AUTOMATION – CONTROL
AND INDUSTRIAL ENGINEERING SERIES

Introduction to Sustainable Transports

Bernard Favre

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Series Editor
Bernard Dubuisson

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First published 2014 in Great Britain and the United States by ISTE Ltd and John Wiley & Sons, Inc.

ISTE Ltd
27-37 St George's Road
London SW19 4EU
UK

www.iste.co.uk

John Wiley & Sons, Inc.
111 River Street
Hoboken, NJ 07030
USA

www.wiley.com

Library of Congress Control Number: 2013955376

British Library Cataloguing-in-Publication Data
A CIP record for this book is available from the British Library
ISBN 978-1-84821-545-0

FSC
www.fsc.org
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Paper from
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FSC® C013604

Printed and bound in Great Britain by CPI Group (UK) Ltd., Croydon, Surrey CR0 4YY

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Introduction

Investigation into the subject of sustainable transport broaches the question of mobility. Mobility is an end in itself, and transport is the means by which it is satisfied. The current hunger for mobility is a vital part of the human essence, similar to food, clothing, the exchange of ideas or goods, consumption and evacuation, etc. For all these activities, humanity is confronted with the crucial challenge of combining a harmonious development that provides good levels of well-being, with protecting the limited and fragile resources present in our environment.

However, the solutions for sustainable transport are not capable of solving the contradictions that we face today on their own.

On the one hand, the Earth's population is increasing at great speed. This evolution puts various players (in both political and economic worlds, the media, etc.), as well as the collective subconscious, in a schizophrenic state that gives rise to many concerns; there is no form of transport that is sustainable for the day when the amount of transport consumed explodes exponentially if current consumption levels are multiplied by the observed growth rate of the world population; yet, this frightening, well-established observation is matched to the individual tendencies of consuming more transport for personal needs or the desire to be mobile; furthermore, political objectives intend to make this particular consumption available to all.

On the other hand, technology may bring both the best and the worst in terms of transport sustainability[1]: the best can be achieved by developing efficient, economical solutions that will facilitate, simplify and accompany the action of transportation; the worst is the consequence of deploying and depleting the resources needed to cope with the enormity of certain new transport solutions facilitated by technologies that are faster, go further and are more accessible; and therefore more energy-intensive and "space-intensive", more polluting, noisier, omnipresent in space and time, and affecting all aspects of daily life, either social or private.

Yet, the current era is also characterized by the ability to connect the objects and data that compose the space that we live in daily. This recent but strong tendency evidently disrupts our relationship with transport. In places where people produce and use vehicles that move around on infrastructure, these people are now faced with connected systems that integrate superimposed layers of "intelligence." "Traditional" solutions which relied on physical products (in this case, transport vehicles) no longer exist. This recent integration of connected intelligence into transport gradually leads to the interaction of multiple players and sectors, which produce new objects combining the virtual and the real world. They are focused on valuing use, and not on the product's performance, as was previously the case. Through this new paradigm, we aim to implement effective solutions for mobility instead of inventing vehicles. From now on, it is a matter of developing mobility systems.

At the same time, our relationship with mobility is affected, and it impacts on the demand for transport and the evolution of the demand typology. For example, instead of buying an individual vehicle such as a car for the sole the purpose of owning it, one could buy access to transport systems which provide secured mobility performances. The consequences for the automobile market will be considerable, and cars

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[1] Note that this characteristic of technology is, of course, not the panacea for transport.

will (at least partially) lose their status as an object to be owned. The consequences for the economic models that structure the transport market are equally significant.

This book proposes lines of approach to better grasp the various aspects that come into play in encouraging more sustainable transport.

Chapter 1

First, what are *the fundamentals of sustainable transport*? The aim of transport is to provide a means of moving people or goods between a set of origin points and a set of destination points. This “origin to destination” channel is located at the center of other complementary channels: with respect to energy, the “well-to-wheel” channel; with respect to materials, the “cradle to grave” channel; and concerning intelligence, the “sensor to service” channel. In order to be more sustainable, transport must incorporate means of ensuring compatibility between transport consumption which satisfies mobility and conservation of the resources that it mobilizes, while making the most of the access to intelligence. These resources are space, energy and matter (water, air, minerals, etc.).

If solutions have to draw on *technological innovations*, the success of a shift toward more “reasonable” choices is still governed by various factors. Replacing carbon fossil fuels (oil or natural gas) with renewable energies is one of the main stumbling blocks. This issue by no means concerns transport alone, but transport is still massively involved; transport almost exclusively uses liquid fuels (gasoline, diesel, kerosene, heavy fuel oil, etc.) due to their excellent energy density and the flexibility for mobile onboard applications. There is an urgent need to replace these (gradually) with alternative sustainable energy sources, but it is also problematic as we need to intervene at all levels of the system in a coordinated manner, and this is more easily done for some forms of transport than for others. However, the pertinence of the different possible options (electricity, liquid or gaseous biofuel, hydrogen, etc.) needs to be carefully examined because in this sector details may obscure the bigger picture. It is a question of understanding the link between primary energy (produced at the source) and secondary energy (used by transport in an onboard form).

It will also be seen that *human and social factors* include other incidences that have another more direct impact than that of climate change. Questions linked to safety (particularly road safety), impact on health and discomfort, security and quality of service, all naturally have an important position in the problem of sustainable transport, which must help minimize negative effects on the relationship between populations and transport, either as transport users, operators, or transport infrastructure near-by residents.

Chapter 2

We shall then focus on the analysis of the significant and very current evolutions concerning transport vehicles, taking road vehicles as an example because they are a good reference for overall trends.

Information and communications technology (ICT) upsets and even revolutionizes the way in which vehicles are designed, whether they move on roads, on rails, on water or in the air. However, technology linked to energy, structures and materials is not forgotten. Their assembly and packaging require design methodologies that involve collaboration among specialists in various areas of engineering and design. Thus, we can imagine vehicles whose performance greatly varies from that of the vehicles of the previous decades, in terms of their environmental footprint (decreased weight, improved energy efficiency, recyclability, acoustic quality, etc.), safety and intelligence. However, our abilities to anticipate the future are limited to the timescales represented in the roadmaps of laboratories or industries involved in the development of these technologies, which rarely extend to over 20 years.

New vehicles use diverse energy systems for which gas and noise emissions are strictly regulated, and which have been considerably improved in terms of “local” emissions (nitrogen oxides, particles, noise, etc.). Electricity is used for omnipresent functions. On the one hand, it becomes the reference energy for regulating and controlling both vehicle drivelines and onboard systems. Above all, it is seen as an alternative to combustion motorization and has already acquired a remarkable position as such. However, we need to avoid considering it as the only possible “engine” in tomorrow’s vehicles (or the-day-after-tomorrow’s vehicles) as electricity must be stored in order to use it onboard. Due to their great variety, vehicles require specific motorization, and combustion engines will always have a future, whether as a stand-alone engine or combined in a hybrid associating, for example, thermal energy and electricity. The chapter will also discuss the confirmed tendency toward the use of decarbonized energy (or energy with a lower carbon content) due to the range of energy solutions that satisfy the diversity of uses. Some, though not all, uses are particularly conducive to this.

In the era of “intelligent transport”, another crucial concern for the evolution of vehicles relates to the *human being – master on board*: people now share the role of pilot (or driver) with electronic systems. In this case too, the way forward is partially staked out, although progress is uncertain. One can conceive of and build a fully automatic vehicle that moves and decides “by itself”. However, actual and widespread implementation is not going to take place in the near future, with the exception of dedicated infrastructures and regulated sites. In the meantime, man–machine interfaces for driving and steering vehicles are functions that are particularly sensitive and intervene strongly in the development of driver assistance systems in order to minimize the risk of accidents and energy consumption. They request very careful design in order to best fit needs and human capabilities in any contextual situation, and must therefore be nurtured.

Chapter 3

Vehicles represent only one element of transport systems. What about infrastructure? What about the rules which ensure that it is well managed? The core issue related to infrastructure must be considered, as well as the way in which it is organized, ranked and exploited. Infrastructures (roads, rail, airports, ports, etc.) use a huge amount of space and also leave an environmental footprint on neighboring sites. They must be designed not only for the link flows that they must deliver, but also for vehicle parking, intermodal and internodal exchanges at their extremities, and for their interfaces. As for the circulation of vehicles on these infrastructures, their variable density influences their flow capacities: too many vehicles will induce saturation phenomena that cause infrastructure performance failure (congestion) in various areas. The operating procedures (surveillance, signaling, intervention, etc.) ensure that safety and flow performance are maintained, and now also operate in order to minimize the environmental impact.

It is therefore important to view transport systems in terms of their overall structure: the context is multimodal as road, rail, waterways and airways cooperate. There is a certain hierarchy between the various elements, and their effects on the environmental footprint can be quantified. A virtuous, calm, efficient and fluid flow through networks is favored: *transport schemes* show the compared respective performances of a variety of scenarios, over a long or short distance, and of various transport organizations: individual, collective, mass transport, etc. *Systemic analysis* indicates invariables that reappear at different territorial levels, from the scale of a district to that of an intercontinental space. A formal similarity appears between the transport of people and goods. This systemic analysis demonstrates that transport segments (corridors) and transport nodes (platforms that ensure exchanges and connections) are equally important. It enables us to develop a method to design sustainable transport systems, combining infrastructures, modes of transport, vehicles and organization. It is important to minimize the environmental impact of each element as well as the entire system at different scales, which can lead to intermediary compromises: local drainage must be ensured by capillary channels, accompanied by a global massification on pertinent corridors at each territorial level, with the capacity of the "pipes" designed on the basis of the mobiles flowing through them and the territories that they cross. In parallel, we must contribute to the evolution of the definition and the configuration of these mobility aids (vehicles) and the organization of their operation.

Chapter 4

However, can *sustainable mobility* be organized? This assumes that the state of mobility has been established, as well as the root of its causes. Various analysis methods enable us to determine the characteristics of mobility, both for towns and interurban territories, and of both people and goods (the supply chain), and to understand its driving forces. For example, movements between home and work are an essential driving force for people mobility in urban areas. However, they are conditioned by a variety of factors, including the presence in the territory of activities and accommodation, or even of uses associated with working organizations, or with individual or collective cultural behaviors. Some of these factors evolve slowly (such as town planning), yet others have much faster dynamics (such as the recent explosion of e-commerce or telework).

A range of tools are already at our disposal: the principle of *massing*, if applied efficiently, is considered to be a founding factor for calm mobility as it allows the performance of a transport mode to be improved considerably. Sustainable mobility will also benefit from the rise of *mobility services*. Such services can be built using a wide variety of data (“cloud”, “big data”). Their creation and use will produce new services with the potential to be highly efficient. The role of public authorities must be taken into account as the (excessive) number of regulations generates technical and financial devices for control, restriction and optimization of access to infrastructures and urban territories. The diversity of transport modes provides an offer for mobility with connections that can be improved between mild “active” modes, individual motorized modes, collective motorized modes and massed modes. Their potential complementary nature has been established, as well as the impact that varies strongly in terms of ecological and societal performance. It is also important to ensure the assignment of necessary infrastructure resources at interfaces between transport modes (exchange platforms), which can lead to the harmonious juxtaposition of mobility and proximity services.

People mobility and freight logistics are based upon organizations that are very different in nature and that can be made to evolve progressively whether they are for towns or for long distance. The convergence can be a source of inspiration, as each one embraces "best practices" that are probably not exploited to their full potential. They concern technologies for different modes (road–rail–water–air, etc.) as well as the way in which they are organized, articulated (mixity, juxtaposition, etc.) and structured (corridors, platforms, governance). Actual innovations can therefore be proposed for the field of transport systems.

Chapter 5

Projects on the development of technologies for *sustainable transport systems* are countless, aiming at deploying innovative solutions. They introduce a keyword for the operational implementation: *consultation*. Indeed, this is crucial for solutions to be deployed for sustainable transport, which must coherently combine all the essential systemic building blocks: vehicles, infrastructures, services, operational processes, energy and intelligence. Concerning energy, the use of electricity requires recharging stations whose performances are compatible with the vehicles and their uses: slow or fast, with or without contact, static or dynamic, etc. Does the future include electric highways that provide a continuous electrical output required by the moving vehicles on the road? However, other energy solutions are appearing, starting with "traditional" fuels originating from re-examined energy systems. Natural gas has new ambitions for transport, either compressed or liquefied depending on applications; hydrogen is still stalling although it may yet, and probably will, take off. Concerning the design of vehicles, the restrictions introduced by handling, lane-keeping and loading lead to new propositions for transport modules, individual vehicles, organized collective systems and infrastructure. In terms of intelligence, a number of European projects on intelligent transport systems (ITS) are progressively producing the ingredients necessary for their implementation and deployment. However, will people remain in command when the age of connected vehicles dawns?

