strategy is shown in figure 7.8.*

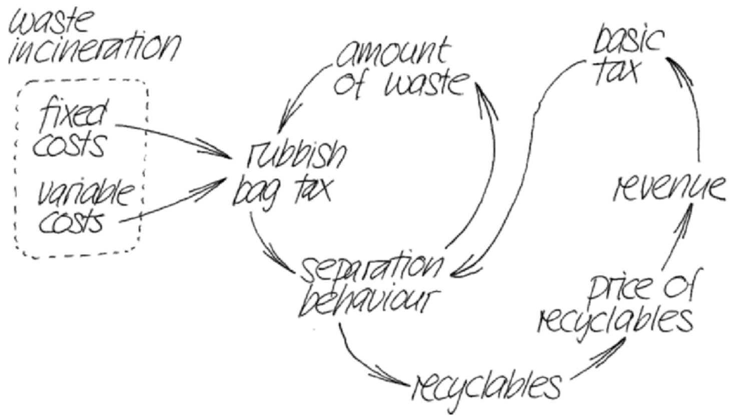


Figure 7.8. Recycling and waste collection strategy.

The introduction of the rubbish bag tax can be presented as a network of objectives, measures and consequences with deferred but effective feedbacks. The evaluation of this network of effects where human behaviour is playing an important role is not trivial.

Below, we show how such a network can be presented and evaluated (see also: Gomez and Probst (1995)).

In a first step the structure of the system is determined (figure 7.9). Typically, the analysis of the influencing variables is accomplished first. For example the amount of waste – in this case the number of waste bags – and the costs for waste collection and incineration have an influence on the rubbish bag tax. This influence is shown with an arrow in figure 7.9.

It is examined how one element affects another. If for example the costs for waste collection and incineration are increasing or decreasing, the rubbish bag tax will also increase or decrease. The change is parallel. The arrow in figure 7.9 is therefore positive and gets a plus sign. If, however, the waste quantity decreases, then the rubbish bag tax has to be increased and vice versa. The change is in the opposite direction; therefore the arrow is marked with a minus sign.

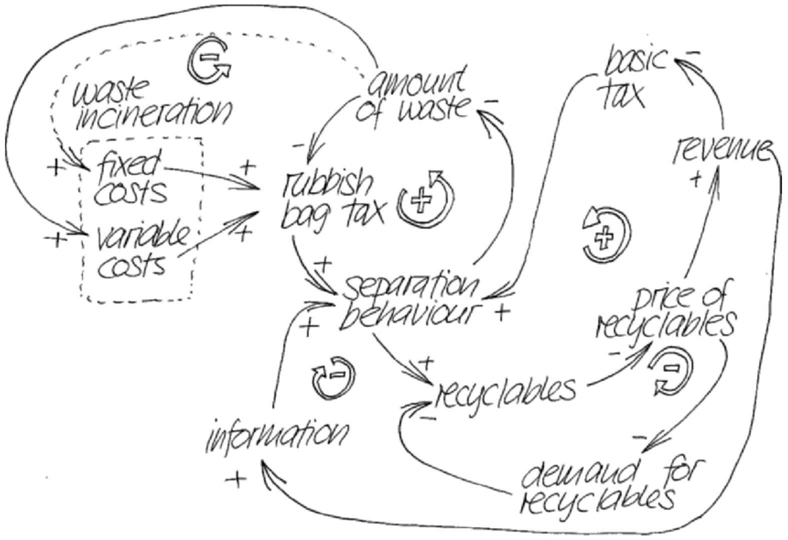


Figure 7.9. The socio-technical system of recycling and waste collection.

If there is feedback, further considerations are useful. Figure 7.9 shows for example that the rubbish bag tax influences the waste separation behaviour. The waste separation behaviour again influences the waste quantity and the waste quantity influences the bag fee. A plus sign marks a closed feedback loop with positive feedback. Negative feedback loops receive a minus sign. A feedback in a whole loop is positive, if the result of the multiplication of the algebraic signs of all the arrows of the loop is positive. If the product of the algebraic signs is negative, it is a negative feedback loop. This is why the feedback 'rubbish bag tax – waste separation behaviour - waste quantity' carries a minus sign.

The structure of the network of effects can now be illustrated in a further step in a symmetric matrix. If there is no relation between two elements of the network, this is indicated by a dash in figure 7.10.

The variable costs in figure 7.9 have a minor influence on the rubbish bag tax because they are clearly smaller in relation to the fixed costs. If the variable costs change, the influence on the rubbish bag tax is below average. This is indicated by a figure of '1' in the appropriate field of the matrix (figure 7.10).

on **Effect of....**	Variable costs	Fixed costs	Rubbish bag tax	Separation behaviour	Information	Amount of recyclables	Price of recyclables	Revenue	Basic fee	Demand for recyclables	Waste quantity
Variable costs	X	-	1	-	-	-	-	-	-	-	-
Fixed costs	-	X	3	-	-	-	-	-	-	-	-
Rubbish bag tax	-	-	X	3	-	-	-	-	-	-	-
Separ. behaviour	-	-	-	X	-	3	-	-	-	-	3
Information	-	-	-	1	X	-	-	-	-	-	-
Amount recycl.	-	-	-	-	-	X	2	-	-	-	-
Price recyclables	-	-	-	-	-	-	X	2	-	2	-
Revenue	-	-	-	-	1	-	-	X	2	-	-
Basic fee	-	-	-	2	-	-	-	-	X	-	-
Demand recycl.	-	-	-	-	-	2	-	-	-	X	-
Waste quantity	2	2	2	-	-	-	-	-	-	-	X

Figure 7.10. Matrix of influences.

The amount of recycables has a proportional influence on the price of recyclables. Therefore a '2' appears in the appropriate field. The influence of the fixed costs on the rubbish bag tax is above average. A '3' appears in the appropriate field.

In the next step the dominance D and receptivity R can be computed for each element examined. For this purpose the values in the individual rows and columns are added. Figure 7.11 shows these values.

on **Effect of....**	Variable costs	Fixed costs	Rubbish bag tax	Separation behaviour	Information	Amount of recyclables	Price of recyclables	Revenue	Basic fee	Demand for recyclables	Waste quantity	***Dominance D***
Variable costs	X	-	1	-	-	-	-	-	-	-	-	***1***
Fixed costs	-	X	3	-	-	-	-	-	-	-	-	***3***
Rubbish bag tax	-	-	X	3	-	-	-	-	-	-	-	***3***
Separ. behaviour	-	-	-	X	-	3	-	-	-	-	3	***6***
Information	-	-	-	1	X	-	-	-	-	-	-	***1***
Amount recycl.	-	-	-	-	-	X	2	-	-	-	-	***2***
Price recyclables	-	-	-	-	-	-	X	2	-	2	-	***4***
Revenue	-	-	-	-	1	-	-	X	2	-	-	***3***
Basic fee	-	-	-	2	-	-	-	-	X	-	-	***2***
Demand recycl.	-	-	-	-	-	2	-	-	-	X	-	***2***
Waste quantity	2	2	2	-	-	-	-	-	-	-	X	***6***
Receptivity R	***2***	***2***	***6***	***6***	***1***	***5***	***2***	***2***	***2***	***2***	***3***	***33***

Figure 7.11. Interfluencing Matrix of influences with appropriate sums D (dominance) und R (receptivity).

A large value of 'D' means that this element exerts a large influence on the other elements; a smaller value of 'D' indicates a small influence.

The value 'R' characterizes the receptivity e.g. shows how strong this element is influenced by the other elemants.

Thus a large value 'R' means that this element is strongly influenced by others.

The individual elements can be characterized as follows:

- *active elements with large 'D' and small 'R'*
- *passive (reactive) elements with small 'D' and large 'R'*
- *critical elements with large 'D' as well as large 'R'*
- *inert elements with small 'D' and small 'R'*

For the example rubbish 'bag tax' following picture is shown (figure 7.12).

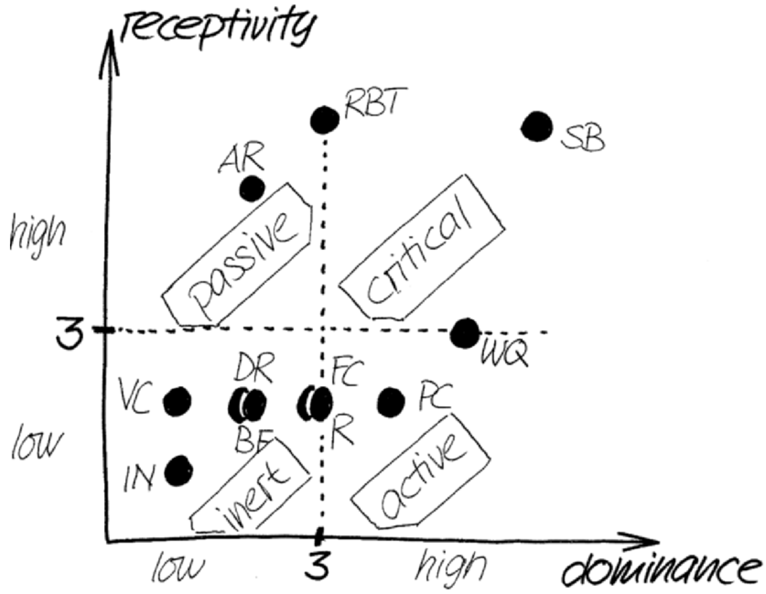


Figure 7.12. Classification of elements as active, passive, critical and inert elements.

The limits for small receptivity and for small dominance can be determined in a simple way. The sum of all the individual values in the matrix – in the example it is '33' – is divided by the number of elements of the matrix.

So, in the example, the result is '3' which is the upper limit for receptivity and dominance to be classified as small.

The question is now which system elements are able to influence a system effectively. These are called steering values.

- *Ideal steering values have a large 'D' with a small 'R', as for example the price of recyclables.*
- *The rubbish bag tax is both critical and passive. Because of its large receptivity and its small dominance it is not suited as a steering value.*
- *Basic fee and information are inert elements and are not suited as steering values.*

Apart from a qualitative assessment it is sometimes inevitable to analyse the cause-and-effect chains quantitatively in more detail. There exist scientific methods, such as the event-oriented simulation, to carry out such in-depth analyses. An example of an event-oriented simulation is found in the SE Case Book (Züst, Troxler (2002)).

The results of the search for solutions are documented in writing. This report has at least three groups of recipients with different needs:

- the client who has to decide about the remaining alternatives and the further procedure,
- the system designers who, in case of a positive decision, have to develop the concept further,
- the future users who have to assess the concept from their own point of view.

7.5 Summary

Starting point for the search for solutions (concept synthesis and analysis) are results and findings from the situation analysis as well as the catalogue of objectives with its mandatory, supplementary and best-case objectives. In particular the concept synthesis has to guarantee that as many solutions as possible are generated and that at the same time these solutions differ as much as possible. In the concept analysis, unsuited alternatives or deficiencies of individual solutions are recognized and eliminated. Improvements of solutions are initiated and the spectrum of alternatives is narrowed down using the mandatory and supplementary objectives from the catalogue of objectives in a detailed formal analysis.

Creativity, being of central importance in the concept synthesis, has to be promoted specifically. This can be achieved by reducing creativity barriers and by using special methods and techniques.

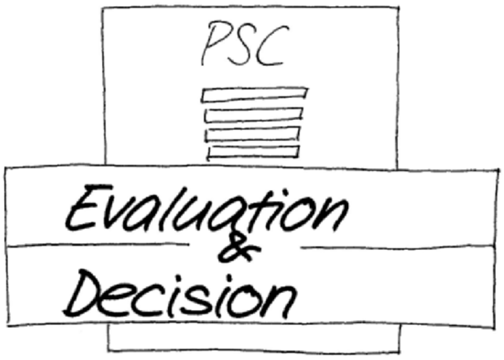
The individual solutions have to be expressed in concrete terms, refined and improved gradually. Applying the principles of ‘thinking in alternatives’ and ‘from general to detail’ consistently is of great importance in this planning step.

The most important aspects for the assessment of solutions are:

- fitness for purpose (normal situation, exception, malfunction) as well as functions and processes,
- integration into the meta-system,
- usability and maintenance,
- ease of implementation,
- necessary preconditions,
- comparability of alternatives.

The result of the concept synthesis and concept analysis is a list of possible solutions that fulfil mandatory and supplementary objectives.

8. SELECTION: EVALUATION AND DECISION



In the selection phase it is made transparent to everybody involved what the options are to choose from, how they are evaluated, and how a decision for one solution is reached. Particularly the evaluation of the options is carried out systematically and comprehensively. In that way the task of the decision makers to select one option as the (final) solution is supported so it can be easily documented and audited.

The selection is devided into two steps, 'evaluation' and 'decision'. The intention is to separate the two, preparing the decision, i.e. gathering all the relevant information the decision will be based on, and the actual decision-making. Suitable solution alternatives are assessed comprehensively, in particular based on the mandatory and supplementary objectives and any complementary criteria from the search for solutions. Such a procedure, which is supported with specific methods, guarantees that all relevant aspects for the decision are taken into account appropriately. Thus the risk of a naive, prejudiced or arbitrary decision is reduced. Additionally it promotes finding a consensus in group-based decisions.

The decision makers select the preferred solution and determine the further procedure. The decision by the decision makers themselves is an act of free will. The advantages and disadvantages of all options available should be known before a decision is made. However, the result of the decision depends on the values of the decision makers.

8.1 Selecting the Evaluation Method

Initially it must be clarified whether there is a preferred or binding way in which decisions are made. If this is not the case the question arises whether the decision needs methodical support. If so, the next question is which evaluation method or which combination of evaluation methods can be used in the given situation and whether their application makes sense.

Evaluation methods can be obtained from literature research (see the references section for guidance) and from expert surveys. It needs to be checked if they are applicable; the questions below can be used as a checklist:

- Which conditions have to be met so the chosen evaluation method can be applied? Are these conditions met?
- Which are the limiting factors for the application of the evaluation method? Do these apply? How do they influence the result?
- Which significance do the results have? Which uncertainties does the evaluation method contain?
- How much effort does the method require? Does the application of the appropriate method for the question make sense?
- Is the information the method requires available? Can it be obtained? Which uncertainties exist? Do the results justify the effort?