Infrastructure for transport is continuing its mutation as well as its intermodal interfaces. *New systemic objects prefiguring sustainable transport* are created by associating infrastructure and vehicles with the development of services, and these include operational innovations. *Linking systems* is a solution for mobility that has yet to move on from a concept to actual rollout. This requires a pertinent and long-lasting political desire, compatible with economic fundamentals: the safety and cost of energy, competitiveness, sensitivity to ecology, internalization of external costs, ability to invest, territoriality, and local political and social networks. Current projects have the potential to turn quickly toward alternative solutions without the need for massive investments for equipment or infrastructure: everything can happen very fast in the age of data processing, of access to "knowledge" and of proximity between solutions and uses. However, new business models are needed if we are to reach a systemic integration based on new data and communication technology with organizational innovation.

Chapter 6

In conditions such as these, how should one lead the *political convergence* between the multiple requirements of society that give rise to often contradictory restrictions for the evolution of transport? The aim is to successfully create connections and a consensus between different territorial scale levels and their organizations, from the local level (that of a street or commune) to the global level (that of the planet). Reciprocally, the quota objectives for greenhouse gas emissions must be agreed upon, and they must be distributed from the global to the local level – "from the Kyoto objectives to a local municipal climate plan".

The tools developed in the great world "regions" are installed differently, although globalization in the field is the subject of active (though as yet incomplete) research. The European Union has developed a set of "top-down" tools: support for research (R&D Framework Programmes, Horizon 2020) by means of {public–private} partnerships, support for investments, development of roadmaps, development of regulatory directives and their implementation. The White Paper on Transport Policy proposes principles that provide some structure in terms of transport policies, and is accompanied by a plan of action for mobility, for the implementation of ITS, on road safety and on freight transport and logistics, etc.

At the level of European regions and European cities, “bottom-up” principles are also being established. As for the (ultimately intermediate) scale of States, the example of France illustrates how they aim to provide coherence, and what compromises result from the finer points of a policy that aligns both ecological and economical objectives. Investment in equipment and infrastructure, vehicles and virtuous transport systems is accompanied by the development and installation of mobility-support services having a more immediate effect, and whose environmental, social and political impact becomes apparent sooner.

Conclusions – Directions

To conclude, the real difficulty of *establishing solutions for sustainable transport* leaves us at the heart of our contradictions: contradictions between individual and collective objectives or short- and long-term ones. Indeed, it is impossible to reach an agreement: within ourselves, as consumers, taxpayers, commuters, etc.; between our communities, whether they be territorial, political or economical, or for tomorrow or the more distant future. Therefore, how can we make accurate predictions in order to pave the way for the future of transport? To what extent can we predict anything? Research into efficiency is a prerequisite, yet the definition of efficiency varies according to context and perspective. The good behavior of the set of players – both public authorities and private initiatives – is part of the route to success. Transport requires space, energy and matter, for which an expenditure quota must be introduced. In modern times, the intelligence factor has also come into play, and without this factor, sustainable transport would be an impossibility: not just technological intelligence, but first and foremost human intelligence.

This book therefore presents the elements in context, it puts forward tools. However, it also warns the reader against reading the subject of sustainable transport in too linear a fashion. Interactions of cause and effect, interlocking of domains and disciplines concerned, the consideration of distance and time scales, the diversity of geographical and cultural territories, everything demonstrates the complexity of the possible answer or answers.

Chapter 1

The Fundamentals of Sustainable Transport

1.1. The ingredients of sustainable transport

Etymologically speaking, the word *transport* means “to carry across” (from the Latin *trans* (across), and *portare* (to carry)). Ever since transport first appeared, the vehicle attributes were observed to be twofold, which ensures the function of transport: movement must be created, and energy must therefore be spent. The loads must also be supported, which requires both materials and structure.

The last few decades have brought in a third dimension, which has now become unavoidable: “intelligence” (from the Latin *intelligencia* (the ability to understand)). Similar to the other domains of contemporary society, but maybe even more than most transport is effectively being swept along by a wave of information and communication technologies (ICTs). The sudden evolution in the field of intelligent systems is applicable to transport. It contributes to a profound alteration of performance. It allows new functionalities to be constantly introduced: information made available to transport drivers, users and operators; on-board vehicle automations; communication between mobile units and infrastructure; real-time traffic management;

etc. Intelligent systems enhance the abilities of transport systems and place them in a new context: one that is highly interactive and connected.

Transport satisfies part of the contemporary needs for mobility. On the other hand, it is known that transport has a worrying impact on the balance of resources in the ecosystem at planetary level. Research into solutions that reduce this impact while answering to mobility demands forms a major mobilizing axis for various types of player: scientific communities, and political and economic players. The aim is to design, implement and use *sustainable transport* – the result of a balance that needs to be found between the two restricting fields:

– Implemented solutions for mobility must be made efficient and accessible to all in order to fulfill the requirements of society.

– But the stability and sustainability of our natural resources, air, water, space, biodiversity and landscape, must also be guaranteed as they are our communal heritage that must be managed, protected and passed on to future generations.

The objective of this book is to provide a perspective on the initiatives in this field. They concern the transport of goods and people, both individual and public transport, and the transport of small and large quantities. The initiatives involve vehicles, infrastructure and rules of operation: vehicles move loads; infrastructure is intrinsically linked to vehicles, as they form the framework; operational rules define their use. The whole works as a system with complex interactions: the "transport system". It must be arranged in such a way that sustainable transport solutions can be reached, helping to optimize the creation of mobility in the context of long-lasting sustainable development. Depending on the arrangement, the physical support used for transport can be the ground (road or rail modes), water (inland or maritime waterways) or air (airways). These modes[1]

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[1] In this book, the notion of transport mode is broadly used and refers to the support (road, rail, water, air, cable, etc.) as well as to the organization and the vehicle (for example walking and buses are two different transport modes). We also mention multimodality (to refer to transport that involves more than one transport mode), intermodality (to express a connection between two or more modes), co-modality (to express formal cooperation between different modes), etc.

are juxtaposed and are connected in different ways depending on the territory, and their connections for a given use depend on the distances between origin and destination.

It will be seen here that the question of geographical scale is essential and that it should be apprehended from the local scale (the threshold) up to the global (planetary) scale. Roads are a quasi-universal structure for transport infrastructure and are encountered in various forms at each level of focus: at district, commune, regional, state and continental levels. (Nearly) all begins or ends with a road, which allows the neighboring areas around each territory to be served. In normal practice, these sections are called "first and last mile" (even if in some cases, it may only be a few meters). Other transport modes have less omnipresent infrastructures. Regardless of the mode of transport, the development of new infrastructures requires considerable investment, paired with a long-term, determined political will: it is necessary to secure the public and private parties whose involvement is inevitable. From this point of view, it seems that it is easier to modify vehicles, or their operational rules, than to modify infrastructure. It will be seen that this appreciation must be weighed as soon as the transport is considered as an interactive system in which all the constituents are coupled, because the optimum solution is reached by adapting each individual component harmoniously (and includes infrastructure, of course).

Transport needs to satisfy a very wide range of requirements:

– Mobility of people (commuting to and from work, shopping, leisure, etc.), which has a diversity of physical, social, professional and geographical characteristics, thus involving many different expectations in terms of means of transport.

– Goods mobility depending on the logistic branch ("B-to-B" – *Business to Business*, "B-to-C" – *Business to end Customer*, etc.)[2], which has diverse needs and includes specialized lines of work

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[2] Logistics chains are formed from elementary links with nodes that are represented either by intermediary transformation and management centers (B), or by end consumers (C).

(mailing, distribution, refrigerated goods, construction, household rubbish, etc.), which also impose their demands.

How do we satisfy the objectives of sustainability while providing the correct transport solution for everyone, at the right place, and at the right time?

Sustainable transport is located at the heart of a set of "channels"[3], which has a point of connection in the "transporting object" (in other words, the vehicle).

The channel termed "origin-to-destination" must be discussed first. Naturally, this is the founding channel, which demands the coordination of (a set of) vehicles using appropriate infrastructure along the optimized itinerary, in order to ensure the best possible mobility with the highest possible efficiency. This channel, projected according to geographical dimensions and integrating time factors (time and space being linked to each other by speed), is accompanied by complementary channels: their incorporation in the value chain[4], depending on the expiry date of decisions (namely public ones)[5], proves to be a determinant factor in the understanding of the issues of sustainable transport.

The channel called "well-to-wheel"[6] expresses the outcome that must be confronted in order to establish the environmental footprint of the energy chosen for a transport mode. The outcome is obviously not limited to the vehicle's energy consumption during its use. It also involves the outcome related to energy produced from the primary "matter" (oil or gas field, solar radiation, hydraulic or wind, etc.), to its transport (with transport vehicles, pipes, electrical networks, etc.),

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[3] Here, the word "channel" is used to mean the path that links cause to effect, or departure to arrival. This approach is hinged in the way that the various dimensions intervene in sustainable transport: {space–time}, energy, material, intelligence.

[4] Internalization of factors and external costs enable a group of direct or indirect elements to be attributed to transport, which results, in a certain way, in an estimation of its value.

[5] Depending on whether one is considering the short term (e.g. one year, elections), medium term (e.g. 5–10 years), long term (e.g. 20–50 years) or even the very long term (expiration nearly unimaginable).

[6] From oil wells to wheels of moving vehicles.

to its storage and its distribution. The environmental impacts of the various types of energy used on board vehicles are highly dependent on the way that they are produced and conditioned. This core question is unfortunately often overlooked or simplified in debates on transport's environmental footprint.

"Cradle-to-grave" channels express the outcomes that relate to the environmental footprint of the material required to construct (and even operate) the modes of transport. It conveys the environmental impact of this entire sector: production of raw materials, their transport, their transformation, their integration into products and then completing the loop by returning to the "grave to cradle", their dismantling and recycling into new branches of production (by recovering waste products). It is also the case here that the environmental outcomes are dependent on the energy and environmental cost of the various steps of material enrichment and recovery. This can prove to be disastrous in terms of the environment if the demands of the entire branch are not taken into account. This is, in particular, relevant for certain rare materials, or for certain on-board components, even if they have a reputation for being virtuous due to the functionalities they introduce (but which are potentially harmful depending on the materials and methods used to produce or implement them)[7].

We also suggest a new rising channel "from sensor to services" , that relates to the layer of intelligence obtained by incorporating information on context and use, with regard to transport efficiency. This channel goes hand in hand with the transformation of vehicles into mobility platforms connected to the outside world, and communicating with it. The revolution of data acquisition and processing is now an essential contribution to sustainable transport.

The foundations of sustainable transport require us to move from paradigm to paradigm, from a concept of transport that is exclusively based on the assembly of technical bricks available, to another that involves taking into account their historical aspect, their culmination,

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7 For example, batteries that store electrical energy in electric vehicles may require materials or procedures for their development and lifecycle that are widely questioned in environmental terms.

and their origin and purpose. Whether they be technologies for transport itself, uses, or else channels (from well-to-wheel, from cradle-to-grave-to-cradle, from sensor-to-services), reasoning in terms of these branches illustrates the importance of having a systemic approach toward transport. However, this naturally has the effect of making the problem even more complex. According to this approach, the different dimensions of the problem must be tackled in their relative context as they are connected and interactive: the exit of one can thus become the entrance of another. For example, optimizing the energy aspect of transport can lead to a worse use of resources for necessary raw materials. It is therefore crucial to give more in-depth consideration to energy channels, to material channels, to knowledge channels, in addition to geographical and temporal channels implied by "transport" objects and their purpose: mobility.

As a consequence, there is a surge in the number of players involved in the development of sustainable transport, especially due to the numerous restrictions linked to the need to find consensual solutions. How can we reach a compromise between demands that are often contradictory, depending on the players? How do we define the correct optimum for short-, mid- and long terms simultaneously? The problem here is to successfully achieve "integration". This does not only consist of juxtaposing each player's efforts toward a shared solution. In reality, it also consists of constructing a cooperative combination, finalized by a coherent solution at different layers, with links at different levels: from the chip in a vehicle control automatism, or else a microcell that stores energy in a battery, to the transport system that is integrated into its territorial and functional environment, and of which all the interfaces are operational.

Such is the state of sustainable transport. Its success involves a common goal, enabling the efforts of each player to be channeled according to road maps that are coordinated to guarantee coherence. It also involves flexible connections and acceptance (for example sacrificing the short term for the long term) in order to enable their implementation.

Nowhere is it written that these conditions will be collected. We should therefore be ready to see erratic oscillations in the process of reaching this common goal. These variations have a variety of origins:

– Technological: several technologies are being developed in parallel; the conditions linked to their emergence are in competition (namely financial ones)[8]; the introduction of new technologies presents a risk-related compatibility with technologies already on the market.

– Economic: the financing and competitiveness of solutions are not guaranteed in the short term and/or the long term.

– Political: local authorities compete with each other, with respect to national or supranational visions; various sensitivities occurring within public authorities apprehend the problem from different angles; *lobbies* intervene and exert pressure in their favor, etc.

New technologies change the way in which we appropriate transport for ourselves. Visions related to the subject have strongly evolved and are demonstrated in the wordings of transport technology's recent history:

– The years from 2000 to 2002 introduced the concept of "e-safety" to designate the improvement in transport safety by introducing ICTs. Here, the prefix "e-" symbolizes electronic.

– New terms were then coined: "eco-mobility" (2008–2010), then "e-mobility" (2011) was coined where "e" stands for electricity[9], followed by "i-mobility" (2012) where "i" is used to mean "integrated", "innovative" or even "intelligent".

– Mention of "clean" vehicles, "green solutions" and "blue corridors" is also made.

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[8] Hype cycles, popularized by Gartner research in the 2000s, are a way of representing apparently erratic conditions in the emergence of technological innovation (maturity, adoption and dissemination) [GAR 13].

[9] The term electromobility is also used.

– Still more recently, a trend is emerging to qualify solutions as being "smart", with "zero" objectives: zero accidents, zero emissions, zero congestion, zero ground coverage, etc.

A common intention becomes apparent through these uncertain and provisional denominations: sustainable transport and sustainable mobility. However, they also express the instability of the paradigm implied by communities that create these concepts, before their eventual abandonment. It may seem that these neologisms will yet evolve even more quickly because the complementary functionalities are introduced and the involvement of new players tends toward an efficient and sustainable mobility based on an integrated transport system[10], which would be termed, for example, "systemobility"[11].

Transport ensures the mobility of people and goods. The demand for mobility is constantly changing on a global level. It tends toward a continuous increase, which concerns all regions in the world and all activities, with strong variations depending on demographic, economic and socio-cultural cycles, and having geographical scales ranging from local to global. A solution for transport may be found for each need for mobility, as a chain of transport systems, as will be discussed in Chapter 3. The expectations of users in terms of mobility concern transport from point A to point B, the final destination, in a great variety of points A and B. They can be summarized as "seamless mobility for all", for the optimum conditions for efficiency, safety, comfort, reliability and service quality. Sustainable transport does not alter specifications, but enriches them with the systemic dimensions mentioned previously. It requires new improvement methods to be found for the efficiency of transport systems – vehicles, infrastructure, operational methods – in order to satisfy the rising demand, while still applying a quota to the use of necessary economic and environmental resources.

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[10] The concept of integration involves coupling between different elements of the system (vehicles, infrastructure, operators, users, etc.) in an organized manner so that the performance in its entirety is greater than the summed performance of each of its different elements.

[11] Let it be noted that this evolution is similarly observed in other fields, such as cities, for instance "smart cities", "eco-cities", etc.

Questions related to energy and environmental impacts are therefore at the heart of considerations concerning sustainable transport. The stakes involved in the question of energy will be recalled in the following and is expressed depending on the course of action:

– Impoverishment of resources facing the unsustainable pressure created by the demand for energetic material (of all sectors of human activity).

– The need to be relatively independent with regard to the hazards of impoverishment, namely geopolitical.

– The cost of energy.

– Major environmental impact.

The last point concerns greenhouse gases in particular, and mainly carbon dioxide (CO_2), in addition to other polluting gas emissions that have a more local impact: particles, nitrates and other gases with a potential or proven impact on the health of exposed populations. Public policies now display voluntary goals over the entire set of human activities involved (including transport), such as "facteur 4" in France: it will nonetheless be extremely difficult, and even impossible, to satisfy this objective that aims to cut greenhouse gas emissions to a quarter between 1990 and 2050.

We must also insist on human and social factors that, besides satisfying needs for mobility, include mastering the negative impact of mobility on the population in terms of risks (accidental or intended)[12], of inconveniences to the population exposed to noise and gas emissions, of preserving the health of workers and users in the transport sector. In particular, *aspects related to safety* are an integral part in the consideration of sustainable transport. In terms of accidents, road transport is the mode that is by far the most penalizing. Road safety continues to provide distressing consequences on a planetary level. It was thus observed that during the year 2010 [WHO 13], more than 1.24 million deaths occurred, of which 46%

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[12] "Safety" is used here to mean controlling the risks linked to accidents, and "security" to mean the risks related to malevolent intentions and deliberate acts.

were "vulnerable users"[13], consisting of pedestrians (22%) and users with two-wheeled vehicles, both motorized and non-motorized (24%).

Ninety percent of deaths related to road transport occur in countries with low or intermediate incomes, in spite of them owning under half of the world's fleet of registered vehicles. In developing countries, the growth rate of outcomes related to road accidents is mostly disastrous. In 10 years time, it is estimated that traffic accidents will cause up to 2.4 million deaths per year, thus becoming the fifth greatest cause of death in the world, whereas it is already the first cause of death for young people aged between 10 and 24 years[14].

In more industrialized countries, the results of public policies and vehicle improvement techniques have led to road safety performances that have strongly improved and can even be spectacular. It has also been observed that the most devastating types of accident, as well as the category most frequently involved in accidents are "vulnerable" users. For other types of users (mainly car occupants, but also truck drivers and people transported by public transport vehicles), the outcomes are rapidly improving. In the European Union, where the trend is roughly a 50% decrease in the number of deaths over 10 years, 31,000 people were killed in 2010, of which 19% were pedestrians [CAR 12][15]. In France, 3,963 people were killed in 2011, with 13% being pedestrians [ONI 12]. The European Union has set itself a target to decrease the number of severe victims by half in the current decade (2011–2020). The objective of the so-called "quasi-zero vision" (no victims killed or severely injured) is still out of reach at this point in time, although it constitutes a possible challenge in the long term by associating all the ingredients of an "integrated

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[13] Vulnerable users are people who use transport infrastructures that do not have vehicle protection for those who use it and consist of the following categories: pedestrians, motorized or non-motorized cyclists.

[14] According to WHO, only 28 countries, representing 7% of the world population, have comprehensive road safety legislation, encompassing the five main risk factors for accidents: drink-driving; speeding; not wearing a safety helmet, for motorcyclists; not wearing a seat belt; not using safety devices for children.

[15] CARE is a European Community database on road accidents resulting in death or injury .

approach" (the combination of different feasible solutions in terms of technology for vehicles and infrastructure, regulations, training, etc.).

The requirements linked to transport security are also proving to be strongly "dimensioning": the ability of an organization or a transport system to prevent the risk of deliberate malevolence, or to reduce its effects, must be strengthened. Under certain circumstances, transport is targeted by actions that aim to harm the integrity of users, workers, carried goods and resident populations. Some striking examples can be recalled (such as the infamous 9/11 attack in 2001).

Figure 1.1 shows a synthesis of the ingredients for transport, which appears in multidimensional form: elements in the context of societal, economic or technical order (*in italics)*, challenges and objectives (framed), the "{mobility–productivity}, {environment–productivity}, {safety–security}" trio, to which the systemic anthropocentric "man and cooperative systems" is added, the latter being represented by a circle that symbolizes the interface with other associated systems (energy, materials, intelligence, etc.). However, man remains at the center of sustainable transport.

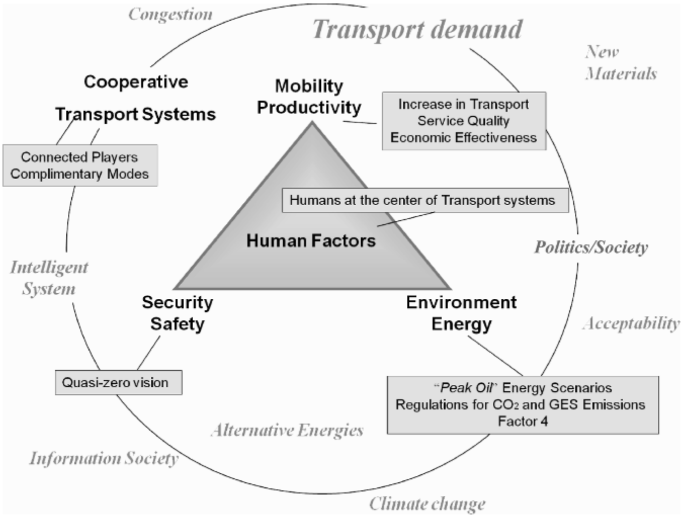

Figure 1.1. *Ingredients for sustainable transport. Context and challenges [FAV 07]*

1.2. Towns, territories and sustainable transport

Transport is to territory what blood is to living organisms: a vital function to supply and drain the territory, to move “nutrients” around, and to evacuate “waste”, which enables it to exist and develop harmoniously with the various systems that form its economic, social and environmental aspects.

More than half of the world’s population already lives in cities and the trend will continue for the foreseeable future, particularly with the further emergence of “mega-cities” (23 towns with more than 10 million inhabitants in 2012).

Improving urban mobility is one of the points included in the agenda of all governing bodies, from a local level to a global level: transport within towns to guarantee the movement of inhabitants for their daily activities, transport on the outskirts of these towns to link living and working zones, connecting these towns by intercity transport means to connect them to each other or to guarantee the supply of base materials and consumable goods, etc. The need for transport is therefore essentially associated with towns, which have both a systemic organization and uses it to impose the best possible integration of their transport systems into the urban structure. However, the provision and maintenance of infrastructure for transport, its operation, as well as programming and developing new infrastructure, are at the heart of political debates on the management of towns. They need areas of land in addition to financial resources and are in constant competition with the other main elements of urban fabric. The same holds true for the operation of infrastructures and the management of vehicles associated with them, particularly in terms of gas and noise emissions, congestion and safety. The development of public transport is also one of the main topics of urban politics. Strengthening the governance of transport systems in urban areas is perceived by public entities as an inescapable requirement for the sustainable development of towns, from economic, social and environmental points of view. Guaranteeing adequate needs for mobility and promoting transport solutions between public and private spheres have also been considered. In order to do this, initiatives to form partnerships have been encouraged. They can lead to regulations for the use of infrastructures serving urban territories. They can also put forward the development of integrated solutions for transport systems within urban systems, by handling vehicles, infrastructure, operators and operational rules in a coordinated manner. Public policies play a major role in steering the choice of the favored transport mode, investments, by controlling through regulations or promoting good practices. They must also arbitrate between a variety of constraints, of actors and of expectations. Private entities develop solutions for the transport market. They encourage innovations in the fields of energy, intelligence and materials. The evolution of technologies and services regularly provides pertinent solutions for urban transport, although they are used differently depending on the urban agglomeration and according to the region of the world being considered[16].

As for *intercity transport*, expectations and solutions are usually of different orders depending on whether the problem is being considered at a regional, state, continental or world scale. In terms of transport modes, expectations focused on modes with performances that permit long-distance transport, high-volume transport and/or the need for speed: here, air travel, and river and maritime waterways all play an important role in comparison to road and rail. In terms of demand, transporting people corresponds to the need for mobility for work or tourism. These are usually affected by weekly or seasonal cycles whereas urban transport is affected by daily cycles. As for freight transport, it ensures the flow of goods between raw material pools, transformation pools and consumer pools, without forgetting returning material for treatment or recycling.