In a business context profitability usually has the greatest importance in decision-making. It is an attempt to express the financial consequences of a solution from certain aspects and given certain assumptions. There are a lot of methods for the evaluation of profitability, for instance:

- cost comparison
- profit comparison
- payback
- ROI
- net present value method
- cost benefit analysis
- cost efficiency analysis

In the context of Systems Engineering those evaluation methods are important that link both the economic and non-economic aspects systematically. In literature, the term ‘multidimensional criteria comparison’ is used for such methods. Because these evaluation methods also consider aspects that may not always be expressed in financial terms, they make more comprehensive decisions possible. Examples are:

- balance of reasons
- portfolio analyses
- environmental statements (Life Cycle Assessment)
- social statements
- ...

Frequently several evaluation methods are combined when evaluating solution alternatives.

The effort for the assessment of suitable evaluation methods and for the evaluation itself should not be underestimated. To actually use a certain evaluation method, usually additional information is needed. This information must be obtained and prepared, possibly by additional analyses.

8.2 Determining a Set of Criteria

A substantial element of a methodical evaluation is the set of criteria. ‘Criteria’ are variables that measure to what degree a solution meets its objectives. Discussing the ‘goal definition’ above, it was already mentioned that it is not always possible to define a measureable variable directly. All the criteria used in the evaluation are called the ‘set of criteria’ (figure 8.1).

The mandatory and supplementary objectives obtained in the goal definition phase, their characteristics and the corresponding, measurable targets are the primary basis for creating the set of criteria. If there are obvious and substantial differences in performance between some solutions that cannot be expressed in terms of the criteria derived from the catalogue of objectives, additional criteria may be defined.

The criteria have to meet the same formal requirements as the catalogue of objectives. The variables should be operational and measurable; the set of criteria must be balanced and complete in itself. No contradictions or redundancies are allowed between the individual criteria. Ideally the criteria should also be mutually independent.

In practice it is evident that using ‘mutually independent criteria’ is not as simple as it sounds. The example of buying a family home, below, illustrates this.

A family wants to purchase a new family home. After intensive discussion the following objectives are specified (figure 8.1):

Criteria	Quantity to be measured (objective revenue):
Number of rooms	Count of bedrooms and family rooms
Size of rooms	Area in square meters
Shape of rooms	Length of walls without windows and doors in relation to the perimeter
Location of the house	Distance to the neighbouring buildings, divided by the relative height of the neighbouring buildings
Plot area	Area in square meters
Capital expenditure	Cost in Euros

Figure 8.1. Set of criteria.

At first sight the criteria in figure 8.1 appear to be independent from each other. In a more detailed analysis we find that the individual criteria are interrelated:

- *For large rooms the shape of the rooms is less important because furnishing larger rooms is simpler.*
- *If capital expenditure is low and the plot area is large, the rooms may be smaller and the number of rooms may be lower because it might be possible to build an extension to the house.*

- *Capital expenditure is connected to most other criteria.*

Interrelations between criteria can be described in so-called ‘production rules’. A ‘production rule’ consists of a condition and a consequence in the form: if ‘A’ and ‘B’, then ‘C’, ‘D’ or ‘E’. The letters A, B, C, D and E describe conditions, actions, characteristics and more.

In the example of the family home, production rules can be set which reflect the values of the potential buyer:

Rule 1: *If the ‘plot area’ is large, then the ‘location of the house’ is rather insignificant.*

Rule 2: *If the ‘size of the rooms’ is large then the ‘shape of rooms’ is less important.*

Rule 3: *If ‘capital expenditure’ is small and the ‘plot area’ is large, then the ‘number of rooms’ is less important and the ‘size of the rooms’ is less important.*

The example above shows a nonlinear solution space. The interdependencies of the individual criteria must be considered when choosing an evaluation method and in particular during in the process of the evaluation.

Cross Reference to Cases in Chapter 9

In the planning example (case A) the catalogue of objectives is the basis of the evaluation. It is examined precisely to what degree mandatory and supplementary objectives are fulfilled. The results are presented graphically. Thus the interpretation of the results becomes easier.

8.3 Evaluation Procedure

Ecological life cycle assessments are challenging because they try to make certain statements about the complete product life cycle and about future user behaviour based on uncertain information. To deal with these challenges experts recommend a four-step, cyclical procedure, which can also be applied in Systems Engineering (figure 8.2):

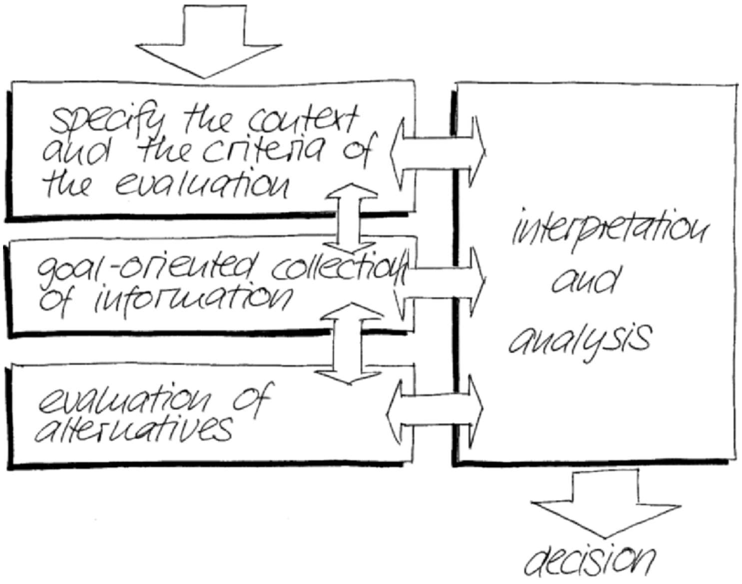


Figure 8.2. The four steps of a systematic evaluation, based on the method of life cycle assessments (ISO 14040 (1999)).

- ***Specify the context and the criteria of the evaluation:*** First, the context of the evaluation and its purpose are determined. This sets the boundaries for the investigations, guides the evaluation, and builds the basis for selecting the evaluation methods.
- ***Goal-oriented collection of information:*** As a second step, the information required is identified. The set of criteria is usually the basis for this activity.
- ***Evaluation of alternatives:*** The evaluation of alternatives is the core step of the evaluation. In this step the focus is on the evaluation of the characteristics of the different solution alternatives.
- ***Interpretation and analysis:*** Interpreting and analysing the evaluation results guarantees that the previous steps are reviewed critically and systematically.

The first two steps ‘specify the context and the criteria of the evaluation’ and ‘goal-oriented collection of information’, guarantee that the information for the evaluation is available. The step ‘evaluation of alternatives’ is the evaluation itself. In parallel to the first three steps a systematic ‘interpretation and analysis’ is required.

8.4 Application Examples

Below, two methodical approaches often used in SE are presented in more detail. These are:

- the balance of reasons as a purely qualitative approach and
- the quantitative cost-effectiveness analysis

8.4.1 The Balance of Reasons

The balance of reasons is a method combining aspects of more intuitive and more formal evaluation. In comparison to a purely intuitive evaluation it has the advantage that it can be audited if documented appropriately. Additionally, the balance of reasons can include aspects that are not easily expressed formally but still might be of substantial importance. The balance of reasons caters to the decision behaviour of many managers who prefer to form their opinion during a discussion about a problem.

A balance of reasons can be developed in the four steps presented above: ‘specify context and criteria of evaluation’, ‘goal-oriented collection of information’, ‘evaluation of alternatives’ and ‘interpretation and analysis’. The three examples below show the balance of reasons applied as part of the ‘evaluation of alternatives’. The examples illustrate how to ‘list advantages and disadvantages verbally’, ‘analysis of strengths, weaknesses, opportunities and threats’ and ‘grouping of criteria based on their importance’.

Example ‘listing advantages and disadvantages verbally’:

Advantages and disadvantages of alternatives to be evaluated have to be listed in verbal form. Thus, the evaluation takes place qualitatively. This approach is particularly relevant if information is incomplete or fuzzy.

In a preliminary study, for instance, solution concepts are often not described in enough detail to evaluate them quantitatively. The simple example below shows how a systematic, qualitative evaluation can be accomplished by means of a balance of reasons.

A student looks for the optimal means of commuting to university. Commuting to university during the coming winter term should be:

- *as cheap as possible P (cost in Euros),*
- *as quick as possible T (time in minutes),*
- *as ecological as possible E (noise and emissions),*
- *physically and mentally as little demanding as possible (D)*

In the search for solutions the student found three suitable alternatives:

- *Alternative I: car*
- *Alternative II: public transport*
- *Alternative III: bicycle*

These have to be evaluate (figure 8.3).

Criteria	***Alternative l car***	***Alternative ll public***	***Alternative lll bicycle***
Travel expenses (in €)	*8.—*	*7.—*	*1.—*
Travel time (in minutes)	*25 minutes*	*40 minutes*	*90 minutes*
ecological effects (noise and emissions)	*noise and emissions*	*noise*	*none*
physical (p) and mental (m) demands	*p: low* *m: yes*	*p: low* *m: no*	*p: large* *m: yes*

Figure 8.3. Effectiveness matrix for the ‘commuting to university’ example.

The criteria are:

- *travel expenses P (in Euros),*
- *travel time T (in minutes),*
- *ecological impact E (noise and emissions) and*
- *physical and mental demands D (exercise, driving responsibility).*

In this example the student describes the three alternatives in terms of the four criteria as summarised in the table below (figure 8.3). We call this table 'effectiveness matrix'.

The student now evaluates the individual effects in nominal values and documents this personal evaluation as shown in figure 8.4.

Criteria	***Alternative l car***	***Alternative ll public***	***Alternative lll bicycle***
Travel expenses	*high*	*moderate*	*very cheap*
Travel time	*short*	*moderate*	*long*
ecological effects	*high*	*low*	*negligible*
physical and mental load	*low and high*	*both low*	*both high*
Overall Evaluation	***insufficient***	***good***	***moderate to good***

Figure 8.4. Effectiveness matrix with nominal values and overall evaluation.

The student examines the influence of changing travel time on the effectiveness of solutions. Under the assumption that there will be more traffic jams in the future, the travel time for car travel will increase. Public traffic timetables will become more efficient in the foreseeable future. Therefore travel time will be reduced. These future scenarios, however, do not change anything overall evaluation. Thus using public transport remains the preferred way to commute.

Example ‘analysis of strengths, weaknesses, opportunities and threats’

Another possibility to establish a balance of reasons is listing strengths, weaknesses, opportunities and threats for the alternatives, which are all assumed to be realisable. The information collected in the situation analysis is re-used since the same analysis has been made for the existing situation during the analysis of the current state and the analysis of the future. The analysis could also just consider the opportunities and threats of each alternative.

To more easily visualise the evaluation of alternatives, this can also be done using the already existing diagrams of the analyses of strengths, weaknesses, opportunities and threats (see chapters 5.2.3 and 5.3.3). Differences between the existing solution and each alternative become obvious accordingly.

Analysing the strengths and weaknesses of a solution is particularly useful and recommended if it is based on fuzzy information.

	Evaluation		
Criteria	**–**	**~**	**++**
Number of rooms		**B**	**A**
Size of rooms		**A**	**B**
Floor plan		**B A**	
Location of the house	**A**	**B**	
Land area		**B**	**A**
Capital expenditure		**A**	**B**
Ecological construction	**B**		**A**
....	**...**	**...**	**...**

Figure 8.5. Analysis of strengths (++) and weaknesses (–) for the example of two family homes A and B (detailed reasons not given).

A family assesses two different family homes. The corresponding set of criteria has already been presented (figure 8.1). Below is the result of their analysis of strengths and weaknesses (figure 8.5).

> *Family home A has many medium sized rooms, a large property area, and it has been built ecologically. The strengths of the house B are the size of the individual rooms and the lower capital expenditure.*

To visualise strengths and weaknesses a radar diagram can be used. For each criterion the evaluation of each solution is shown in radial distance to the centre. If the solution is weak, it gets a mark close to the centre; if the solution is strong, it gets a mark far from the centre. For clarity, a line connects the marks for every solution. This representation is also called a polarity profile.

However, to visualise an evaluation as a radar diagram has several disadvantages. Firstly, the line suggests a connection between the criteria. Thus for instance people tend to read the area enclosed by this line as representing the quality of the solution. Yet since the individual criteria are usually different in their importance, but also due to general methodological considerations, this interpretation is not valid. Additionally, the size of the area is dependent on the order of the criteria; and the area increases with the square of the values of individual criteria.

Grouping of criteria based on their importance:

The evaluation of a balance of reasons or the analysis of strengths, weaknesses, opportunities and threats can be simplified by grouping the individual criteria according to their importance. Usually not all criteria carry the same weight (figure 8.6).

If very diverse alternatives have to be evaluated as shown in figure 8.6, it usually becomes evident that certain alternatives meet the most important criteria better than other alternatives. This may well be used to specifically exclude ‘weak’ alternatives. In the example, alternative A seems to be better than alternative B.

	Evaluation		
Important criteria	**–**	**~**	**++**
Ecological construction	**B**		**A**
Number of rooms		**B**	**A**
Land area		**B**	**A**
Capital expenditure		**A**	**B**

Unimportant criteria	**–**	**~**	**++**
Size of rooms		**A**	**B**
Shape of rooms		**B A**	
Location of the house	**A**	**B**	
…….	**…**	**…**	**…**

Figure 8.6. Analysis of strengths and weaknesses grouped according to the importance of the criteria for the example of evaluating a family home.

8.4.2 Cost-Benefit Analysis

In contrast to the balance of reasons, the cost-benefit analysis focuses on quantified statements. It calculates the relation of the benefit of a certain solution to the expenditure (cost):

$$\text{Cost-Benefit} = f\,(\text{benefit, expenditure}) = \frac{\text{Benefit}}{\text{Expenditure}}$$

The benefit (or profit) can be expressed not only in financial terms, but also as the sum of weighted partial values of benefit as used in a cost-benefit analysis. This is recommended when multi-dimensional objectives exist that cannot be expressed in financial terms. Expenditure is typically expressed in financial terms.

8.5 Decision

To reach a decision, two preconditions have to be met: the evaluation of alternatives needs to be completed and the decision makers need to have the authority to make the decision. Typically the decision makers and the designer of the system are not the same people. Implementing new solutions often leads to interferences with and changes to existing systems that have substantial consequences. The designers of the system typically cannot have the authority to decide on these consequences.

The process of making a decision can be divided into different steps:

- Presentation of alternatives:
  The alternatives must be presented neutrally to the decision makers.
- Evaluation of the alternatives:
  Subsequently the evaluation of the alternatives has to be pre sented. This includes the selected criteria, the evaluation methods, together with the reasons for their selection and application. In this phase, decision makers might want to impose different values or add additional knowledge.
- Decision-making:
  Apart from the results of a formal evaluation, the decision makers' personal interests, intuitions and emotions are part of the decision. However, attention has to be paid that personal interests do not dominate decisions.
- Rationale:
  Specifically stating the rationale for a decision supports rational and auditable decision-making.
- Documentation:
  A clear presentation of the reasons and the considerations that led to a decision are the basis for a smooth implementation of the selected solution. The documentation should contain at least the description of the solution as well as schedule, necessary resources and the responsibilities for its realisation.

8.6 Summary

The selection concludes the problem solving cycle. It consists of the evaluation of the suitable alternatives from the concept analysis, and a subsequent decision.

This is the basis for an evaluation:

- the catalogue of objectives compiled in the goal definition,
- additional criteria for the evaluation and
- the list of alternatives deemed suitable in the concept analysis.

Evaluation is the preparation of a decision. It is always based on subjective values and subjective interpretations of facts.

The decision is an act of the decision makers' free will. The decision maker can be an individual person, a committee or a planning team.

Methodically preparing a decision aims at

- making the decision process transparent and
- presenting all the essential information for a decision to the decision makers in a clear form.

The balance of reasons is used in particular in the case of multidisciplinary problems, if information is uncertain, or if criteria are interdependent and do not permit to calculate an aggregate value. Additionally, the decision makers can easily compare the advantages and disadvantages of a solution.

Using further methods can additionally support such a selection process. There are many references in literature how to draw up a balance of reasons and how it can support the decision-making process. Therefore, it has to be examined when selecting evaluation methods, which methods might be used generally or in what combinations. The importance of the balance of reasons as a method should not be underestimated. It can be applied in the most different areas and in the most diverse ways.

The result of the evaluation is a proposal for a decision that includes indications how to proceed in case of a positive decision.

9. CASES

The SE methodology is not only suitable for engineering problems, its real strengths only become apparent in solving more complex problems – such as setting up and rolling out an Environmental Management System (EMS), planning communication infrastructures, or repositioning a product platform in the marketplace.

These three case studies are selected from our collection published in 2002. The cases tell how practitioners applied the SE methodology in real life situations. The authors let us participate in their experiences in a way how no textbook could do it: Every problem has its unique ambiguities and contradictions, which requires engineers and managers to skillfully and considerately interpret the methodology to bring its power to fruition in the particular circumstances of the individual project. In this way these cases are more like stories than textbook examples, the authors let us participate in their exciting struggle of applying pure teaching to their, the practitioners' reality.

Our notes relate the stories of the actual projects to the overarching concepts of the SE methodology. So we are able to demonstrate how SE professionals apply the methodology to real-life projects. This opens a different, more intuitive approach to understanding the SE methodology.

9.1 CASE A – Introduction of an Environmental Management System (EMS) at Volvo

by Gabriel Caduff

9.1.1 Introduction

All companies that have something to do with a Volvo car in the course of its live have to introduce an environmental management system based on the requirements of the Volvo Environmental Management System. This implementation has to be completed for importers until the year 2000 and for dealerships until the year 2002.

In 1998 the search for a solution for an effective environmental management system started in Switzerland. The system needed to be developed, introduced and put into operation rapidly and with as little resources as possible, and it needed to suit the importer, Volvo

Automobile (Switzerland) AG (VASAG), and all eighty Volvo representatives in Switzerland.

Volvo succeeded to find an economical solution despite difficult conditions, using Systems Engineering, and especially a comprehensive situation analysis. The solution basically is a third party certification according to ISO 14001 of the importer, and the creation of a specific environmental label according to ISO 14024 for the representatives.

At the beginning of 1998 the environmental officer of VASAG, Lotta Stridbeck, had many questions. How many elements does an environmental management system need? How can they be implemented? How can it be introduced at all representatives? Etc. After a short time she became aware that the implementation of an environmental management system was not as simple as she thought and that additional knowledge and a systematic approach was necessary for the solution.

At a meeting in Adelboden in autumn 1998, I met Lotta Stridbeck personally. She started to tell me about her job at Volvo and that she needed support. Since environmental management is my field of expertise I could convince her that I could give her the support she needed. After a short discussion, the idea to initially develop a concept applying the methods of Systems Engineering was quickly taken up.

What is an Environmental Management System?

An environmental management system, according to ISO 14001, has the objective to continuously improve the environmental performance of the activities, products and services of a company. In order to reach this objective, the company has to, above all, introduce different management procedures and apply them periodically. The procedures focus on executive tasks such as planning, decision-making, execution, and monitoring and checks (figure 9.1); these are discussed in detail below.

- In accordance with the requirements of ISO 14001 the improvements primarily have to be made where the organisation has the largest environmental impacts. Activities, products or services that have an important effect on the environment have to be determined first and their product life cycle has to be evaluated (‘relevant environmental aspects’).

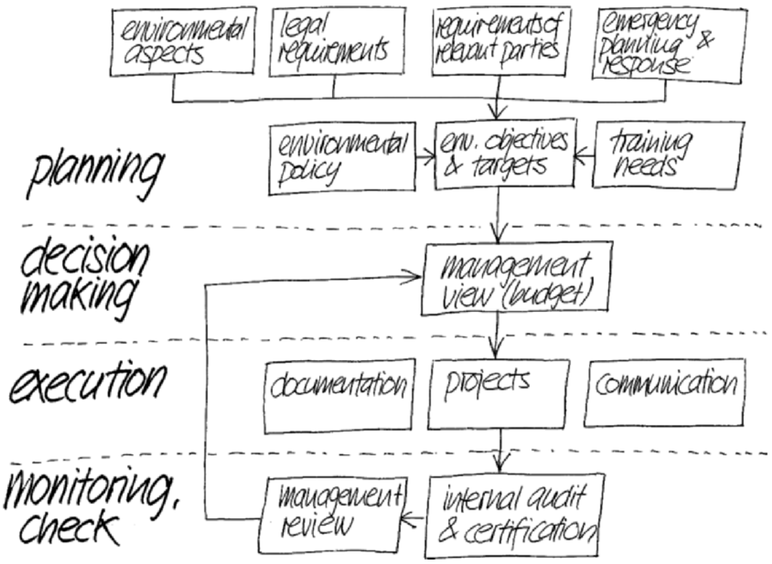


Figure 9.1. Essential elements of an EMS based on ISO 14001.

- By introducing an environmental management system the company also commits itself to compliance with environmental laws. This has to be evaluated regularly with a specific procedure. Thus the company's own responsibility becomes more important than the law-enforcement by authorities ('legal requirements').
- Environmental concerns of relevant parties have to collected and evaluated. The term 'relevant' or 'interested parties' describes individuals or groups who feel affected by the environmental performance of the company ('requirements of relevant parties').
- In order to prevent possible impacts of environmental emergencies, risks have to be assessed and suitable measures have to be planned, implemented and possibly tested ('emergency planning and response').

- The environmental policy defines the importance of environmental protection within the company and expresses the values of the company's management. Essential items of the environmental policy are the obligation to continuously improve the environmental performance and compliance with environmental laws. The environmental policy must be accessible for the public ('environmental policy').
- To be able to master these requirements, the relevant knowledge has to be available. If there is a knowledge gap it has to be filled ('training needs').
- Environmental objectives have to be consistent with the environmental policy and aim at the improvement of the environmental performance on the basis of the requirements specified above. A small number of clearly defined objectives that are regularly revised usually shows the best results. How, by which means and by whom the defined objectives have to be reached, is shown in the environmental programs. If ecological improvements are implemented effectively and efficiently, economic improvements will follow ('environmental objectives and programs').
- The top management decides, on the basis of operational capabilities, which objectives and programs are to be implemented, and issues the appropriate instructions. This so-called management view is an integrated component of budget approval ('management view (budget)').
- Environmental programs are projects that can be implemented based on the rules of project management ('projects').
- In order to guarantee tasks are auditable, they have tasks to be documented and communicated ('communication' and 'documentation').
- The compliance with the requirements of the standard ISO 14001 is tested in an audit of the controls. This audit specifically checks if environmental objectives are met and programs are executed. There is a difference between internal and external audit. External audits include certifications and regular audits by a certifying body ('internal audit and certification').

- In the management review, the top management evaluates the environmental management system as a whole and its interaction with other activities. Based on the results the individual elements of the EMS are evaluated and adapted if necessary. According to ISO 14001, the management review starts the process of continuous improvement afresh by the formulation of new objectives and programs. The management review is usually a component of the audit ('management review').

The Contract is Awarded

Some time passed until Lotta Stridbeck got permission to start the project. The management of VASAG was not easily convinced that the proposed results could be delivered. They did not want a concept but clear results in the form of a certified management system. However, the introduction of environmental management systems at all the 80 Volvo dealerships in Switzerland would have caused substantial expenditure and would have been hardly manageable, particularly for small enterprises. The requirement for a certified environmental system at all dealerships is based on the conditions in Sweden where they have between 100 and 300 employees, whereas in Switzerland they have only between 5 and 30.

Only a cost estimation convinced Hans E. Eklund, the general manager of the VASAG at that time, of the need for a solid concept. In February 1999 he gave the written instructuion to develop a concept for the implementation of an effective and efficient environmental management system with the Volvo representatives, which fulfilled the requirements of the Volvo Environmental Management System (VEMS) and considered the specific conditions in Switzerland as well. The actual work, however, had already started, right after the verbal promise in December 1998.

Comment:

Clarifying the task at the beginning of the project has central relevance. The example here shows clearly that the more systematic a task is analysed and possibly adapted, additional solution might be found. The solution space is therefore larger, and really new solutions might now be possible. In this planning example there is scope for innovative solutions.

Once we had the official go-ahead, Lotta and myself started planning the work. Situation analysis, goal definition and the search for solutions including their individual elements were planned out over the next four months. Based on experience we allowed more than half of the time for the situation analysis, actually more than two months. We fixed various project meetings, and we set up two extra project management meetings with our reviewers. The reviewers checked the project in terms of progress and content as a third party. Additionally, meetings were arranged with important stakeholders which were a selection of Volvo representatives, a certification body and the Swiss accreditation office.

Comment:

The first project phase was structured according to the problem solving cycle. A relatively large proportion of time was allocated to the situation analysis. This was necessary in the present case because the actual direction of the solution was not yet clear. An intense analysis, directed mainly at parties outside VASAG, should guarantee that the solution would be viable and could be integrated into its environment. Typically this kind of emphasis emerges during the situation analysis of a preliminary study or a possibly of a main study.

9.1.2 Study

Situation Analysis

Defining the system boundaries was one of the first tasks. We decided to include all elements that could possibly influence in the system. Thus the system boundaries were defined rather widely (figure 9.2).

Comment:

Defining system boundaries aims to specify the area that may be changed in the project and thus the degrees of freedom a project team has or does not have. Defining the system boundaries has another effect that should not be underestimated. When creating a representation of the system the participants of the project develop a shared model of the system to be designed and of its relevant context. This is one of the bases for success in future cooperation.

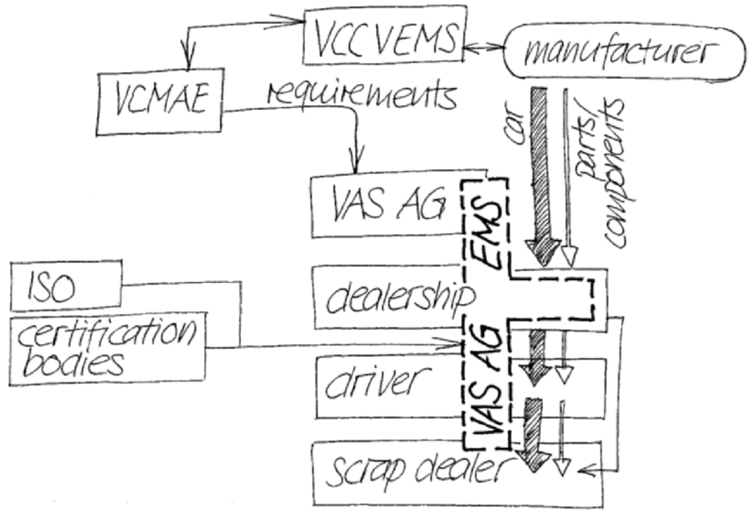


Figure 9.2. The environmental management system of VASAG with influencing elements.

In a next step, the elements shown in figure 9.2 were evaluated in regard to their contents, to their relations to further elements, and to the requirements of an environmental management system. The most important results were: Firstly, the guidelines of the VEMS essentially coincide with the requirements of the ISO 14001 respectively with the European environmental audit regulation (EMAS). Secondly, certification or validation by an independent organisation is required.

The dealerships were the most critical element. They had almost no financial or personnel resources available to introduce an environmental management system.

A comparison with other countries did not lead to any new information. Apart from Scandinavia, the other European countries were not even one step ahead introducing environmental management systems. As already mentioned above, the Scandinavian experience could not be transferred to Switzerland.

A substantial constraint for an environmental management system according to ISO is that the organisation to be certified has to be legally independent in terms of its function and responsibility. This means that a certification of all representatives as a collective was not possible.

The ISO 14001 standard is not the only standard for environmental management. From the entire family of standards, which consists of over 20 standards, ISO 14020, environmental labelling and environmental declarations, was of particular interest to us. As long as certain conditions are met, specific requirements can be defined for an environmental label of type I (ISO 14024). An independent body awards the label to every interested organisation if this organisation meets the specific requirements.