Structuring flows and the need for the transport of goods broadly depend on implementing infrastructure for production, factories and work zones (often associated with urban zones), which, by means of logistics and setting up transshipment platforms, provide infrastructure for transport and its vehicles. The geographic role of ports (and complementary airports) in the movement of goods on a global scale

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[16] Thus, spectacular transformation of towns in developing countries causes very chaotic and catastrophic situations in terms of the environment, congestion, often in very diverse contexts, which require adapted solutions.

is quite spectacular. The planet's main flows pass via maritime routes, the importance of which has been profoundly confirmed in the last few decades, for the trade of raw materials, fuels and manufactured products. In just half a century, production has increased by a factor of 10 in South-East Asia, and by a factor of 5 in Western Europe and in the United States. The global exchange of manufactured products has increased by a factor of 45, that of agricultural products by a factor of 10, etc. On average, 30% of supplies are imported and 30% are exported [CNA 07]. The main maritime trade routes connect industrialized countries to each other (North America, Europe, Japan, China and India) (Figure 1.2). International maritime routes are closely linked to the increasing demand in oil, coal, steel and other resources originating from developing countries, as well as to the exchange of manufactured products mainly intended for developed countries. There is therefore a steady rise in the intercontinental traffic of containers. New road paths are developing between Asia and Europe. Due to global warming, Nordic movements through Arctic seas are progressively being made feasible. Transport between Asia and North America tends to saturate the ports located on the West coast of the United States, and transport from America's East coast ports via Europe is also being experimented with, in addition to traffic through the Panama Canal (which is being enlarged with an added capacity for mega-ships).

Structuring infrastructure for transport located in the hinterland[17] of relevant countries with ports, is widely associated with the requirements demanded by the flow of goods to and from neighboring intracontinental regions. These infrastructures, railways, waterways or road networks are the extension of maritime waterways. The crucial issue is how to connect this planetary network, which is mostly maritime, to local networks aimed at feeding the cities, especially road networks, in the best possible way. For landlocked countries, which do not benefit from the advantages of a coastline, these flows may require long-distance land transport, and the aim is then to make the most out of connections and the complementary nature existing between

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[17] Hinterland is the region "behind" the coastal area, endowed with transport set-ups that guarantee movement to and from the port(s).

railways and roads, each of which will only provide a partial answer to the problem.

The long-distance transport of people is distributed between road, rail and air flows, depending on the area concerned and the available infrastructure. Airways are the most flexible and permit connections with direct flights going to and from any destination equipped with an airport. It has spectacular growth rates and guarantees all destinations between air hubs that are more than several hundred kilometers away. High-speed railways are currently being implanted in Western Europe and in some of the Asian countries that are more or less developed (the precursor being Japan, and then China, which now has the most important network); development is limited for reasons of economic order even though the technical performances are remarkable.

Mobility within territories, as well as between territories, is therefore linked to the existence of infrastructure, the availability of which is unavoidable for developing the abilities of transport based on the movement of vehicles. Depending on each individual case, it becomes apparent that they consist of infrastructure corridors (roads, railways, waterways), or infrastructure platforms (stations, air terminals, ports), as well as their variations at local levels (see Chapter 3). Infrastructures that supply energy to vehicles (providing fuel or electricity) or “intelligence” (communication, regulations, localization, etc.) are still an indispensable complement[18].

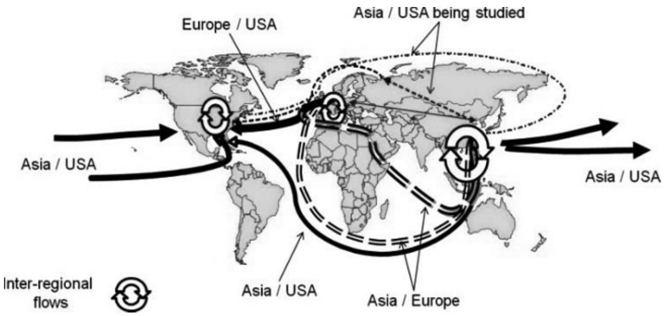

Figure 1.2. *Global routes for goods*

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[18] The GPS network in operation and the GALILEO network, which is due to be finished in 2020, are part of the infrastructures essential for sustainable transport.

1.3. Energy and sustainable transport

Globally, primary energy is divided into oil (roughly 33%)[19], coal (24%), natural gas (21%), biomass (11%), nuclear (7%) and renewable resources (wind, solar, geothermal, hydraulic) (4%). This energy distribution usually evolves slowly[20] and depends on economic and public policies (authorities take into account geopolitical risks and public opinion), the discovery of fossil fuel wells and the market.

This primary energy is used to create secondary energy (at consumer level), by the means of systems that transform, transport, store and distribute it. Secondary energy can take two different forms of energy: either molecules (gas, liquid or solid fuels) obtained through refining, transformation or synthesis, and transported by various means of transport, or electrons produced by generators and transported by power lines. A quarter of the total secondary energy, with respect to consumption, is used for mobility, another quarter for housing and the rest for agriculture, industry and services.

Figure 1.3 shows the evolution of the amount of energy consumed by transport in Europe over the last 20 years, divided into the different transport modes [EEA 12a]. Energy is almost exclusively provided by fossil fuel wells. Road transport holds a dominating place, and mainly uses diesel-type fuels (for diesel engines), as the proportion of gasoline has decreased to become a minority in the 2000s. Transport via water (river and maritime), which uses either heavy fuel or diesel, and air transport (which uses kerosene), have similar contributions with a tendency to increase continuously. Rail transport has a marginal contribution.

As transport uses a quarter of the world's energy resources, *energy is at the center of the sustainable transport problem*. The issue's different components can be seen from the perspective of resource availability, of geopolitical context or of environmental impact. A clear distinction must be made between primary energy (obtained

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[19] Data related to 2011.

[20] This is the global distribution. Faster variations have been observed at "local" levels, that of a state for example. This is the case for the United States, due to the extraction of shale gas at the end of the 2000s.

from its source of origin) and secondary energy (used to make a vehicle move).

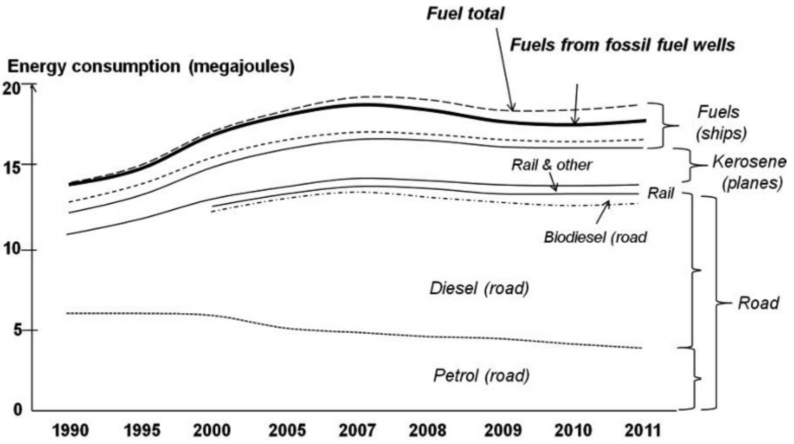

Figure 1.3. *Evolution of the amount of energy consumed by transport in Europe over the last 20 years, divided into the different transport modes [EEA 12a]*

The current debate on resource availability mainly concerns the shortage of fossil fuels, which makes the search for alternative solutions vital. Schematically speaking, newly discovered oil wells, and their commissioning at market value, appear to be no longer sufficient to compensate demand (which increases by 1.6% per year and which consumes the entire production of listed oil wells): stocks identified as available are apparently decreasing, and the point of "peak-oil"[21] has been reached. However, there is still great uncertainty, with regard to petroleum oil, on the potential of extracting oil shale and tar sands, and on deep- and very-deep-sea oil wells. The use for transport – which consumes approximately 40% of the total oil energy – is the first to be involved in the debate. Effectively, liquid fuels are a source of energy that are perfectly adapted to on-board storing in self-propelled vehicles, due to the ease with which they are supplied and their high energy density. In addition, it is difficult to

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[21] The "plateau" stage can also be mentioned, for which offer and demand are in equilibrium in the context of the rising price of crude oil.

consider and execute alternatives for road and air modes, and (to a lesser extent) maritime modes.

Crude oil, which mainly consists of hydrocarbons C_XH_{2X+2} is by far the main source of primary energy used to produce liquid fuels (gasoline, diesel, kerosene, heavy fuel, liquefied petroleum gas (LPG), etc.). Producing liquid fuels with methods other than refining crude oil is possible yet difficult and, above all, costly. The rising price of crude oil will progressively make alternative solutions more affordable. A number of initiatives are based on the production of liquid fuel from natural gas (gas-to-liquid), from coal (coal-to-liquid) or from biomass. None of these methods are currently very competitive (and they are not equivalent in terms of sustainability).

Natural gas mainly consists of methane CH_4, the simplest hydrocarbon molecule, the other constituents being ethane, butane, propane and other gases. LNG and CNG are abbreviations for liquid natural gas and compressed natural gas, respectively. Natural gas is a major alternative to petroleum oil in terms of access to fossil fuels. It is found in abundance and is geographically distributed in a homogenous manner; new methods (which are widely debated) allow these resources to be amplified with the extraction of shale gas[22], by accessing high levels of potential that was previously unreachable[23]. In the long term, natural gas is still an important possible form of energy for transport by sea, river or land, and has both inconveniences and advantages in comparison to petrol. The inconveniences include its low energy density in gaseous form, meaning that it must be compressed (up to 200 bars, for example) or liquefied (cryogenically to −163°C) in order for it to be transported by vehicles. We can add the lack of infrastructure to distribute natural gas to vehicles for cost and market reasons, the lack of standards for infrastructure and vehicles, etc. As for its advantages, it has a good reputation for its combustion qualities, emitting low levels of pollutants (nitrous oxides, particles), less noise, slightly lower CO_2, by providing possible access

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[22] Also called “source-rock gas”.

[23] In 2012, the price of gas in the United States collapsed and was accompanied by the separation, with respect to price, of petrol due to the implementation of the mass extraction of shale gas.

to local resources, etc. However, methane is in itself a powerful greenhouse gas, which has an impact 20–30 times stronger than that of CO_2 and leaks into the atmosphere have a worrying greenhouse effect. At this point in time, there is a lack of tools available to establish what the real risks are, which could modulate its pertinence for sustainable solutions.

Biomass can provide liquid or gas biofuels (or agro-fuels) and represent a resource for which use is still at the developmental stage. The lifecycle of this type of fuel has the following virtues: CO_2 produced during combustion is recovered in the atmosphere by the plants that are processed to create the fuel, during their annual growth cycle. Transformation and synthesis methods are numerous – esterification, fermentation, carbonation, enzyme hydrolysis, etc. Therefore, they result in a great diversity of proposals for biofuels on the market, which may have ranked differently, according to their virtues in terms of sustainable transport: they must be categorized according to their energy efficiency (how many kilocalories per liter of fuel?), their carbon footprint (how many grams of CO_2 per liter of "well-to-wheel" fuel?) and their territorial footprint (how many m^2 of land is immobilized to produce a liter of fuel each year?).

Among all these biofuels, biogas, mainly composed of methane, shows the best results in terms of energy potential and efficient use of land. It can be produced by fermenting organic matter from a wide variety of different sources, its composition is identical to that of fossil gas and can therefore be mixed without any significant difficulty in distribution set-ups that supply vehicles with methane gas.