Comment:

The situation analysis is not only limited to the system to be designed. It is equally important to recognise important variables from the context or environment of the system and their influence.

What are Our Objectives?

Based on the knowledge of the situation we agreed to setting up the following catalogue of objectives with the company management of VASAG (figure 9.3).

Comment:

This catalogue of objectives shows what the new solution has to achieve and what it has to avoid. It consists of ten system objectives and two process objectives (with reference to timeframes), thus it is sufficiently detailed and still manageable. The column ‘type of objective’ indicates which objectives are mandatory (e.g. mandatory objectives and their restrictions) and which are supplementary (optimisation objectives). Additionally the boundary conditions point out constraints for the project. The client should formally agree the catalogue of objectives.

Which Solutions are Possible?

In the context of the search for solutions a set of potential solutions were found. Some of these ideas had to be discarded, since they would not meet mandatory objectives or constraints.

Objective definition	**Measure**	**Type of objective**
minimal total costs for system introduction	working days	S
minimal total costs for system operation	working days	S
minimal introduction costs for the dealerships	max 10.000 CHF (inclusive internal expenditure)	M
minimal operational costs for the dealerships	max 5.000 CHF (inclusive internal expenditure)	M
maximize financial benefit	payback period max. 3 years	M
secure maximum system efficiency for the dealerships	influence of VASAG	S
use synergies with existing management systems whenever as possible	proportion of use of elements of existing systems	S
secure modularity to ISO 9000	yes/no	M
maximize identification of involved employees with the EMS	proportion of system elements developed by employees themselves	S
communicate the environmental effort to the customers as simple as possible	public recognition of the award	S
finish introduction of the EMS at VASAG in time	deadline December 2000	M
finish introduction of the EMS at the dealerships in time	deadline December 2000	M
fulfilment of VEMS requirements, fulfilment of ISO requirements		M

Figure 9.3. Catalogue of objectives.

Comment:

In the first step of the concept synthesis, when ‘incrementally developing and separating solution ideas’, a wide range of ideas is encouraged. These ideas are then compared with the mandatory objectives and constraints. Unsuitable ideas are discarded immediately; the others are developed and detailed further.

Below is a list of some of the solutions that were identified:

Collective certification:

To reduce the effort for introduction, maintenance and certification to a minimum, VASAG and all its dealerships could participate in only one single environmental management system that would be certified (figure 9.3).

Concept analysis: This option does not comply with ISO, which forbids that several independent organisations obtain a certificate collectively (principle of independence of the EN 45012 (mod. for EMS), EA-7/02 and SAS N 511.d).

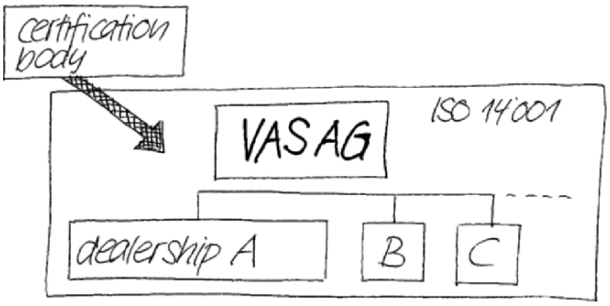


Figure 9.3. Collective certification.

Individual certification:

VASAG and all dealerships individually introduce their own environmental management systems. The environmental management systems are subsequently certified individually (figure 9.4).

Concept analysis: This option does not violate any ISO rule. The introduction and maintenance costs requested in the catalogue of objectives might only be met if synergies are used during the introduction and maintenance of the individual systems.

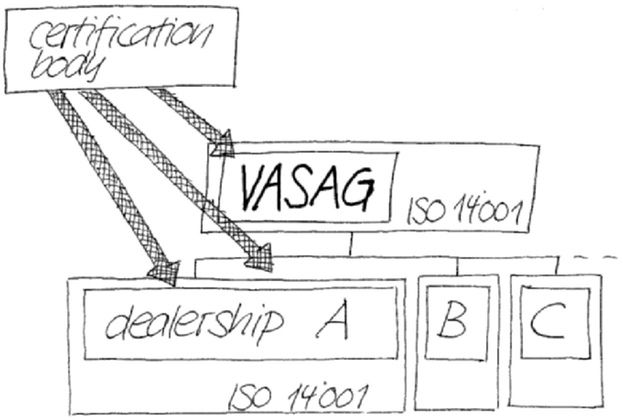


Figure 9.4. Individual certification.

Group certification:

Independent certification of VASAG according to ISO 14001, grouping of similar dealerships that develop a collective environmental management system. VASAG and each individual group are certified separately (figure 9.5).

Concept analysis: This option does not comply with the ISO rule, according to which independent organisations cannot be grouped to obtain a collective certificate (principle of independence of the EN 45012 (mod. for EMS), EA-7/02 and SAS N 511.d).

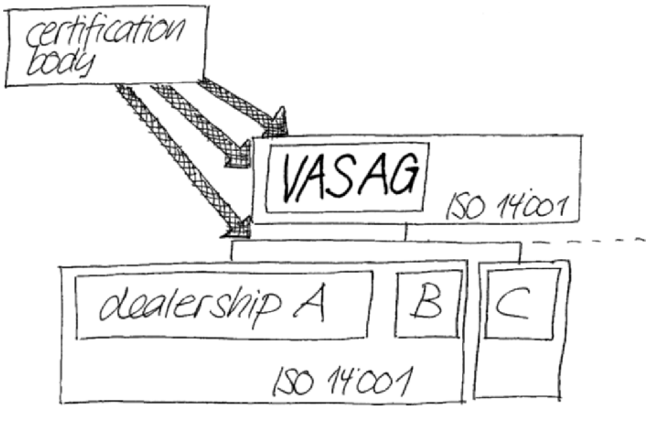


Figure 9.5. Group certification.

Partial certification:

VASAG develops an environmental management system according to ISO 14001. Mechanisms are included in the system to check how environmental requirements are to be determined, communicated and examined for the dealerships. It would be also conceivable that VASAG carries out environmental audits at the dealerships (figure 9.6).

Concept analysis: This option contradicts VEMS which requires dealerships to be certified by an independent third party organisation.

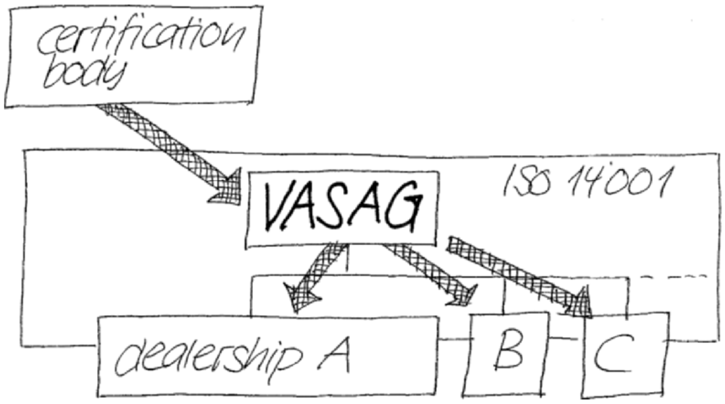


Figure 9.6. Partial certification.

Self-certification:

VASAG introduces an environmental management system according to ISO 14001 and gets accredited as a certification body itself. Thus VASAG is able to certify its representatives (figure 9.7).

Concept analysis: This option is contradictory to VEMS which requires the dealerships to be certified by an independent third party organisation. However the solution complies with the ISO rules.

Environmental label according to ISO 14024:

VASAG introduces an environmental management system according to ISO 14001. For the dealerships, an environmental label is developed according to ISO 14024, which covers the demands of the VEMS. The certification of the dealerships can be done by an independent third party organisation (figure 9.8).

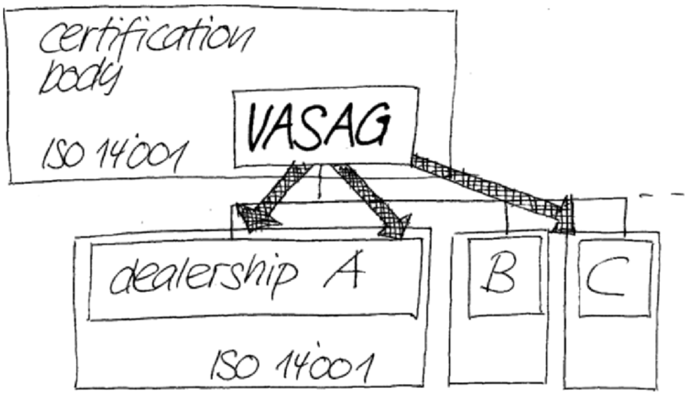


Figure 9.7. Self-certification.

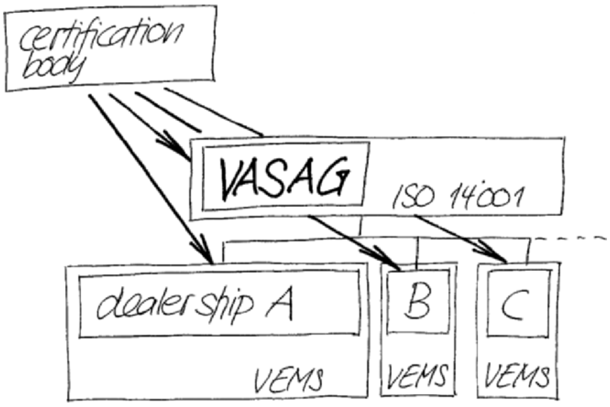


Figure 9.8. Environmental label according to ISO 14024.

Concept analysis: The environmental label can be designed in such a way that all constraints can be fulfilled.

Conclusions from the Search for Solutions

Only the two options ‘individual certification’ and ‘environmental label’ are suitable solutions. They are described in more detail below.

Analysis of the option ‘individual certification’

In this option VASAG and each Volvo dealership introduce an environmental management system based on the requirements of ISO 14001 and VEMS. They are individually certified according to ISO 14001 as independent units.

If choosing this option it would be sensible to introduce the environmental management systems in two phases. In phase 1, VASAG and one or two representatives should introduce an EMS. Based on their experiences, the EMS is introduced at the remaining representatives in a second phase. In order to make optimal use of synergies, introduction and certification have to happen simultaneously at all dealerships in the second phase.

The introduction of the EMS can be supported by regular workshops. The environmental officers of the individual dealerships would have to carry out certain tasks on their own between the individual workshops. An optimal group size for the workshops would be 5 to 10 participants. So dealerships from the same region, e.g. differentiated by language, could attend the same workshop.

Analysis of the option ‘environmental label’

Only VASAG introduces an environmental management system according to ISO 14001 and has it certified by an external certification body. Additionally, VASAG issues requirements for an environmental management system at the representatives. The representatives introduce their environmental management system according to these requirements. If a representative fulfils these requirements, they are awarded an ISO compliant label by an external certification body. For the label to be valid internationally, the corresponding requirements set out by VASAG need to be approved by an external certification body. This external certification body needs to be accredited with the Swiss Accreditation Service (SAS).

Implementing the relevant procedures for an environmental label is basically done in two phases. The first phase covers the certification of VASAG's EMS according to ISO 14001, and the second phase defining and awarding the label. In analogy to the suggestions for 'individual certification', the label can be awarded initially to one or two representatives. In order to make use of synergies during the award process, it has to be scheduled appropriately.

Awarding labels gives VASAG more control than the introduction of individual environmental management systems. Additionally the label offers differentiation possibilities compared to ISO 14001 certificates. It is easily possible to demand higher requirements than those of the ISO 14001 standard. In particular, labels can define specific and quantified requirements as far as the environmental performance is concerned. Further, the term ISO, which is well known with customers, can also be used in connection with the label.

Comment:

In this project, two options comply with the mandatory objectives and constraints. These two options have to be assessed in regard to the objectives of the client.

Evaluation and Recommendation

The evaluation of the two options is based on the catalogue of objectives. As shown in figure 9.9, the option 'environmental label' fulfils the defined objectives better than the option 'individual certification', except for the criterion 'identification of the employees with the (self) defined EMS'.

Lotta presented the two options and their advantages and disadvantages on 29th of March 1999 at a management meeting. The minutes of the meeting summarised the decision: 'The management of VASAG decided to implement VEMS by establishing an environmental management system according to ISO 14001 for VASAG and a label according to ISO 14024 for its Swiss Volvo representatives.'

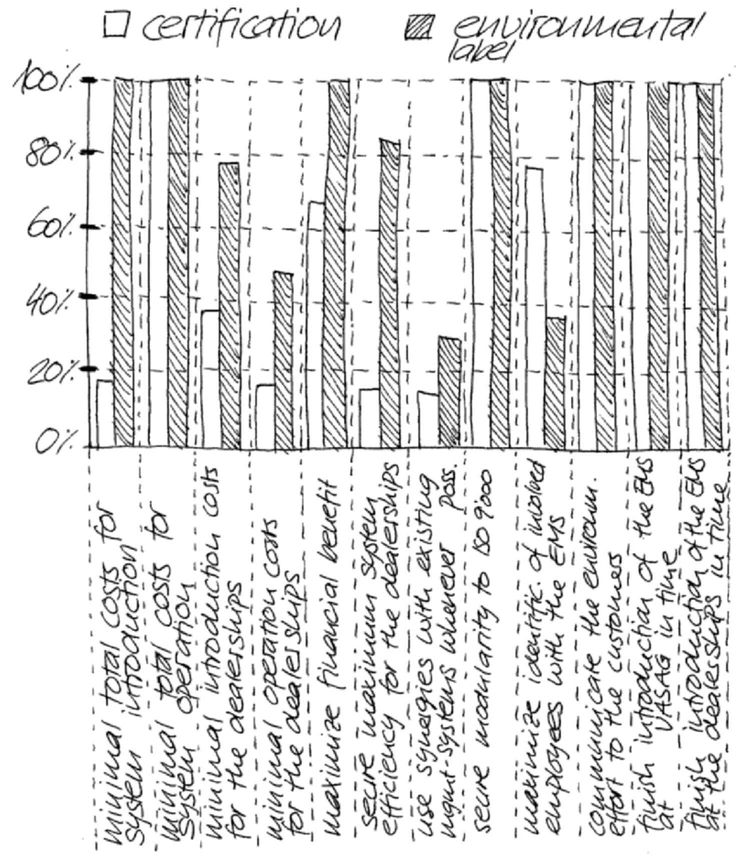


Figure 9.9. Assessment of the two options in terms of VASAG’s objectives.

The decision for the option ‘environmental label’, which was promoted mainly by Hans E. Eklund, though being obvious, was nevertheless courageous. Obviously, VASAG secured the support of Krister Larsson, director of quality and environment of the Volvo Car Corporation in Gothenburg. A label according to ISO 14024 was new territory for all participants. The ISO 14024 standard had only published shortly before that decision. So, there was no prior experience whatsoever. However, the implementation proved the decision right.

Comment:

After the decision of the management the concept is now clear, that is, the direction in which the new EMS has to be developed. A framework has been set for the general solution. All parts of the system developed and implemented subsequently have to be within this framework.

Although the solution has only been outlined in general terms, the majority of its consequences have been determined. So, in practice, the early phases of a project deserve particular attention.

When developing the solution further and when planning the implementation of the individual elements of the system, the methods of system engineering can be applied. The problem solving cycle described above can be used for the development of the EMS as well as for the design of the environmental label.

9.1.3 What's Next?

In summer 2000, VASAG was certified according to the international standards for environmental management, ISO 14001. The environmental label was developed by VASAG, in cooperation with Tensor Environmental Consulting AG and the Swiss Organisation for Quality and Management Systems (SQS). It is characterised by management and performance requirements tiered to the size of the dealerships.

The introduction of the environmental label at the dealerships was done through workshops and took approximately eight months. It was concluded with the audit and certification of each dealership by SQS, when the dealerships were awarded the environmental label. During the audit it was checked whether the dealership met all requirements according to its individual situation, whether the dealership could already show first improvements, and whether the management system was developed and introduced in a way that guaranteed continuous improvement of the dealership's environmental performance. After the label has been awarded, the dealership has to demonstrate annually how it improves its environmental performance. A comprehensive audit occurs only every third year.

The dealerships Hüsser & Palkoska in Baar and Klingental Garage in Basel were the first to be awarded the environmental label in accordance with ISO 14024 in December 2000. In February 2001, two further pilot dealerships followed, the Gill-Garage in Ebnat Kappel as the smallest Volvo dealership in Europe, and Barth AG in Bern. In March 2001, the label was successfully awarded to the last pilot, Baldegger AG in St. Gallen. Based on the experience with these five pilot representatives, the workshops were adapted slightly.

Comment:

‘Participation’ was a central element of this project. For this purpose workshops were run with the future users of the system. Frequently project managers forget, that people have to accept new solutions, which often is easier if they feel being part of the solution.

Currently work is done to raise the public awareness of the environmental label and to make it available for dealerships of other car manufacturers. Further Volvo dealerships acquired the necessary knowledge in five-day-workshops run by Tensor Environmental Consulting AG and developed their own individual environmental management system within approximately eight months.

In addition to the time spent in workshops, the employees of a dealership spent approximately five working days to establish the structure of their own systems. Together with the other simplifications for certification, this resulted in substantial savings in costs and expenditure compared to an environmental management system according to ISO 14001. In addition the pilot application of the system at selected dealerships proved that the assumptions made developing the concept were correct. Most objectives could be met.

9.2 CASE B – Cantonal Communication Network KOMNET

by Oliver Vaterlaus

9.2.1 Introduction

Only two years after the government’s decision, the communication network KOMNET could start its operation successfully. It connects all the 180 offices of the cantonal administration with 90 municipalities and the national administration.

The project started with a meeting of representatives of the canton, the municipalities and a private application provider. They developed the vision to establish a common communication network that connected all offices of the local and cantonal administrations.

To realise the project, Systems Engineering was applied thoroughly since it was the preferred method of the consultancy company that was brought in to lead the project. The success of the project was a result of splitting the project into well-defined project phases, of systematically involving the participants in all phases of the project, and of setting out clearly what intermediate results could be expected from every phase. Below, the project manager recounts his experience of applying Systems Engineering in this project.

New Project is Created

Two attempts to establish and use the synergies of a joint communication network for the communal and cantonal administrations had already failed. Due to historical reasons, two physically different networks were operated and maintained, with overlaps in several areas. One network connected the cantonal administration and the police, the other network connected most of the municipal administrations. The situation was dissatisfying. The proper operation of the networks required more and more know-how and resources. Outsourcing was considered a possible solution.

The cantonal finances minister, the president of the association of municipalities, and the chairman of the board of the application provider that run the municipal network started a new attempt, a few months before the end of the year. For the first time an unemotional discussion on a matter-of-fact basis was possible, and completely new solution approaches could be identified.

At the end all participants were convinced that the cooperation of all parties potentially had high synergies and that this could bring not only a better performance of the network, but also large cost advantages. The project KOMNET was born and the three parties formed a contracting body.

Comment:

The project is now positioned on a higher problem level. The solution space could be enlarged as the canton, the municipalities and the application provider jointly approached the problem. In the context of Systems Engineering this is called extending the intervention system. Instead of isolated solutions, comprehensive integrated solutions become possible.

The Project is Prepared

The contracting body quickly agreed on the project objectives:

- to establish a single network with a uniform communication infrastructure within the canton
- to achieve 100% area coverage on municipal and cantonal level
- to establish a separate body that would be responsible for the network and would monitor the performance of the network operator according to well-defined performance standards.

Comment:

These objectives cover technical, operational and organisational aspects. Outsourcing is a possible solution but it is not predetermined. Equally it is not predetermined how the operation of the network would be realised.

The contracting body decided to split the project into individual phases, at the end of each phase it would be decided if and how the project would be continued. The consultants of AWK Engineering AG proposed to use Systems Engineering as a method, which was agreed.

The project phases were defined according to the Life Cycle Model:

- Preliminary study: analysis of the requirements and the needs of the users, technical preparation of different solution principles
- Main study: specification of solution principles for the general concept, detailed cost estimation for the establishment and the operation of KOMNET and for the technical preparation of a reasonable network organisation
- Detailed study: detailed specification, preparation of a system specification for the evaluation of tenders for network operation
- System realisation: call for tenders, evaluation of offers and conclusion of the contract

- System introduction: install KOMNET and start its operation, functionality test of the system and adaptations
- Project completion: final works and review

As a last step the contracting body defined an effective project organisation. It was clear to everybody that the complexity, the different interests and the financial implications of the project had to be considered in the project organisation. This was done as shown below (figure 9.10).

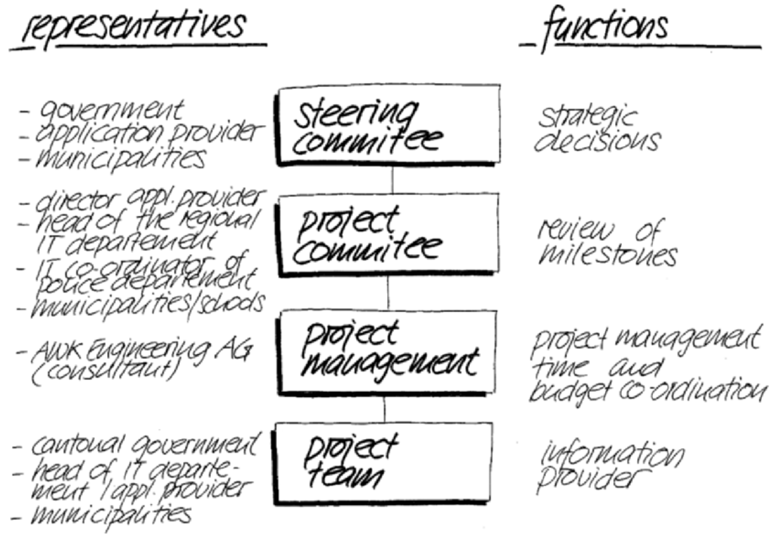


Figure 9.10. Project organisation.

- Steering committee: responsible for important milestones. The first decision was planned for the end of the main study
- Project committee: review of all milestones
- Project management: due to the complexity of the project an external consultancy was hired for the project management. From three candidates the independent engineering and consulting company AWK Engineering AG was selected. The task of AWK was to manage the project team consisting of representatives of the different user groups and the of current network operator

- Project team: The proposed members of the project team were formally nominated by the contracting body and by AWK Engineering AG.

9.2.2 Preliminary Study – Develop Solution Principles

An extensive analysis of the actual and future situation became really important because there already was a history of two failed attempts and because of the large number of participants. Thus an airtight and accepted basis to define the requirements for KOMNET had to be created. In the first step the project manager planned the resources and milestone dates for the complete project. Furthermore he organised a kick-off meeting where the project organisation was constituted, the project and the project objectives were defined, the scheduling was discussed and dates for further appointments were set.

Comment:

The preliminary study is supposed to define the actual problem, the basic requirements for the solution, different solution principles e.g. potential strategic directions, and to show a selection of them.

The project manager conducted interviews with the current network operators, i.e. the IT officers of the cantonal administration, of the cantonal police and of the application providers, he requested inventory lists of the current network components, studied existing documents and guidelines and analysed the current cost situation. The project manager also talked to the people responsible for telephony. The question if speech and data integration with newest technologies would be economical had also to be answered in the project. Based on the results of the analysis of the current state, an analysis of strengths and weaknesses was carried out. As an immediate measure all investments in the existing networks were cancelled.

Comment:

The numerous bits of information of the analysis of the current state can be summarised in a analysis of strengths and weaknesses. This usually requires intensive reflection because the aim is to find a few but very significant statements.

A broad and well-founded analysis of the future completed the analysis of the current state. The project manager conducted interviews with many additional persons. The results were pooled in an analysis of opportunities and threats. After the situation analysis the project teams started to define detailed requirements for KOMNET and presented them in a catalogue of objectives.

Comment:

The direction of the solution is roughly defined with the catalogue of objectives. Therefore it makes sense that the deciding parties agree upon and approve the catalogue of objectives respectively the identification of the problem during the situation analysis.

In the next phase, the concept synthesis and concept analysis, the project team started to develop different ideas for solutions.

- Two to three technologies were quickly identified as solutions that were adequate for establishing different logical networks with only one physical infrastructure. Other technologies were rejected.
- Regarding the operation of the network, the focus was primarily on the question of outsourcing. Here even temporary solutions were possible. To produce and test possible solutions, a morphological chart was developed.

The technical and operational solutions were identified separately and then discussed and combined to one solution in a workshop with the project team. The different combinations were examined for their basic suitability. Two options were recommended for further development.

- In-house development: the network would be built by the canton. Different technologies would be possible, for example 'Asynchronous Transfer Mode' (ATM), 'Synchronous Digital Hierarchy' (SDH) or 'Frame Relay' (FR). The operation of the network would be carried out by the cantonal IT department or by a partner. This would have to be examined further.
- Outsourcing: complete outsourcing of the network; neither the canton nor the municipalities would buy any equipment. An external partner would establish, operate and finance the network for a fixed fee.

Costing and financing models and the details of operating the network were intentionally not considered in the preliminary study. These questions had to be addressed in the main study. The decision which option to realise could not be made in the preliminary study. Six months after the start of the project, the steering committee accepted the recommendation of the project team to further develop the two options in-house development and outsourcing. This lead to a main study that had to develop two different solutions into a concepts – an interesting but extensive task.

Comment:

It is very well possible that the preliminary study does not lead to a clear-cut decision. In this example, two completely different solutions had to be developed further. This is not unusual for a complex question. In such a situation the preliminary study could be extended or the two solutions could be detailed in the main study. Considering the consequences of a wrong decision, the extra work is justified.

9.2.3 Main Study – Concepts are Developed

At the end of the main study, all the information needed to be available to support a qualified decision for one of the options, in-house development or outsourcing, with all their technical, organisational, operational and economical consequences. In a first step, the project team started to define the option in-house development. Different technologies were analysed and processed on a detailed level. We don’t report the detailed technical discussion but list a few key elements for better understanding instead:

- Cable infrastructure: to connect all buildings there were no alternatives to the existing rented cabling. The fibre optic cables along the motorways, owned by the canton, were available as a backbone. Using these cables would not necessarily be less expensive than renting cables.
- Network topology: The network topology was more or less predetermined by the geographical situation of the canton and by the location of the connections. The project team developed a model network that distinguished the two options with and without the use of the fibre optic cables along the motorways.

- Network technology: Basically different network technologies can be used; additionally they can be combined with each other.

The project team developed different technology options in detail. These options were examined for their advantages and disadvantages with an analysis of strengths and weaknesses.

Comment:

The analysis of strengths and weaknesses can not only be used in the situation analysis but also when different options are assessed.

The differences were marginal. In the first step the project team focused on the option in-house development. A detailed cost calculation was made. One result for example was, that to build and operate a proprietary network would only be economical for about 250 or more network connections (see figure 9.11). In the KOMNET project the number of network connections was 270 in the first stage which was just above the minimum limit for a cost-efficient operation. The number of network connections would be rising in the foreseeable future, so the costs per network connection would drop.

The interesting elements of the cost estimation were not the absolute values but the influence of several parameters on the expected costs, as for example the discount structure of network rental prices, the number of physical network connections, or the expected life span of KOMNET. Varying these parameters, however, showed similar results. In a second step the project team developed the option outsourcing in detail. The project team quickly agreed that everything, even up to the network connection components in the individual buildings, would have to be installed and operated by a third party to be able to use all synergies in an optimal way. Hereby the level of outsourcing was defined.

The project team also discussed operational aspects because outsourcing would require an additional coordination unit which would act as a clearing centre between the technical operator (outsourcing partner) and the users in regard to technical and operational matters. The coordination unit would be called KOMNET Coordination Unit (see figure 9.12).