As for liquid biofuels, which may directly replace fossil fuels in vehicle tanks, the hopes were initially placed in *methods* termed "first-generation" methods[24], which result in using vegetable oil esters as additives to diesel, or ethanol (for which Brazil is the winner) as an

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[24] First-generation biofuels are agro-fuels produced from cultures traditionally intended for food. Second-generation biofuels use either all of a plant's lingo-cellulose, or biomass: wood, straw, waste, agricultural and forestry residues, or dedicated crops. The crops used will no longer be in direct competition with food crops. Third-generation biofuels differ from second generation ones in the type of biomass used. The latter originates from algae.

additive to petrol[25]. Efforts are now firmly placed in the category of "second-generation" methods, which process organic waste from agriculture and forestry, or else plants having a fast growth rate, with dedicated crops. They are therefore produced using cellulose, a molecule present in all plants. Concerns about the potential competition between these products and the food market have already been debated. However, a better estimation of their actual benefits in terms of sustainable development has recently been provided and shows that these benefits had been overestimated: it became apparent at a late stage that if the indirect modifications to ground allotment resulting from the production of biofuels are taken into account[26], some biofuels emit quantities of greenhouse gases equivalent to those of the fossil fuels that they replace[27]. Significant political changes have thus been agreed upon in Europe and have resulted in limiting first-generation biofuels, and encouraging second-generation biofuels by providing community help to those that show a reduction of greenhouse gas emission of at least 60% in comparison to traditional fuels. The energy efficiency in terms of biomass per hectare of land can vary from 1,400 elp (equivalent liters of petrol) (for biodiesel produced from rapeseed) to 500 elp (for biogas produced from specific plants), for example. New avenues for the use of algae are being investigated[28]. The biofuels obtained via this method, termed algae fuels, are also called "third-generation" fuels.

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[25] Those derived from alcohol are produced from sugar-rich plants, such as sugar cane, beetroot or plants rich in starch, such as wheat. They consist of bioethanol and its derivative ETBE. As for oils, they are extracted from oleaginous plants such as rapeseed, palm, or soya. In some cases, the oils are pure vegetable oils, termed "crude oil" (sometimes kitchen oil), or modified products. In the latter case, mention is made of diester, biodiesel or VOME (vegetable oil methyl ester). They are produced using 90% oil and 10% methanol, a derivative of petrol.

[26] For example, moving agricultural production (intended for human or animal consumption) to land that is not farmland, such as dedicated forests.

[27] Energy efficiency is the relationship between the energy available and the energy used to produce it. Estimations vary but, according to ADEME, the energy efficiency of alcohol obtained from sugar cane is 5.82%; 2.23% for diester made from rapeseed; 1.35% for wheat and 1.25% for beetroot. For ethanol made from maize, it is less than 1%, meaning that more energy is needed to make it than it provides [ADE 10a].

[28] Certain species of microscopic algae can synthesize oils that may be processed in the same way as traditional vegetable oils, once extracted. The yield per hectare is

Biofuels can be criticized for having one of the lowest yields. They are limited by photosynthetic yield (<1%), and will generally be less efficient than any "electrical" solution, namely the use of solar energy[29].

Electricity is at the heart of the debate on electromobility and does not exist in primary form as it must be created. The same is true for hydrogen, a gas rarely found in its native state, but which has great potential with respect to environmental considerations when used in addition to electricity for transport, as will be seen later.

Two-thirds of all the electricity in the world is made using fossil fuels (coal, fuel, natural gas). This situation is detrimental toward the environment and is even more so in countries that must dominate global demand in the next few decades, the United States and China (Europe being the third "region", which is the largest consumer of electricity). The remaining third is mainly divided between nuclear and hydraulic electricity. At the moment, other sources (solar, wind, biomass and geothermal) only have a minor contribution. However, these distributions vary greatly from one country to another (nuclear power is important in France, hydraulic power in Canada and in Brazil, gas in Russia, coal in China and India, etc.). Programs aiming to provide renewable electricity (wind turbines, photovoltaic panels, etc.) are currently implemented in Japan, China and most European countries. Their long-term potential does not make assumptions related to the fraction provided for transport, with respect to other consumers (housing, for example). It will nonetheless be shown that there is a genuine project aiming to develop an array of solutions that will connect mobility – and thus transport – to other needs and services, in a concept centered on use and "neighborhood". From an energy point of view, this will lead to a differentiation between the needs of short-distance transport, focused on the user and widely able of using electricity, and the needs of long-distance transport, based on massing and flows and which use liquid or gas fuels (at the very least autonomous vehicles – road vehicles, aircrafts, ships). The "engines"

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estimated to be 30 times higher than that of rapeseed and their cultivation is calculated so as to absorb significant quantities of CO_2.

[29] Photovoltaic yields currently obtained are in the order of 15%.

used in both these types of transport may lead to different on-board energy solutions.

We must therefore remember that electrical energy, in principal preferred by those in favor of decarbonized mobility, is only "virtuous" (particularly in terms of carbon footprint) depending on its origin, and its current outcomes are more or less favorable, depending on the country, the area and the time of day, in comparison to solutions that use fuels directly from oil wells. This is a widely controversial fact and is often ignored in debates on the topic of sustainable transport. The increasing incorporation of electricity into solutions for transport (particularly urban ones) cannot avoid the deadlock appearing when its "well-to-wheel" pertinence is investigated in detail. This concerns the carbon footprint (in the case of electricity of thermal origin), long-term risks (in the case of nuclear and hydroelectricity[30]), and other economic and environmental impacts. It is noteworthy that in terms of carbon, the electricity produced in France has the lowest rates in comparison to the other major industrialized countries, due to its mix in energy[31] (0.08 kg CO_2/kWh, in comparison to a rate that is approximately 0.50–0.56 in Italy, the United Kingdom and Germany, for example). The debate on electromobility in France is therefore strongly affected by this "regional" context.

The benefits to be expected from developments in "green" electricity produced by means of wind turbines, photovoltaic cells and underwater turbines may slowly lead to important changes in the outcome, as long as the environmental criteria for the production and maintenance of equipment are satisfied. The interconnection of networks for transport infrastructure and electricity distribution should also be mentioned because the immediate links between electricity

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[30] The debates on nuclear power are currently relevant, especially after the disasters that were Three Mile Island, Chernobyl and Fukushima. For dams, the ecological and main climatic impacts of some, as well as the resulting risks (namely) of natural disasters, cannot be neglected. In general, infrastructure for the production and transport of electricity holds a powerful grip on territories and on the landscape.

[31] The energy mix or energy bouquet is the distribution of different sources of primary energy used to produce different types of secondary energy, in this case electricity.

consumers and producers must be perfectly controlled. The potential demand in electricity from the fleet of vehicles subject to synchronous time-cycles must be managed by anticipating the risks associated with peak hours, and with the need to separate local and global management of electricity needs (so-called “smart grids”).

Hydrogen molecules (H_2) are another possible secondary energy that can be used for sustainable transport. By combining it with oxygen (air), it produces electrical energy and water molecules. Hydrogen is a very light gas that does not exist in its natural state in vast quantities in terrestrial conditions[32], and must therefore be made using primary energy (a fact that is often omitted). It therefore results from the decomposition of hydrogenized molecules (for example water by electrolysis) and thus requires an intermediate energy (in this case electricity). Its advantages include its high energy density, which cannot be compared to electricity (1 kg of hydrogen contains as much energy as 2.9 kg of petrol, 140 kg of Li-Ion batteries, which allows an autonomy comparable to that of combustion vehicles), as well as the fact that it can be stored under pressure in gaseous form after compression (up to 700 bars) [AIR 13], or in the form of a cryogenic liquid after liquefaction (−253°C), making it significantly more favorable than electricity, which has very limited storage capacities. When available, the implementation of hydrogen in transport will involve the same problems as electric vehicles: fueling infrastructure. However, this does not prevent experiments on captive fleets[33] that use hydrogen produced locally. Its potential will most likely be restricted to niche uses while current conditions become more favorable for extension.

The systems related to hydrogen are therefore in parallel with the system related to electricity. The latter travels along conducting cables, whereas, conversely, hydrogen gas (or its liquefied cryogenic

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[32] Traces of natural hydrogen originating from the Earth’s crust or sub-ocean have recently been confirmed. Signs of hydrogen gas have also been detected in deep-sea telluric emissions, and in some geological terrains (peridotites, cratons, Precambrian). They are the focus of research aiming to evaluate their potential for industrial extraction [IFP 13].

[33] Vehicle fleets managed in a coordinated manner, which are generally used locally and depend on specific centers that provide the energy required.

form) must be transported between production site and site of use, and then reconverted into electricity for its final use in the vehicle. This requires the use of a fuel cell, operating by means of hydrogen and air. Hydrogen is both an alternative and a complement to electricity: an alternative as it needs to be produced from primary energy (similarly to electricity) and has an end use by means of electric motorization; a complement, as it disposes of specific characteristics in terms of storing, distribution, transport and transformation[34], and is advantageous for areas where electricity has disadvantages (the opposite is also true). It has comparable characteristics in terms of CO_2 footprint (which depends on the source of generic electricity[35]). It should be noted that hydrogen can also be used as a fuel in combustion engines, for example as an additive to natural gas (hythane[36] is a mixture of hydrogen and methane, with a volume consisting of up to 20% hydrogen).

The use of hydrogen for transport is promising as long as the production of green electricity is generalized, even though the "hydrogen revolution" in the field of transport, announced many years ago, and its expiry date are receding at the same speed, due to the current known difficulties associated with its implementation being understood: we must develop robust technical solutions for production and storage, it is necessary to invest in infrastructure, safety standards need to be implemented, costs must be reduced for systems to be competitive, etc.

Figure 1.4 shows the *various energy* systems used in road transport. The secondary energy provided to the vehicle (to its driveline, engines – combustion or electric engines, and transmission) comes from very diverse sources, either fossil or renewable. The problem with sustainable transport is rebalancing the source of primary energy in favor of renewable energies, the former being currently very costly in terms of carbon footprint and the footprint of

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[34] Hydrogen lends itself to local and diverse production methods for storage of surplus electrical energy.

[35] While possibly waiting for the so-called "third-generation" bioprocesses to mature (hydrogen produced by bacteria, without the need of additional energy).

[36] Hythane® is a trademark registered by the *Université du Québec à Trois Rivières* (UQTR).

other greenhouse gases (methane). The problem is to minimize the environmental impact of transforming primary energy into secondary energy, as well as transporting it for distribution purposes. Finally, the difficulty is also to save fossil fuel resources, which could be safeguarded, or else reserved for more pertinent uses. As for secondary energy, the problem is producing it from renewable energies, as well as distributing it by storing it in a form that can be used by vehicles directly, close to supply points, with appropriate interfaces (distribution storing/vehicle points). For vehicles, the aim is to make them easy to power, and for them to have the appropriate on-board conditions for the storage of energy: storing fuels in liquid or gas tanks, under atmospheric conditions, or under pressure (compression) or in certain temperature condition (cryogenics); or else storing electricity in batteries or supercapacitors.

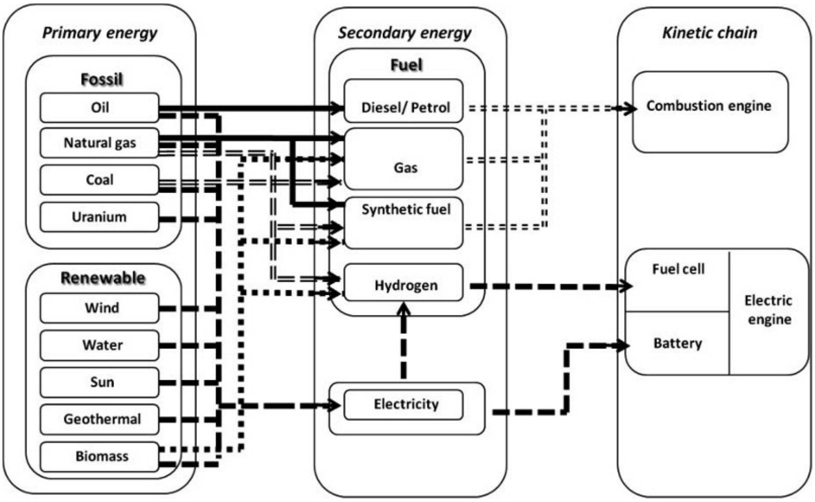

Figure 1.4. *Well-to-wheel systems for energy [ERT 11]*

1.4. The environment and sustainable transport

From an environmental perspective, transport instantly invokes the notion of disturbance, the first of which is noise, in addition to smells, smoke and toxic gases from the exhausts of combustion vehicles. It should be noted that CO_2 does not directly entail noticeable effects unlike the other listed pollutants. Sensitizing public opinion is associated with debates in the media (on the subjects of particles, the ozone, acid rain, smog, greenhouse effects, the climate, etc.), which have important echoes. However, it seems that the natural concern of explaining everything in simple terms too often gives way to slogans and labels which, due to ignorance, interest or as shortcuts, exaggerate or, on the contrary, underestimate the actual impact, depending on the period in time and on the context. The debate hence does not gain anything in educational quality and tends to obscure the accurate understanding of the subject. Moreover, some effects are immediate (noise, smells), some are the result of prolonged exposure (particles) and others contribute to a slow evolution that does not have a direct effect on populations (CO_2). They bring about diverse impacts affecting discomfort, health, quality of life and the economy, which are all strongly interconnected and thus difficult to disentangle.