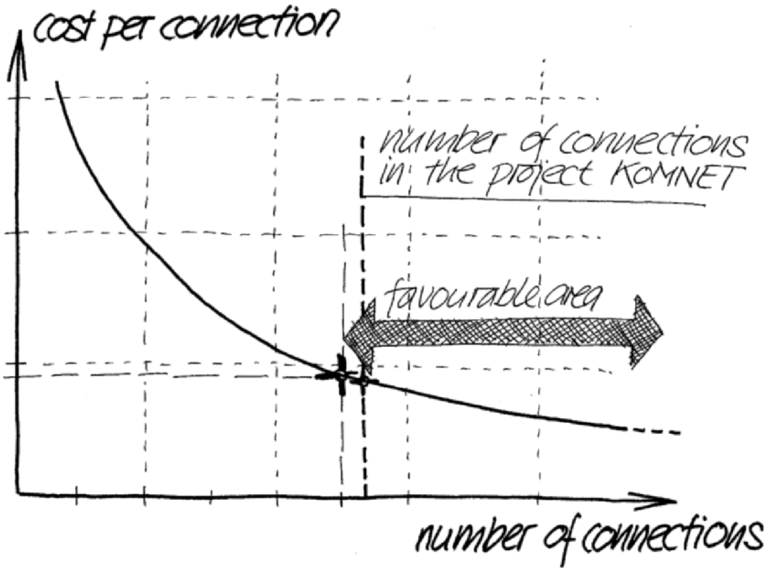


Figure 9.11. Costs per network connection depending on the number of physical network connections.

The option outsourcing had already been preferred in the preliminary study. It fulfilled all the requirements of the client and it had certain important advantages over the option in-house development. Particularly it promised to be more flexible and to reduce dependence on the increasingly shorter product development cycles. These two reasons and the fact that outsourcing involved none or very little investments lead the project committee and the steering committee to decide in favour of outsourcing at a milestone meeting in summer 1998. In-house development should only be reconsidered if no suitable outsourcing provider could be found.

Comment:

The extra effort for the development of two technical concepts in the project KOMNET was not wasted. The extra information was an essential basis for the development of the specification document and for the later evaluation of the received offers.

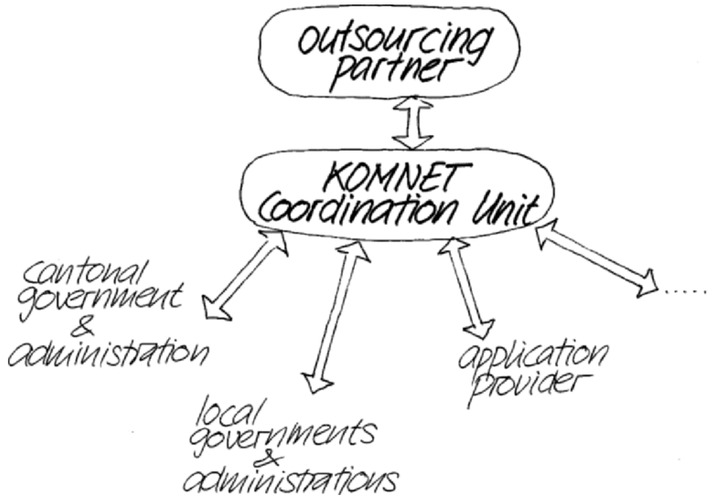


Figure 9.12. Possible organisational structure with the KOMNET Coordination Unit liaising between users and operators.

9.2.4 Detailed Study – Requirements are Specified

After this milestone decision the project team had the task to refine the concept and to specify the resources and processes for KOMNET as accurately and unmistakably as possible. Such a total package consisting of technical and operational services is often also called a ‘service level agreement’ (SLA or service agreement). A SLA defines the technical and the operational framework and requirements and is the basis for any cooperation with potential system providers. Apart from the specification of the SLA the project team developed the requirement specification purposefully in such a way that the detailed offers would be comparable and would leave the potential providers with sufficient freedom to suggest innovative solutions.

In many projects, an SLA is only prepared after the tenders have been received or when contract negotiations have already started. In the KOMNET project, the project team decided to specify the SLA parameters already in the requirement specification, for one simple reason: bidders are often under such enormous competitive pressure that they easily accept certain requirements of the contract in order to be considered in the evaluation. In the contract negotiations the bidders know that their offer is interesting and competitive. Later on they will not easily agree to additional requirements that are hard to fulfil.

In autumn 1998, the detailed requirements were available which contained a 'service level agreement' in addition to the actual specification. They were adopted by the project committee in their next milestone meeting.

9.2.5 System Realisation – the Search for a Network Operator

Due to the financial volume of the KOMNET project it had to be put to tender according to WTO procedures. Strict guidelines had to be obeyed so that all bidders had equal opportunities and none of them was unduly preferred in any way.

The tender for the KOMNET project was published in the appropriate media in particular in the 'Swiss Official Gazette of Commerce', the official journal of Switzerland, at the end of autumn 1998. Eleven bidders stated their interest and obtained the requirements specification. When examining the requirements specification, some bidders asked questions which had to be addressed to the project manager in writing. According to the WTO guidelines, the answers to these questions had to be sent to all bidders.

Two offers were submitted to the project manager within the required period. The project manager and a further witness opened the offers, and minutes were taken. Receiving only two offers was not due to a lack of interest but to the fact that Swisscom, the former national telephone company, still virtually had a monopoly on the last mile connections, therefore all bidders relied on rental lines from Swisscom for their network connection to the individual buildings.

The project team based the evaluation on three aspects:

- Benefit: the benefit was determined using pre-defined criteria and their weighting. The information was taken from a questionnaire that was enclosed with the requirement specification that hat do be filled in by the bidders.

- Cost analysis: the costs of the two offers were revised and compared to each other.
- Quality: this aspect served for the evaluation of the general impression of the offer.

Offer 1 clearly had a higher benefit than offer 2. At first a cost comparison was not possible because the offer of bidder 2 was very general and allowed no conclusions over the expenses that would effectively be incurred. Additional clarifications were necessary while still adhering to the WTO guidelines.

The evaluation lead to the conclusion that the offer from bidder 1 could be characterised as very good whereas the offer of bidder 2 was insufficient and could not be counted as a valuable alternative (figure 9.13).

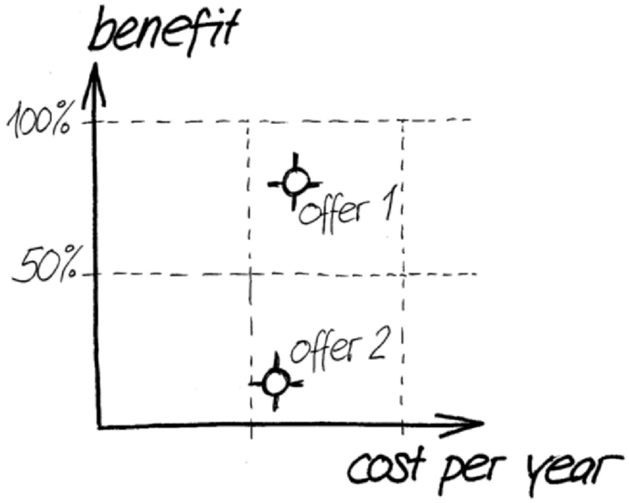


Figure 9.13. Cost benefit portfolio for both offers.

It was easy for the project team to agree with the project committee and for the steering committee to eliminate bidder 2 and start negotiations with bidder 1.

Comment:

In the project ‘costs’, ‘benefits’ and the ‘quality as general impression of the solution’ were used as the three main criteria. The parameters were examined separately and put in reference to each other afterwards (see figure 9.13). Intentionally, the project team did not use a full aggregation such as for example a ‘Nutzwertanalyse’. The three criteria are interdependent. Thus a network situation had to be evaluated. In such a situation the values of each single criterion cannot be aggregated to total value by multiplication or addition.

It proved to be good that the ‘service level agreements’ were already specified in detail in the requirement specification. In the contract negotiations only details had to be clarified. For example a negotiator interrupted a longer detailed discussion with the remark: ‘Why do a few Francs matter when the bigger “nails” are already banged in anyway’. This gave the negotiations a personal, friendly and partly even funny touch, which was a good foundation for a five-year cooperation. This was extremely important because everyone who already experienced an outsourcing project knows: the key of success is a good, mutual relationship based on partnership and trust. There are no examples of successful outsourcing project with each party only trying to make the best for themselves.

Furthermore the question was still open whether outsourcing of KOMNET was actually more economical than in-house development. The results were as follows:

- Compared to extending the existing network, outsourcing of KOMNET was approximately 25 per cent cheaper.
- Compared to an in-house development of KOMNET. outsourcing was approximately 15 to 20 per cheaper.

In a milestone meeting about one year after the start of the project the steering committee and the project board agreed on the evaluation procedure and the draft of the contract. The contract had also to be approved by the bodies involved before it could be signed.

9.2.6 System Installation – KOMNET is Installed

The installation of KOMNET with its 270 connections within six months was a project for itself. Six months are approximately 120 working days. Every day two to three new connections had to be realised. In order to realise a connection, on the one hand a cable to the respective building had to be established, on the other hand various installations in the buildings, many times in security sensitive areas e.g. with access restrictions, had to be accomplished. In addition to that configuration and tests of the individual connection components had to be carried out before the transfer to the new network. Furthermore the backbone of the network had to be developed and configured. Spring of 1999 was entirely dedicated to the detailed planning of the system installation.

The project team also had the task to prepare the future accounting model in detail, to develop the KOMNET organisation, to form its legal framework, and to source the personnel. Different alternatives for the organisation were examined, from becoming part of public administration to founding a company or an association, and then evaluated in regard to their suitability. Based on an analysis of the strengths and weaknesses of the individual alternatives, the project team clearly decided in favour of an association. One reason was that this form of organisation seems to be well-suited for a non-profit organisation. Secondly the weighting of the individual parties could be managed simply through the number of members and even further parties could be accepted at any time later. But the work was not done yet: The development of the articles of the association proved to be very difficult; in return the following first meeting went according to plan. The the association had an office that took over the tasks that were already described for the coordination office.

Comment:

In the implementation phase of KOMNET further parts of the system were developed, as for example the ‘accounting model’. To develop such tasks in further detail only makes sense when the basic circumstances are clearly fixed. A preliminary clarification would only be necessary if there was a danger that the involved parties could not agree on an accounting model easily.

The project KOMNET was concluded in a formal act of acceptance. Representatives of the contracting body and the provider compared the goods and services ordered with the ones delivered. Specifically they examined the completeness of the documentation. Since only smaller deficiencies were detected, the acceptance could be completed successfully and was minuted accordingly. The deficiencies were collected in a list of deficiencies, and their elimination was put on record in a regulation of remedy. Thus KOMNET was operational; the operation of the two original networks could be ceased.

Comment:

Apart from the technical implementation, numerous organisational and operational aspects had to be clarified during the realisation phase, and the individual operational processes had to be refined, documented and implemented. These tasks are often underestimated and can't be started early enough.

9.2.7 Project Completion

KOMNET went operational in just under two years, after a realisation phase of six months. Apart from the actual communication network, the operational and organisational structures for effective and efficient operation over the next five years were realized and, if necessary, resourced with personnel. In autumn, just under two years after the project start, the project KOMNET could be regarded as completed. The project organisation was transformed into the operational organisation that was established during the introduction phase to run KOMNET over the five years of planned operation. A ceremonial opening with important persons from politics and media marked the inauguration of KOMNET and illustrated the completion of a complex and ambitious project that was very successful and satisfactory for all parties.

9.3 CASE C – Market Success with Systematic Product Planning

by Stefano M. Achermann

9.3.1 Introduction

Different stakeholders often perceive complex problems differently. This case study shows how important it is to analyse and structure the problem systematically. This can be costly and requires a systematic procedure.

The case describes how a group of products of a medium sized company with about 100 employees that had not enough success in the market could be improved considerably and permanently.

In particular, methodological aspects in regard to the complexity of the task are emphasized. A special characteristic of this case is the combined application of SE concepts and portfolio and value analysis.

Why this Project?

Filtronix AG had been manufacturing clean room equipment for 40 years. The company was founded by Viktor Jausslin who brought the idea from the USA where he stayed with his uncle Albert after his studies. Uncle Albert was employed in a management position at the R&D laboratory of Micropollution and called his nephew's attention to a development that was quite advanced in the USA at that time: The market for clean room and laboratory equipment had grown remarkably, driven by the fast growing biotechnology and micro-biology industry. Micropollution – one of the biggest American producers of this kind of equipment – could increase its turnover by more than 15% annually. With the support of his uncle, Viktor Jausslin's company Filtronix became the general importer for Micropollution's products in Switzerland. Jausslin turned out to be an excellent salesman and an innovative spirit. At the beginning of the 80s, Filtronix was a prospering wholesale company, selling, servicing and maintaining clean room equipment in Switzerland.

This intensive growth wore on Jausslin's strengths. Because of resulting health problems, his doctor recommended to cut down activities. With a heavy heart, he decided to sell his company. The new owners, an international holding company active in different businesses, had to promise to keep the 30 employees of Filtronix, which they did. The alliance of Filtronix with the new owners, however, only lasted three years. In the course of a strategic reorientation the business area clean room technology was abandoned. Filtronix was to be sold again. With the financial support of Jausslin who never lost contact with his former managers, the three-man management team accomplished a management buyout. Jausslin became chairman of the board but left the executive management to the three partners.

In the following years, Filtronix had increasing problems with procurement. Continuously rising wholesale prices of their American suppliers and unfavourable exchange rates influenced the profit situation negatively. On the 1st of April of 1988, Jausslin called a meeting with the general management to discuss the situation. He proposed to start the development of their own products to reduce the dependency from the American procurement market. There was a tempered discussion about this new strategy. Finally, Jausslin prevailed late in the evening. It was decided to establish a design department to develop equipment for clean rooms. The strategy was to have all equipment manufactured by third parties. Slowly, Filtronix developed equipment; most of it customised products that were sold very successfully.