The problem of energy is obviously connected to the problem with the impact of transport on the environment. The process of understanding this impact goes back far in time and takes different forms depending on multiple aspects: it concerns all interaction between transport modes and their environment, with which they are coupled. This leads to consequences that are potentially detrimental to health, safety, the perceptive ambience and quality of life in all its forms. The impact of gas emissions is particularly relevant, as well as the impact of sound emissions, the use of natural resources (raw materials, space) and other widely diverse impacts (water pollution from transport infrastructure, effects on landscape, electromagnetic environments, vibrations, etc.). Thought can also be given to the environmental impact of all the systems associated with transport itself, but this would prove to be a never-ending exercise (which is beyond the scope of this document).

1.4.1. *"Sensitive" pollutants*

From 1970 to 1990, industrialized countries were preoccupied with the environmental impact of transport, largely related to *the quality of the air breathed in, as well as noise*, and with public policies that increasingly stress the emission of sensitive gases, which have a localized geographical impact and an effect on perception and health, besides roads or at the center of urban agglomerations[37], for example.

With regard to gas emissions, the gases considered here concern combustion waste, for which the composition depends both on the quality of the fuel as well as the motorization technology. They mainly consist of nitrous oxides, particles, carbon monoxides and various volatile organic compounds. Combustion engines (in all modes of transport) emit these components in quantities of varying importance, depending on the fuel used and their technology. Higher combustion temperatures favor a decrease in particles and also increase energy efficiency, although it also favors the emission of nitrous oxides, leading to very complex interactions with other gases present in the atmosphere, at the expense of the quality and cleanliness of the air in and around large agglomerations[38].

With respect to particles, many reports show that there is a link between exposure to fine particles and health risks. However, qualifying (proven or suggested causal relationships, existence of a correlation) and quantifying this link is still widely subject to debate. Some entities calculate and report the statistical number of years lost and the health cost caused by exposure to pollutants, with the aim of helping public authorities in the decision-making process. For the current state of things, and for non-experts, it is difficult to form an opinion on the level of rigor and scientific pertinence of methods and hypotheses used in these calculations. Let a statistic put the problem into perspective with this example: taking into account the fact that fine particles are classified as “definite carcinogens”, the International Agency for Research on Cancer estimated that atmospheric pollution

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[37] A rapid deterioration in air quality has been established in big cities that have intense traffic. It is reflected by an opacified atmosphere (“smog”) which interacts with local climatic phenomena, and is one of the eliciting factors for mass awareness in various world regions (European and Japanese cities, California, Sydney, etc.).

[38] Particles that result from mechanical wear (brakes, tires, road surfaces, etc.) are also present but are not regulated. Moreover, atmospheric processes can alter the pollutants emitted locally and result in a regional impact several days after they have been emitted. For example, the contribution of maritime transport to ground pollution, by sulfur oxides (SO_x), particles and by ozone at ground level, is therefore important [EEA 12].

caused 1% of cancers in France in 2000, in 10th place after tobacco, alcohol, infectious agents, work-related risks, obesity and overweight, lack of physical activity, exposure to ultraviolet light, hormonal treatments and reproductive factors. For the rest, the estimation of health costs associated with air quality is still currently limited by certain boundaries, namely by uncertainties in quantifying the dose–response function, as well as uncertainties in the estimation of non-market costs. The current state of knowledge does not seem to enable health risks and/or impacts, connected to the different chemical components of particles, to be identified and quantified[39].

Preparation in the 1980s, followed by the implementation of *regulations for the gas emissions from road vehicles* in Europe, North America and Japan in the 1990s, resulted in the gradual and constant reinforcement of regulatory emission thresholds for vehicle exhausts, for all types of vehicles having petrol or diesel combustion engines. In Europe, "Euro X" regulations gradually imposed a spectacular reduction in the levels of pollutant emitted by all types of road vehicles, with petrol and diesel engines, when put into circulation, starting with the Euro0 threshold (1990) and followed in successive steps by Euro1, Euro2, etc., every 3–5 years. Euro6 thresholds have been imposed starting from January 1, 2014. These results were reached at the cost of considerable work on the technology used in the design of engines. In compliance with the successive decrease in regulatory thresholds, the actual vehicle emissions were reduced drastically. From Euro1 to Euro5, a regulated 97% reduction in PM10 particle emissions (particles with a diameter less than 10 µm) from exhaust pipes in diesel cars was observed. When road traffic in France increased between 1990 and 2010, this reduction, combined with the renewal of road vehicle fleets, enabled measured traffic PM10

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[39] According to the French National Cancer Institute (INC), the estimation of level of risk due to diesel emissions relative to cancer on general population remains complex: the studies which made it possible to assess causal link between diesel particulates and cancer on human were only carried on professional expositions; and under working conditions which should not persist any longer [INC 13].

emissions to be cut by 38% for road transport. Similar performances have been achieved in North America[40] and in Japan.

Despite the existence of highly restrictive regulations for exhaust emissions from new vehicles, the concentrations of pollutants in the urban atmosphere frequently exceed the regulated limit values that ensure minimum air quality. These excesses affect some major European agglomerations, namely in terms of particle concentration. Examples of orders of magnitude include the following: at the scale of a ring road in Paris, 44% of PM2.5 (particles with a diameter less than 2.5 µm) originates from gas emissions from local traffic[41]. Still this value decreases very fast with the distance to the infrastructure.

The air quality at a local scale therefore remains a problem that has not been completely resolved, even for agglomerations in developed countries that benefit from the results of technical improvements[42]. Even though it has improved over the last 20 years despite the increase in traffic, air quality is still affected by emissions from older vehicles and/or from vehicles that have not been well maintained. The full benefit of the regulations will only be observed once the entire vehicle fleet has been renewed (a vehicle's "lifetime" is in the vicinity of 15 years, although there is important scatter). In these conditions, diesel engines, which have a significantly higher energy efficiency (and lower levels of CO_2 emissions) than its petrol equivalent (15–20%), continue to be referred to as "unclean" energy in some circles as responsible for the emission of toxic particles affecting the population's health. Nonetheless, analysis demonstrates that this appreciation is only relevant to old vehicles: the emission rate of modern diesel engines have been cut by 99% in 25 years (an older

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[40] In the United States, the EPA, in partnership with the DoE and the State of California, has led a highly voluntary policy of mastering gas emissions from road vehicles. Since the 1970s, it has financed projects in search of alternative solutions to traditional motorization (such as Stirling cycle engines, Rankine cycle engine and gas turbines). It then imposed the US regulations.

[41] To which we must add the particles from vehicle abrasions (tires, brake pads, etc.) and road abrasions, as well as from residential wood burning [AIR 11].

[42] Concerning urban agglomerations in developing countries, the situation is naturally worse, since they will not benefit for a long while yet from the progress made in the subject thanks to actions on vehicles.

vehicle emits the equivalent of 100 modern vehicles). Moreover, they are to be preferred to petrol engines in terms of controlling CO_2 emissions (if fossil fuels are being discussed).

Noise is another sensitive pollutant, which is caused by the acoustic emission of vehicles into the environment, all modes combined, and is still a worrying issue even though regulations have been put in place to impose progressively lower levels, mainly for road vehicles and aircrafts (see Chapter 2). It affects residents located besides transport infrastructures, roads, railways and airports. Considerable progress has been made in terms of transport acoustics over the last 20 years. Quieter and qualitatively more satisfying solutions have been found for vehicles, although they are not always spectacular in terms of perception[43]. However, the continuous increase in fleets and traffic has strongly reduced the genuine benefits relative to environmental noise. Progress in the subject is extolled by permanent effort over time and requires a multidimensional approach for which acoustic technologies are evolving alongside the technical evolution of products (motorization, vehicles, tire tread/road or wheel/rail), and society's expectations, reflected in norms, standards and regulations. Moreover, the state of vehicle maintenance, and above all their conditions of use, is a particularly sensitive parameter: in the case of cars, and especially of two-wheeled motor vehicles, users themselves may play a part in the quality (or more accurately the non-quality) of environmental noise. Performances obtained under the conditions created by vehicle regulations therefore do not lead to progress in noise levels to the same degree as they are perceived by the exposed population[44]. The arrival of electromobility will change the situation little by little.

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[43] Engineering acoustics is a linear acoustics (expressed in terms of energy and power), whereas acoustics for psychosociologists is logarithmic (in decibels): intense engineering methods must therefore be made to reduce disturbances significantly [FAV 05].

[44] For example, real progress has been made, with respect to road traffic noise, by reducing noise levels emitted by mechanical parts, although it is partially hidden by the "concurring" emergence of noise from contacts between tires and roads. Other elements (traffic volume and make-up, evolution of vehicle fleets, impact of motorized two-wheeled vehicles, lack of maintenance or malevolent use of vehicles, etc.) equally play an important role [SAN 01].

1.4.2. *Greenhouse gases*

Environmental considerations now focus on *the problem of greenhouse gases, mainly* CO_2: 30.6 billion tons were emitted by human activities in 2010, and most of these emissions were due to the production of energy by coal, oil and gas industries, at a rate of approximately 900 g/kWh. CO_2 and H_2O are natural products of fuel combustion, which combines hydrocarbon molecules C_XH_{2X+2} with oxygen O_2. Everything changed once the impacts of human activities on the planet were appreciated, and the priorities were modified. It is a matter of fighting phenomena of another order: impact on climate, increase in atmospheric temperature, increase in climatic risks, rising sea levels. Here, the consequences are on a planetary scale (and not regional): as greenhouse gases emitted anywhere will contribute to aggravating consequences everywhere.

Recognizing the impact of human activities on the climate is very recent, in the historical timescale. Recognition has only arisen in the past couple of decades. Even though it has taken some time to identify the impact on the climate (and although it is still subject to rear guard debates), it has now completely modified the problem of sustainable transport: in particular, it assumes all efforts and all governmental levels to be conjoined to solve the problem in which everyone is involved, and must therefore feel committed to. Objectives to control and minimize these emissions are currently being discussed in world forums (Rio, Cancun, Cape Town etc.) and vary depending on the world's regions and its states. Each country in the European Union must work together. The action plans created to satisfy these objectives involve extremely vigorous policies for all fields that emit these gases, in particular, the field of transport. Not only does it represent an important part of emissions, which are constantly increasing, unlike other fields, but restricting these emissions is also proving to be particularly difficult. As a matter of fact, transport lends itself very poorly to alternative solutions that use energy sources other than liquid fuels.

The debate on CO_2 has also reached the point at which other elements are rarely mentioned. However, it is important to underline that a policy solely aiming to reduce CO_2 may lead to conflicts with the objectives of other environmental factors (local pollution, noise, etc.) and even to errors in judging the actual impacts of different types of energy solutions for transport. In particular, the effect of CO_2 reducing solutions is global, at a planetary level, and does not affect the quality of the atmosphere locally. On the contrary, the improvement of air quality requires solutions to minimize the emission of nitrous oxides or particles, the effect of which is limited to nearby spaces, either local (at street, district or city level) or even regional (for ozone associated with nitrous oxides). For example, electric cars, generally promoted for their environmental qualities, may prove to be beneficial in terms of local pollution, yet detrimental in terms of climate, depending on the primary energy source[45]. The same holds true for other energy configurations that have the reputation of being “clean” (natural gas, hydrogen, etc.). This complex interaction is often omitted in public debates, and even ignored or avoided. Moreover, a variety of lobbies or pressure groups, having various objectives, contribute to obscuring the debate, by concealing part of these aspects in order to give extra value to their report on current state of things as well as to their position. All of this therefore does not help to raise a necessary level of collective awareness. Yet, the context must be understood by all and the paths leading to solutions must be debated, understood and applied within the framework of coordinated public and private actions. It is hence difficult to elaborate this policy, which is nonetheless indispensible for guaranteeing compatible objectives in the short term (<5 years), middle term (10–15 years) and long term (>30 years and beyond), with the aim to maintain acceptable levels of stress on the climate.

1.5. Material and sustainable transport

Creating vehicles and infrastructure for transport requires increasingly elaborate materials. Shaping, assembling and recycling them require industrial processes that are adapted to each one. Although transport uses and adapts the most widespread materials, in particular, a number of technologies (batteries, systems for treating exhaust gases, surface treatment, electronic processors, electric

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[45] They may also accentuate the pressure on rare material resources.

equipment, permanent magnets, etc.) require the use of precious metals (such as platinum), or “rare-earth elements” (such as lithium or gallium). This situation raises two main types of issue.

From a geopolitical stance, this dependency can create serious tensions. For example, the European Union imports an important portion of these materials (100% of rare-earth elements, 75% of copper, etc., in 2012). At the same time, some countries have become vital for supplying these materials. The most telling example is that of China: it is now the first producer of 28 strategic metals (in comparison to 5, 20 years ago). In 2011, China produced 94% of rare-earth materials used throughout the world[46]. Bolivia also owns 50% of all known lithium stocks. Sustainable transport cannot feed of technological solutions that inflame geopolitical tensions in the world market.

Furthermore, in the general context of *world material resources*, their availability can become critical depending on the expiry scenario considered: given the current market conditions, current materials can quickly become rare and hence “precious”. For example, the availability of copper is not critical in the short or middle term but may become so in the long term, depending on the electrification scenarios for means of transport, if all infrastructures are to be equipped for example. A possible answer is again to develop recycling systems, namely the recycling of used vehicles (and transport infrastructures): better organized systems will give waste an added value, a process that is currently poorly taken advantage of. Another solution is to replace some critical materials with others that guarantee comparable functionalities: this gives rise to new possibilities and potential for research and development.

Choosing materials therefore has strategic importance, and tends to a better classification and management in terms of “cradle-to-grave” systems. REACH ratings[47] lists these and provides the rules for

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[46] Sources: IMCOA, Chinese State Council Information Office, Technology Metals Research.

[47] REACH (Registration, Evaluation, Authorization of Chemicals), a European regulation, covers the recording of chemical substances (refer to Chapter 2).

materials, with respect to industry, according to their environmental impact. Other data characterize the materials' sensitivity to the risk of supplying raw materials and their drift in price.

The production procedures for vehicles or their components are a complementary aspect: producing a car emits CO_2, consisting of roughly 15% of its overall carbon footprint for its entire {production–use–recycling} lifecycle [DUP 10]. The aim is to deeply modify these procedures in order to minimize their footprint. Strong efforts are thus being made to improve painting procedures (by reducing or removing some volatile organic compounds, minimizing the quantity of material required to guarantee protection, replacing dangerous materials), which use considerable amounts of energy and water. The overall outcome can be more subtle for materials developed to make vehicles lighter: even though they enable vehicles to use less energy over their life time, some also use considerable amounts of energy in order to be produced (for example aluminum or, even more importantly, magnesium[48]), or they can be difficult to recycle (reinforced carbon fibers, for example). Producing and recycling batteries also gives rise to serious problems. Solutions are also being researched in the field of natural materials (natural fibers), which include their own decarbonized cycle.

1.6. A "committed" change in Europe[49] and elsewhere?

The term committed change implies that the shift to a new transport era has already begun, but that change is also a militant change that requires the involvement of all the players.

The European Commission, in its programming work for transport policies, regularly produces reports on transport in Europe, which it then uses to identify objectives and action plans related to sustainable transport (this will be discussed in more detail in Chapter 6). These reports provide an accurate indication as to trends, even if they seem

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[48] Creating 1 kg of steel emits approximately 2 kg of CO_2. The values are 12 kg of CO_2 for aluminum, and 18–40 kg of CO_2 (depending on the method used) for magnesium.

[49] Most of the data are presented in the report [EU 09a].

questionable in some cases, particularly when compared to a more regional analysis at the scale of a country (France, for example), which produces its own indices with contours that are sometimes different depending on the administrative boundaries. The following elements of change have been identified and can be retained as controlling elements in terms of sustainable transport:

– Aging populations, for which one must guarantee constant access to mobility: issues related to providing information and communication systems, adapting driving assistance, aides for spatial memory, the specific behavior of senior pedestrians, etc.

– The evolution of needs for mobility, which consists of satisfying them more efficiently by implementing efficient and sustainable solutions. The reduction of technical administrative barriers is one of the long-term objectives, which is also associated with conditions linked to obtaining public funding for infrastructure.

– Urbanization, which induces deep-rooted changes in mobility needs, and the necessity to integrate transport requirements effectively in town planning commissions.

– Regional integration, which allows interoperability to be promoted, and to minimize or remove the costs linked to regulations or technical choices specific to each region or each state. This is particularly applicable to railway systems (for signaling, the choice in terms of electric current, safety systems), or to international road transports (for tax systems).

– Globalization, which alters the structure of global exchanges and industrial flows.

– Climate change, which imposes public policies at all governmental levels, and has a direct influence on the fields of transport and mobility.

– Technology, mainly in the field of energy and information.

A certain number of facts on the “weight” of transport in economy are included in the indicators provided by the European Commission: it represents more than 4% of jobs and added-value, half of this being from road transport. Road infrastructure creates a network of more than 5 million kilometers, of which 60,000 km are highways. There is roughly 215,000 km of railway infrastructure, of which 5,500 km are high-speed railways, and waterways have a 40,000 km long network.

From the point of view of users and households, transport represents the second item of cost after housing (approximately 13% of the entire budget). The time-budget for transport is relatively constant, equal to 1.1 h per day per person on average, with rising mobility in terms of distance due to the increased use of faster transport modes. Forty percent of movements are linked to work. Private vehicles represent 72% in terms of passenger per kilometer.

In terms of the transport of goods and trade, globalization should lead to a continuation in the growth already observed over the past few years, in particular between the European Union and new economic giants, consisting of developing countries (China, India, Brazil, Russia, etc.). The growth of goods transport observed in the last 15 years has exceeded that of people transport. Road transport is the dominant mode in all European countries: 85% of tonnage transported by road is done so for distances less than 150 km; in towns, goods and rubbish are nearly exclusively transported by road.

Transport is therefore of major economic importance. The following data can be quoted in no particular order: in 2011, the European Union's (EU27) entire automotive industry (constructors, supply chains and aftermarkets, etc.) represented 12 million direct and indirect jobs, 4% of gross domestic product (GDP) and a trade surplus of 90 billion Euros. The automotive sector is also the first private investor in research and innovation, contributing some 30 billion Euros every year. More than 3 million people are employed in the maritime field, as many as in the aviation field. Logistics (transport, storing, etc.) represent 10–15% of the end product's cost. Costs linked to the congestion of road infrastructure are estimated to represent 1% of the total GDP.

As far as the environment is concerned, *transport in Europe represents 25% of all CO_2 gas emission and strongly depends on oil that provides 96% of its energy demands* and that is mass imported. The consumption of oil by the transport sector must decrease by 70%

in order to respect the European political objectives for the reduction of CO_2 emissions by 2050[50] and implies a double-sided revolution: on one hand, the energy used by transport; on the other, the way in which people and goods move.

According to the values from 2008, roads represent 71% of CO_2 emissions from transport in Europe, waterways represent 15%, civil aviation represents 13% and rail represents 1%. Emissions from transport have increased by 34% from 1990 to 2008. It should be noted that this increase is not uniform for all transport modes, or for vehicles included in these modes.

Figure 1.5 therefore shows the evolution of CO_2 emissions from road transport in France. Overall, they have increased by 9% in 20 years (1990–2010), although the unit emission per kilometer traveled has decreased over the same time period due to progress made in vehicle fleets (which have decreased in consumption by approximately 15% in 10 years). This explains why the predicted increase in CO_2 from transport for the past 20 years does not match the increase in traffic, which is much more considerable.

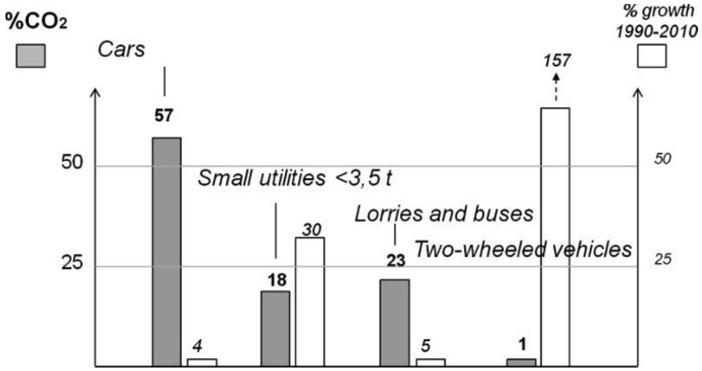

Figure 1.5. *Evolution of CO_2 emissions from road transport in France (distribution in 2010, and growth from 1990 to 2010, with respect to the type of vehicle) [CIT 12[51]]*

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[50] Let it be recalled that the overall objective in terms of CO_2 in 2050 is to reduce emissions by 80% in comparison to 1990.

[51] CITEPA, report on the energy sector, April 2012.

The following are the important elements to be remembered:

– Some types of vehicle affect relative fractions and the CO_2 evolution of transport more than others.

– The proportion of transport tends to increase in comparison to other CO_2 contributors (industry, agriculture, services, individuals, etc.).

Information relative to the carbon footprint of current transport modes is available for European means of transport. It intervenes in the development of indicators relative to the carbon footprint of logistics organizations and of mobility offers, which are now regulated[52].

Figure 1.6 shows the *levels of unit emission* (per passenger per kilometer) of the different transport modes for people that use current technologies. Figure 1.7 presents similar information (per metric ton per kilometer) for the transport of goods. These two figures show the great diversity of values and suggest potential for possible improvement, even by only using solutions currently in existence if they are exploited efficiently.

A great variety of methods are still available for assessing the emission factors of different transport modes in Europe. For road, the values are relatively homogeneous throughout the various European countries. For rail, the disparity between countries correlates with those of the energy mix of electricity. For river transport, disparities are due to the type of ship or basin. Some differences correspond to reality, whereas others are simply due to different approach methods.

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[52] In France, since October 1, 2013, any public or private corporation that organizes or markets transport products, no matter the transport mode or company size, are obliged to inform their clients on the CO_2 emission of their product (Law 2010-788 of July 2010, and decree 2011-1336 of October 24, 2011, establishing the calculation principles). The calculation method is based on a European Standard project, the final version of which is expected for 2013 (European agency TK'Blue, www.label-tk-blue.eu).

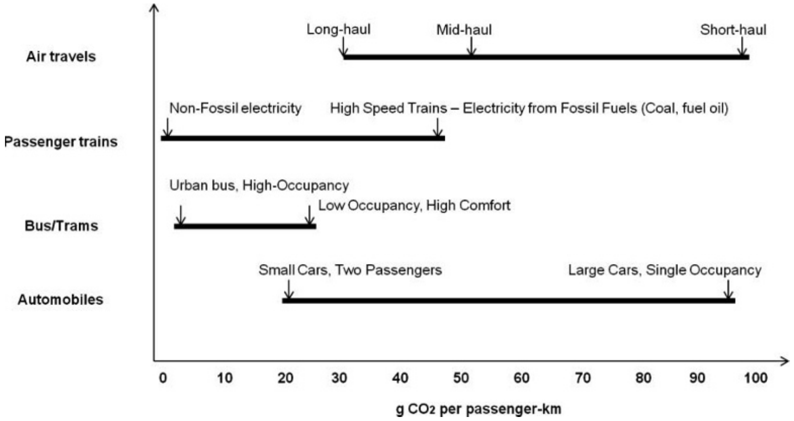

Figure 1.6. *Modal comparison of CO_2 intensities for passenger transport – Europe [EU– 09a]*

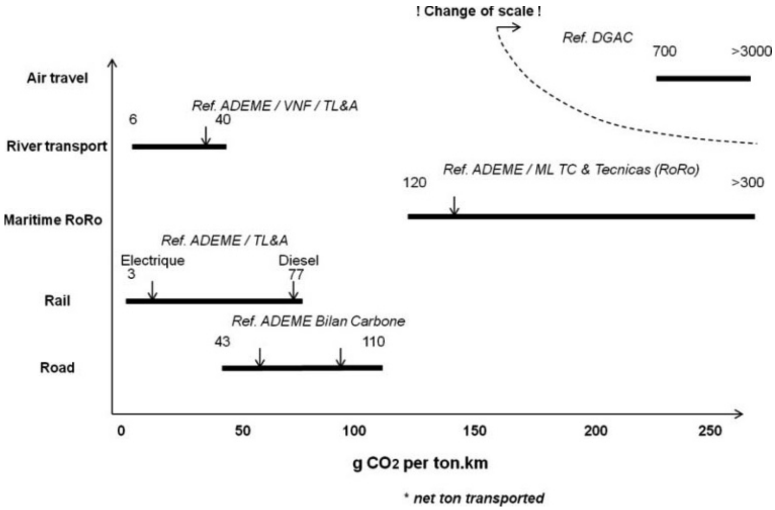

Figure 1.7. *Modal comparison of CO_2 intensities for goods transport – France. Sources indexed by European agency TK'Blue (www.label-tk-blue.eu) are French sources of reference [TKB 12]*

Outside Europe, the demand for transport – namely road transport – should continue to increase considerably in countries that are emerging economically, which have started the most "energy-intensive" phase of their development, such as China or India. These expectations create considerable tensions in the energy market. They are accompanied by a strong increase in the efforts made in the search for alternative solutions. Easy oil gives way to less traditional energies, the cost of which is slowly becoming more competitive as resources become rarer (taking into account costs linked to exploration, production and environmental impact).