In four years the turnover doubled. Filtronix had changed from a national wholesale company to an internationally active company that had about 70% of its products manufactured by third parties. The workforce increased to 70 people over this period. When a trend to a more flexible use of laboratories and laboratory equipment emerged in 1992, Filtronix took the chance to start a new product group. User requirements changed more quickly, so equipment had to be able to be rearranged in the laboratory more flexibly to enable optimal work processes. Yet, traditional laboratory equipment used to be firmly attached to the buildings and furnished with fixed supply systems (power, water, gas, air-conditioning, etc.). If one was to change the use of a piece of equipment, time and cost intensive modifications to the building infrastructure were necessary.

In this situation a large Swiss chemical company in Basel established an interdisciplinary team to should investigate the flexible use of laboratories and the lab technology its environmental impact. The main problem was the extractor hoods used in laboratories at that time. Isolated work places prevented the spread of polluting gases into the surrounding laboratory space. This required large air channels that limited the flexible use of a building considerably. The laboratory technology design office of that chemical company developed a system specification for a new product generation that would solve every weakness they spotted. They also built a prototype themselves, however it did not meet their expectations. The attempt to find a European producer for extractor hoods for the project failed, because production costs would have been too high and development time too long. Dr. Marc Lachapelle, chemist and head of R&D at Filtronix, learned about the project by chance from a friend whom he had known during his time working at that chemical company. Filtronix was producing conventional extractor hoods, and became interested in the project. With the active support of Jausslin, Filtronix built a functional prototype, four laboratory devices for the chemical company and one device for security tests within only six months. Quickly the German Institute for Standardisation approved the conformity of the device with the relevant DIN standards. The chemical company awarded Filtronix the worldwide license to market this product idea.

Until today Filtronix has produced, installed and successfully sold a remarkable quantity of these devices. Although the devices had considerable advantages in terms of quality compared with their main competitors, the economic success did not develop as planned. At a management meeting, called for the analysis of the unpleasant situation, Dr. Lachapelle and Martin Bodmer, head of sales, got into a row. Bodmer blaimed Dr. Lachapelle for including the new product into the product range without a systematic market analysis. Dr. Lachapelle defended his product with the argument that no other competitive product had comparable performance features. All the users in the laboratories only gave good feedback on the product. The problem would be in the sales process itself. Sales responded to price discussion with luscious discounts instead of emphasizing the high performance and the quality of the product.

Comment:

When reviewing why the project was started, the first hints about the differing views of the problem the various partners held and and about possible objects of investigation emerge. Positioning the product in the marketplace seems to be one of the main issues in the case of Filtronix.

Jausslin had to use all his influence to calm down the disputing partners. He was convinced that the high production costs and therefore the high sales price were the cause for the dissatisfactory revenue situation of the new device. Therefore he advised his partners to engage a consultant who should propose recommendations for how to half the production costs. Jausslin was surprised when his proposal found general acceptance. He contacted me the next day. I accepted the mandate, well knowing that it was a complex, interdisciplinary problem.

How Did We Approach the Task?

Because of the lack of secured facts, we agreed to carry out a situation analysis in the form of a preliminary study.

Comment:

The real problem was not known at that time. Information about possibly successful directions was missing, i.e. it was still open where to look for solutions. In this situation it makes sense to carry out a preliminary study to get some clarification.

First I started to analyse the task at hand. This meant:

- identify problem areas
- define project objectives and general framework
- outline the boundaries of the study
- define the process organisation of the project
- structure the project in functional phases

The five steps are described in detail below.

With the support of Jausslin I organised different interviews with members of the management and selected employees. As expected, the identification of problem areas was very difficult because of different points of view. The question ‘what the product should deliver’ was not answered unanimously. I remembered a conversation with Jausslin, on the occasion of the acceptance of the mandate, when he mentioned that he would not accept to reduce the functionality of the product as a solution. An almost unsolvable problem if the production costs should be cut in half. The technicians found it impossible; sales found it not enough. On the other hand, to me it was clear that the potential for cutting down the production costs was highly dependent on the product’s performance characteristics. The question had to be clarified which characteristics of the product were necessary. I started to make a draft (figure 9.14) that outlined the determinants of the product’s success and their interconnections in a visual form as a basis for discussion.

Comment:

Shared models, even in the form of hand drawings, are important elements of problem solving in teams. The objective of creating a model is to structure the situation and to create a shared understanding and shared expectations of all participants.

I took the drawing to our next meeting where I proposed the new definition of the problem and a new project objective to Jausslin. The basic problem we would address would be the lack of competitive advantage rather than the high production costs. Product characteristics that did not meet a market requirement could also be part of the problem. The characteristics of the product had initially been determined according to the requirements of the licensor, yet they

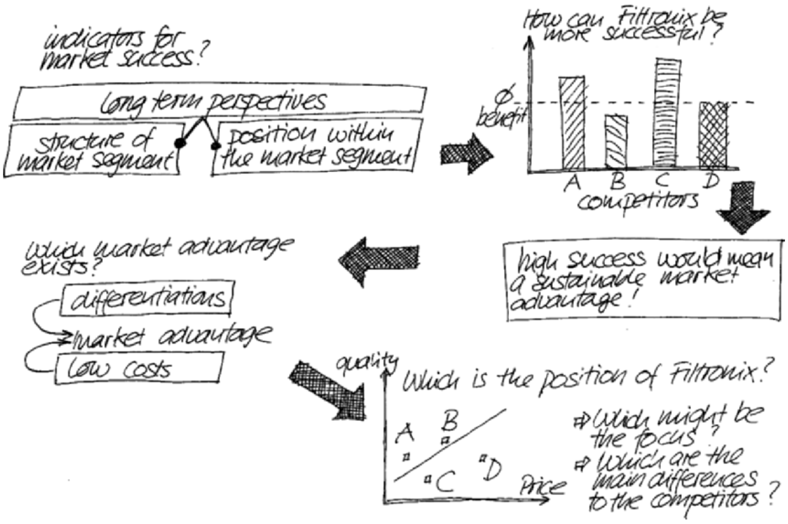


Figure 9.14. Draft of the determinants of the product's success and their interconnections.

had never been reviewed since the development of the device eight years ago. How the market and the customer requirements had developed would have to be taken into account. As the new objective of the project, I proposed to improve the competitive advantage of the device. Jausslin followed my presentation attentively and agreed with my understanding of the problem. However, he feared that a time consuming analysis would compromise our time schedule.

Comment:

The original objective to 'cut production costs in half' was not solution neutral for the actual problem of a insufficient market success. This illustrates that it is sensible to do a task analysis at the beginning of a project.

Apparently I was able to dispel the fears of Jausslin. Shortly after our meeting I received a note from him stating that the project should be started with the changed project objective and respecting these conditions or degrees of freedom:

- Design and material changes were allowed. The outer dimensions of the device, however, could not be changed.

- According to the manufacturing strategy, all sub-assemblies and components would have to be sourced from third parties. The final assembly would still be done in-house.
- The predetermined project deadlines had to be met.
- The day-to-day business must not be affected by the project.

Based on the changed project objective, it became clear that the customer requirements and the main competitors had to be examined in the project (figure 9.15).

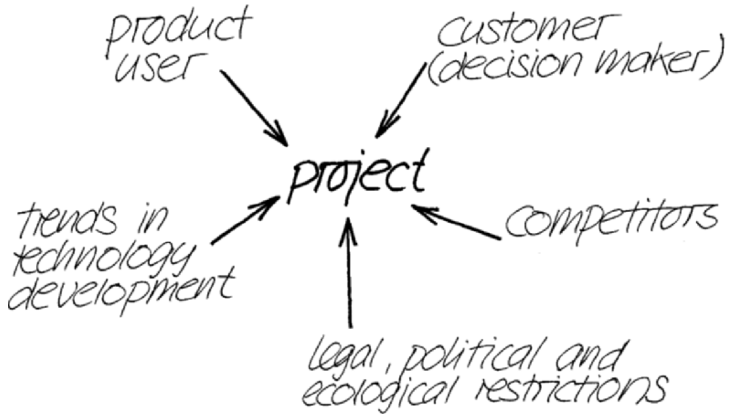


Figure 9.15. The most important parameters of the project.

Furthermore, it was recognized that in many cases the actual users of the product were not identical with the persons deciding about the purchase of the product.

The management structure for the project was derived from the project tasks. I took over the role of the project manager and coordinator. In this role I was responsible for the methods used and the progress of the project in terms of results, deadlines and costs. Furthermore, I would allocate my time and know how to develop solutions for partial problems. The steering committee of the project, consisting of Jausslin (chairman of the board), Bodmer (head of sales) and myself, would decide on strategic questions. According to the task, R&D, sales, procurement and manufacturing sent one representative to form the project team.

To account for the complexity of the problem and based on the experience I had from similar projects it was agreed to structure the project according to the proven phases of SE, however in a slightly adapted form (figure 9.16).

Level	***Key questions***
Strategic level	How should the product perform? How much is the customer willing to pay for it? What are the target production costs and the target costs per function?
Product design	Which technologies allow to realises the required functions with the least costs?

Figure 9.16. Phases of the project indicating relevant problem areas.

It was decided to carry out a preliminary study with a comprehensive situation analysis (figure 9.17).

Comment:

In contrast to the classical Life Cycle Model of Systems Engineering, in this project there was no main study that would end with a decision about the overall concept. To completely redevelop the product was out of question. Additionally, the preliminary study was expected to include a comprehensive situation analysis that would deliver the necessary information to develop a solution for the problem, to assess its consequences and to identify any prerequisites to implement it. Four critical problem areas had already been identified in the project proposal. They each would be investigated separately. The separate solutions would then be consolidated into an overall solution.

It was agreed to review the strategic positioning of the product as a general, high-level analysis. The aim of this analysis was to give directions to the search for solutions for the product design on a secondary level of analysis. Additionally, value analysis would support the customer oriented optimisation of the product. To reduce the complexity of the problem it was agreed to closely examine, on a strategic level, the customer benefits, the competitive advantages and disadvantages, and the position of the product in the marketplace. This would result in a strategic decision about the desired position of the product (figure 9.17).

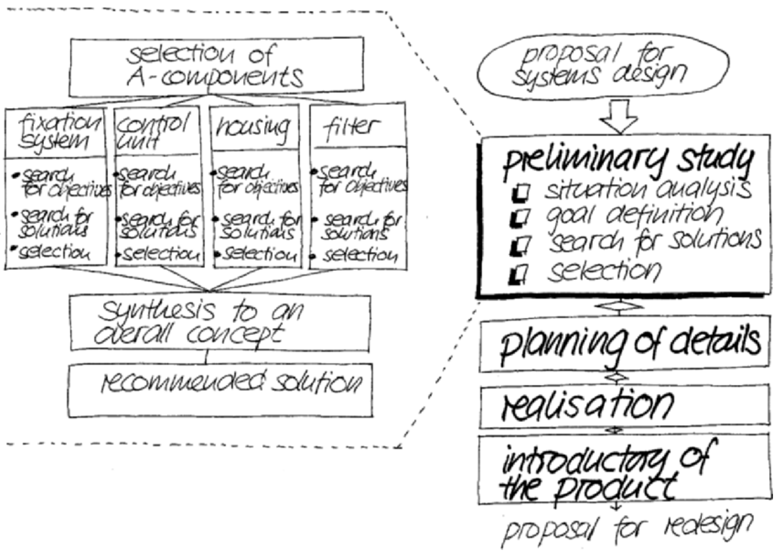


Figure 9.17. From general to detail: different levels of analysis and key questions.

9.3.2 Preliminary Study

The preliminary study would be carried out according to an agreed project plan (figure 9.18).

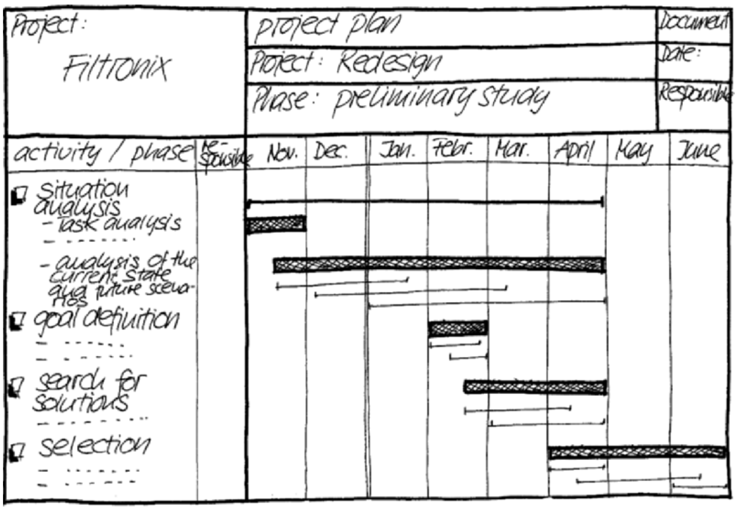


Figure 9.18. Project plan.

Comment:

The action plan in figure 9.18 reflects a cyclical procedure: parts of the problem solving cycle are run in parallel. Additionally, the action plan shows that the focus of the work is on the situation analysis and the goal definition. This relative importance of the activities is typical for a preliminary study.

Below, we describe four parts of the analysis of the current state in more detail:

- customer benefits and strategic position of the product
- overall cost analysis
- identify the functions for the value analysis and
- determine the cost contribution for each function.

customers benefits/reasons to buy the product		**year of investigation:**	
business unit:	**product**	**date of investigation:**	
market segment:	**new design**		

Source: own evaluation and evaluation by decision maker

user criteria **(not price related)**	**importance for the customer in %**	**customer related evaluation** (0 = very bad; 10 = excellent)				
		own product	**product of competitor**			
			A	**B**	**C**	**D**
product related criteria						
compliance with standards	9	6	9	10	8	8
operation costs	12	7	6	7	6	7
additional infrastructure needed	18	9	6	6	5	6
flexibility in the use of the product	15	9	6	6	5	6
risk of damaging people's health	10	8	6	7	6	7
risk of fire	12	9	4	4	5	4
environmentally friendly	7	8	5	5	5	5
design/attractivity of the product	4	7	5	6	5	4
ergonomic design	5	7	7	7	6	7
service related criteria						
service and maintenance	8	6	7	6	6	8
overall benefit	100					
price [index]		100	33	30 - 50	30 - 50	30 - 50
market share [%] (Switzerland / Germany)		3 / 0	50 / 0	20 / 30	5 / 15	20 / 0

customer's decision	*relevance of benefit*	35
to buy the product	*relevance of price*	65
		100

competitor
A:
B:
C:
D:

Figure 9.19. Customer benefits for the market segment ‘new development’

Customer Benefit and Strategic Position of the Product

Based on Filtronix' own assessment and on the opinions of selected customers the reasons to buy a product and their importance in the customers' views were identified. Subsequently the product of Filtronix and the products of its main competitors were rated on how they would meet these criteria.

As I had presumed and expected, the process of defining the customer benefit was accompanied by discussions about the present and future needs in the marketplace. In retrospective, this intensive examination of the customer benefits was very fruitful. The analysis of the customer benefits (figure 9.19) showed that for all the important and very important criteria for the purchase decision (value higher than 8) the product of Filtronix had higher competitive advantages, with exception of the criteria of conformity with standards (figure 9.20).

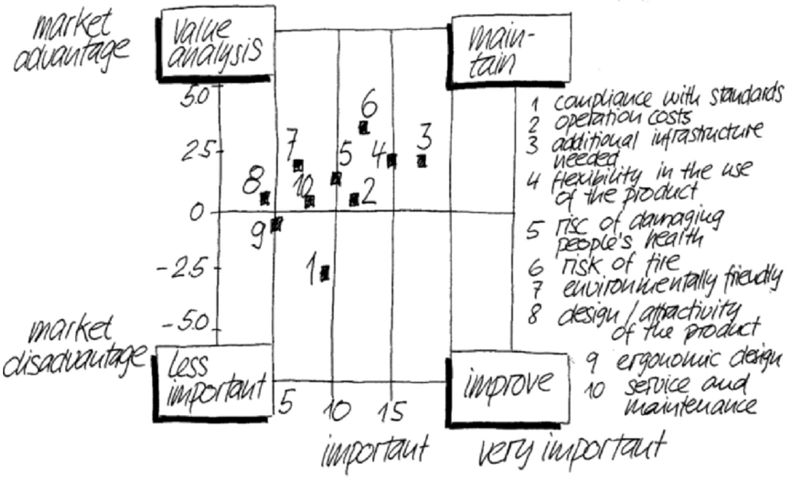


Figure 9.20. Relative importance and competitive advantage per criterion in a purchase decision.

For the less important criteria (value less than 8), the analysis showed that there are advantages in regard to the design and to the environmental impact of the product and disadvantages in regard to its ergonomics.

Comment:

To analyse the problem on a higher strategic level served two aims. On one hand it had to be confirmed whether the problem was tackled from the right point i.e. whether all aspects of the problem were addressed. On the other hand, it was desirable to gain an almost complete overview of the possible basic solutions. This even led to additional solutions such as reducing competitive advantage for criteria that were seen as less important. This particular solution was further developed using value analysis.

The competitive analysis was concluded by determining the current strategic market position of the product (figure 9.21).

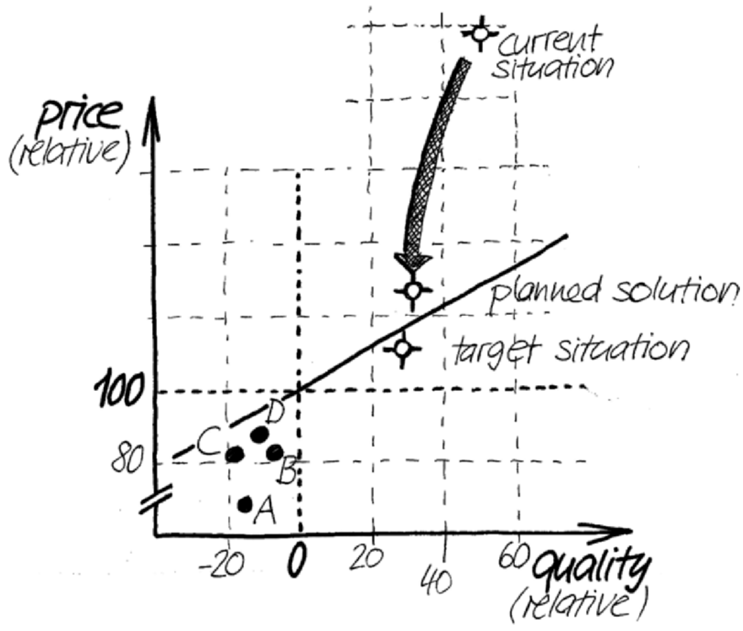


Figure 9.21. Strategic positioning.

The straight line in figure 9.21 represents the expected, ideal price-quality-ratio (in the view of the customers). A position to the left of the line means that, from a customer's point of view, the product was too expensive; to the right of the straight line it was too cheap. Figure 9.21 confirmed what Jausslin had suspected, the product was too expensive. On the other hand it became obvious that all competitors had chosen similar market positions, i.e. with relatively low prices and relatively low quality. Although the market was price sensitive and 65% of the purchase decision of the customer was determined by the price and only 35% by the quality (figure 9.19), Filtronix was following a quality strategy with its product.

Comment:

This functional differentiation of the problem area in the situation analysis, especially taking into account the market and customer needs and the position of the main competitors, helped to identify a weakness of Filtronix' own position.

With its distinct quality strategy Filtronix did not reach the main market, but only a niche market with a low sale potential.

The discussion on the strategic level lead to two further interesting candidate solutions:

- covering different market requirements with one or more products
- combination of two existing product lines into a modular product allowing for multiple use of parts and components and opening up additional retrofitting options for each market segment

All the candidate solutions then were further detailed and elaborated until they could be compared. Filtronix decided to keep the product lines separate. This required repositioning the product (figure 9.21).

Total Cost Analysis

Based on the cost analysis, four fifths of the production costs were material costs. The majority of the material were semi-finished products. The laboratory device consisted of more than 100 individual parts and subsystems. The analysis of all components would have taken us beyond the scope of the project and would have lead to disproportional expenses. An ABC analysis showed that four components were responsible for half of the production costs (see figure 9.22). Because of the relatively low value added by Filtronix itself, the suppliers had a high importance regarding the cost reduction potential.

components	***Production costs/ component***	***Production costs/component in % of the total production costs***
Housing	1’223.00	17.6
Filter	1’057.00	15.2
Control unit	541.00	7.8
Fixation system	425.00	6.2
Total	***CHF 3’246.00***	***46.8%***

Figure 9.22. Production costs of the four most important components.

Identify Functions for the Value Analysis

The functions of the product were identified in order to help structure its characteristics and to find new solutions that would go beyond the existing ideas and their current cost implications (figure 9.23).

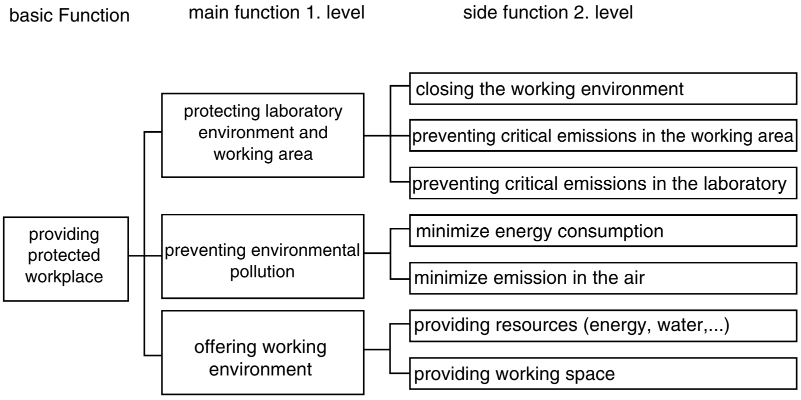


Figure 9.23. Actual functional structure of the laboratory device.

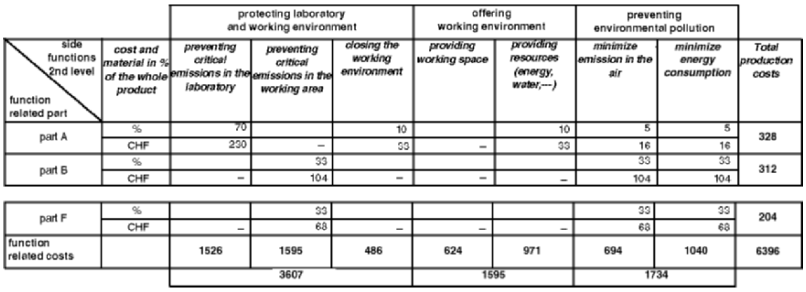
Comment:

The functions and properties of the laboratory device have been defined as abstract functions for the value analysis. These functions are independent from their technical implementation (i.e. they are solution neutral), so an unbiased search for new solutions is now possible.

‘Thinking in functions’ is an approach that focuses on the benefit of a function. There are always many solutions that could implement one function of a product, for example the joining of parts can be done by screwing, gluing, soldering, pinning; the different solutions differ in costs, technology and compliance with the requirements. The functions as used for value analysis are constant parameters; therefore competing products will have the same functions, if these are mandatory functions the product has to provide (main functions). Competing product may be using a simpler or less costly solution for the same function.

Determine the Cost Contribution for each Function

When all functions had been identified, their cost contributions were determined by assigning all costs of components used to provide the corresponding function (figure 9.24).



		protecting laboratory and working environment			offering working environment		preventing environmental pollution		
side functions 2nd level / function related part	*cost and material in % of the whole product*	*preventing critical emissions in the laboratory*	*preventing critical emissions in the working area*	*closing the working environment*	*providing working space*	*providing resources (energy, water,---)*	*minimize emission in the air*	*minimize energy consumption*	*Total production costs*
part A	%	70		10		10	5	5	328
	CHF	230	–	33	–	33	16	16	
part B	%		33				33	33	312
	CHF	–	104	–	–	–	104	104	
part F	%		33				33	33	204
	CHF	–	68	–	–	–	68	68	
function related costs		1526	1595	486	624	971	694	1040	6396
		3607			1595		1734		

Figure 9.24. Cost contributions of the different functions of the laboratory device (part of the complete list).

Then, the contribution of the A-components (see figure 9.22) was evaluated. It became obvious that an effective reduction of functional costs could be achieved by focusing on the A components.

Comment:

As part of the preliminary study, extensive and detailed clarifications were conducted to identify the actual problems and their causes. Based on the results it is now possible to define meaningful requirements and objectives for the future solution.

Definition of Objectives

Filtronix had decided to omit the function ‘reduce exhaust air’ (figure 9.23), based on the situation analysis. This opened up a potential to reduce costs by 10%. The functional objective ‘keep energy consumption small’ was to be kept. Furthermore the high costs of the function ‘media supply’ (power, water, gas, climate and more) were recognized now. It was decided that this should be an optional feature in the future, and that a basic model should be defined. Thus it became possible to reduce production costs by an additional 14%.

Comment:

The market and customer related optimisation of product performance characteristics already showed a potential reduction of production cost by 24%. In the situation analysis, this conclusion is only possible if the problem boundary is defined properly and if the analysis goes into sufficient details.

It was decided not to define cost objectives for each single function because an analysis of functional cost contributions of the main competing products was not possible due to a lack of time. Instead, more cost effective ways to produce or source the A-components should be found – while maintaining the functions.

So the desired position was reached, as presented in figure 9.21, which was substantially closer to the expected ideal price-quality relation. The product, however, should still be of better quality than the products of the competitors, which I do not consider to be the optimal strategy. Filtronix based this decision on the belief that the customers would be prepared to pay a 25% premium for the higher quality of the product.

Search for solution and selection

The general requirements for the A components were defined in a functional specification document. This was sent to suppliers requesting their offers. This resulted in a further reduction of production costs by 22%. Together with the market- and customer-specific optimisation of product performance characteristics this resulted in an identified total cost reduction of almost 50%. So it was possible to implement new solutions quickly and efficiently.

Comment:

In contrast to the standard SE procedure, this project had no main study with a decision for a general solution at its end. The preliminary study aimed to identify the objectives and the strategic direction of any measures to improve competitiveness. Because of the lack of secure facts, it was agreed to carry out a comprehensive situation analysis as part of the preliminary study. In the detailed planning phase that followed the preliminary study immediately, the individual partial solutions were refined so they could be implemented and introduced directly.

9.3.3 What are the Conclusions from this Case?

- Complex problems are perceived differently by different participants and stakeholders. A successful solution requires the creation of a shared understanding of the problem. This process can be elaborate and requires a systematic approach in the diagnostic phase.
- Setting meaningful boundaries, structuring the problem area and taking into account competitors and the needs of customers helped to understand the complex circumstances and opened perspectives for new solutions. However, not all participants did understand right from the start why the problem scope had to be extended.
- It is especially difficult for a designer who was involved from the beginning of the initial product to question existing solutions. Working on the problem as an interdisciplinary team, in other words involving all persons affected and including project sponsors from top management, supports the acceptance of the solution.
- Introducing the problem on a higher, strategic level, narrowing the perspective step-by-step on product design and developing options on both levels corresponds to the approach ‘from general to detail’. Thus all important problem aspects can be collected and an almost complete overview of all solutions that are possible in principle can be developed.

- It was chosen to divide the project into preliminary study, detailed planning, realisation and product introduction was selected. Clearly structuring the phases and explicit decision making with auditable decision processes helped to secure the acceptance for radical measures.
- The Problem-Solving Cycle was applied several times for different problem areas and in combination with value analysis approaches. Explicitly taking into account customer and market needs and – as a result – defining desired functions were concrete examples for a goal hierarchy which secured the development of a market driven product.
- The basis for finding innovative technical solutions was to present the functions of the product as abstract concepts and to determine their cost contribution. It became obvious that it was not always easy to clearly separate the solution neutral function (part of the goal definition) and its technological realisation (part of the concept synthesis)

The potential to reduce production costs was estimated in the preliminary study to be almost 50%, almost 40% cost reduction could be realised later. About half of it was due to market and customer specific optimisation of product performance characteristics and half of it to the critical examination and optimisation of how functions were realised.

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