1.7. Toward a better understanding of the impacts of transport

Communities are actively searching for solutions to remediate economic, environmental and society's expectations in terms of transport. They strive to develop methods and to establish tools and indices that will be necessary to draw up an inventory and are involved in estimating their policies, as will be shown in Chapter 6. These questions can be treated at any territorial level, from local to global levels.

The tools used to evaluate the impact of transport on the urban environment allow critical configurations to be identified and the set-up of action plans related to transport vehicles and systems, to infrastructure, to operational rules and to regulatory policies and incentives. A few examples at regional level will be discussed here, and have been taken from ongoing initiatives at the level of Greater Lyon (France), the community of communes within Lyon's agglomeration.

Therefore, in terms of noise, the road noise[53] shown in Figure 1.8(a) unsurprisingly highlights the agglomeration's main axes: highways, by-passes, ring roads and other urban roads penetrating into the city. All the other street systems are also represented and contribute to the noise landscape. The agglomeration's center is not spared. The agglomeration's outer ring, which is less dense and more agrarian, and green spaces of sufficient size are quieter. We can identify, for example, the *Parc de la Tête d'Or* as being relatively quiet. Outside these quieter zones, road noise can be perceived

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[53] A map established according to the requirements of the European Directive 2002/49/CE on the evaluation and management of noise in the environment.

throughout the agglomeration at different levels. Maps comparable to this one also exist for the other main transport modes, rail (in agglomerations) and aerial (in the vicinity of airports). They are also available for the majority of European cities and make it possible to identify the most critical noisy areas[54].

Figure 1.8(b) illustrates the local impact of gas pollutants (NO_2, NO_X, particles), by showing the values that exceed the limit values of nitrogen dioxide (NO_2). The limit for nitrogen dioxide in Europe is an average yearly value of 40 $\mu g \cdot m^{-3}$. The limit value is exceeded by the most frequently used axes: peripheral ring roads and important by-passes. However, a very favorable trend for the middle term is being suggested by the follow-up of these values[55].

To illustrate the case of CO_2 in terms of transport, Figure 1.9 shows the potential emission from actives in the agglomeration. The most important CO_2 "emitters" are active young people, home owners who belong to a household with one child, where both spouses are active with full-time open-ended contracts, living in an area that is not serviced by public transport, and therefore own two or more cars, etc. The trip from work to home represents structuring and high-emitting mobility, with an average CO_2 emission rate of approximately 2.5 kg/active/day, which conceals very strong spatial heterogeneity.

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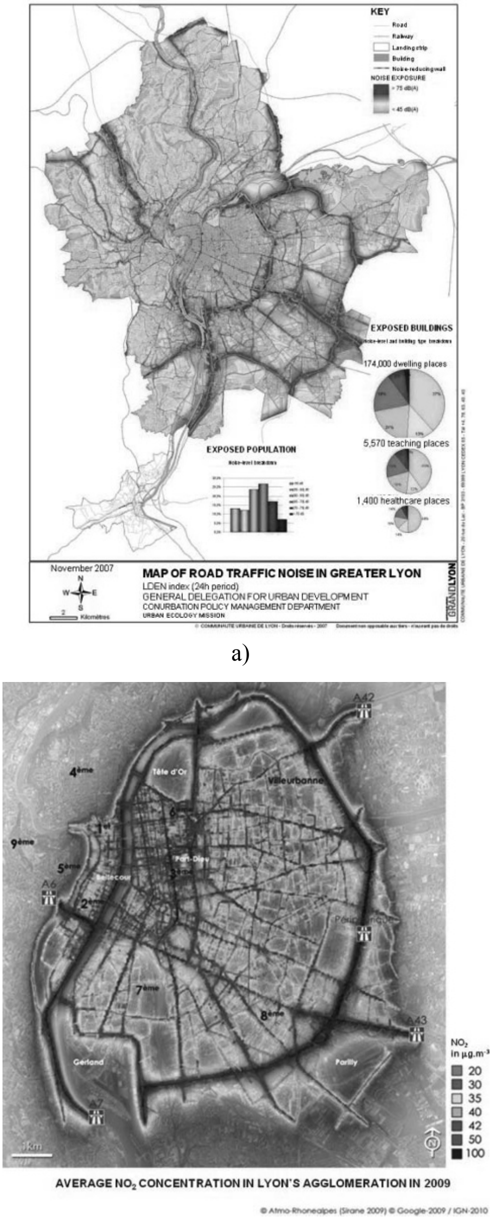
[54] A total of 27,500 people are affected by the 10 main black spots for noise in Ile-de-France (noise pollutions more than 70 dB(A) during the day, and 65 dB(A) during the night).

[55] Airparif, an association that surveys air quality in the Ile-de-France region, has observed "a decrease in pollution intensity in Paris between 2002 and 2012. In terms of NO_2, 80% of inhabitants were affected by an overrun of the threshold in 2002, in comparison to 45% in 2012, whereas 66% of the gas is emitted by road traffic in Paris. Encouraging reductions in the amounts of PM10 particles emitted have also been observed, even though pollution levels are still higher than regulatory levels besides major roads. Evolutions in the levels of these two pollutants are thought to be due to a combination of the following favorable factors: drop in volume of road traffic (−15 to −20 % in 10 years), decrease in the average speed from 19 to 17 km/h in the capital, modernizing the rolling fleet; and unfavorable factors: fleet dieselization, evolution of the fleet composition" [AIR 13].



a)

b)

Figure 1.8. *a) Map of road traffic noise (2007). b) Map of NO2 concentrations (2009). Examples of Lyon [GRA 09] www.grandlyon.com*

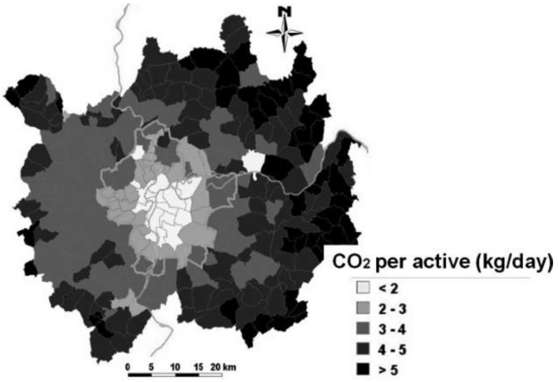


Figure 1.9. *Map of CO_2 emissions from transport per day and per active, Lyon area (2012) [ORT 12]*

These maps do not represent reality perfectly and are likely to improve, thus illustrating what was already known: the impact of transport on the local environment is still a worrying subject. In 2010, three atmospheric pollutants were still an issue in the territory of Lyon's urban community: on one hand, PM10 particles and nitrous oxides, the main issue of which is proximity to road traffic exposing part of the population to high concentrations; and on the other hand, ozone, which concerns a large surface area of the territory and therefore the majority of inhabitants, mainly during the summertime. Moreover, noise is a source of discomfort and affects, in particular, the health of urban populations.

The case of Lyon, which has voluntarily implemented initiatives to characterize its environment by establishing a set of indicators linked to transport and mobility, is considered by the author as being representative of European cities that confront the issue of sustainable transport via anticipation – or which are in phase with national and European recommendations. The existence of gray areas in transport pollutants maps encourages action to be taken, and solutions, connected to transport and the way they are organized in the city, to be implemented. A good understanding of the state of the situation (which can always be perfected) is a token for future quality. Let it be stressed that in other places, the lack of knowledge does not naturally mean that there are no problems: the non-existence of measurements or assessment campaigns, for more important territories, does not allow diagnoses to be made. This is often the case for territories especially affected by transport pollution.

1.8. A strategy for sustainable transport

Different aspects that are necessary to put the current situation of sustainable transport into context have been discussed here:

– Great pressure in terms of demand for mobility, whether it be for goods or people. This pressure originates from global demographic factors, as well as from the evolution of the quality of life. It is reflected by considerable expectations, both socially and economically, which demand transport solutions to be made available to towns and interurban areas, at all territorial levels.

– A worrying, and even disastrous, environmental balance, which concerns local and global impacts equally, and which can only be treated if the community, or communities, understands how to quickly put into place efficient solutions that can rise to the challenge of the identified stakes.

– Difficulties in demonstrating connections between the different players, establishing causes and identifying possible actions, because transport "embarks" other systems on board, such as those for energy, materials and intelligence, and due to the fact that it interacts with all the components of economic and social life, with the behavior of individuals and with political devices.

– The potential for progress, which involves in equal parts technologies and organizations, products and uses, and which assigns elements to the transport system that we are attempting to define and promote (vehicles, infrastructure, operational methods), and also their systemic integration into solutions for sustainable transport.

Their potential will be examined hereafter, as well as the difficulties that pave the paths that link transport elements (vehicles) to the solution for sustainable transport.

Chapter 2

Vehicles: An Element of the Solution for Sustainable Transport[1]

Vehicles are the starting point for everything, whether it is mobility performance, energy efficiency or environmental impact. They are the focal point of the solutions found to help implement sustainable transport as they have the ability to move, to support loads and are (now) capable of intelligence. The modifications that are essential for the vehicles to evolve in this direction will be presented in this chapter and represent general trends perfectly.

2.1. Technology: from evolution to revolution

Regardless of the transport mode (road, rail, water and air), vehicles are undergoing an unprecedented technical evolution that involves different technological domains.

Evidently, *information and communications technologies* (ICTs) deeply modify the electroinformatic design of vehicles and their functions. ICT is evolving at a spectacular rate and this fundamental

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[1] In the context of this chapter, it is not possible to provide an in-depth discussion of all transport modes. The main elements relating to road vehicles are a good example to represent general trends, unless it is specifically written otherwise.

fact is a challenge for designing the general architecture of vehicles. From now on, the impacts primarily affect the ability of the physical functions shaping the vehicle for operating conditions to reach the best possible performance: propulsion, steering, adapting to environmental requirements, management of passenger compartments, etc. This is why solutions are said to be "smart" or "intelligent"[2]. These technologies stand out because of the speed with which they are constantly being renewed. They were popularized by "Moore's law" (a performance that doubles every 18 months), and their integration is a considerable unprecedented challenge for vehicle architect-integrators ("constructors" or original equipment manufacturers (OEMs)) and their supplier partners, who were once in the habit of designing vehicles for which all technologies could be rolled out synchronously. The revolution has already passed this step and continues to produce inventions constantly. At present, it is impossible to imagine where it will lead us to in terms of innovation.

Two major consequences can be highlighted, with regard to sustainable transport:

– On the one hand, the relationship between humans and machines is an unavoidable axis for investigating future solutions. Of course, "humans must remain at the core of the system" for anthropocentric approaches, which prioritize mastering technical solutions by human ingenuity for all situations[3]. However, the gradual introduction of automatisms that partially take over human actions, replacing people for observation (sensors and detectors), for decision-making (processors) or for actions (actuators), raises both technical and societal questions in terms of responsibility, ability to understand, pertinence, etc.

– On the other hand, processes for the maintenance of a vehicle's working conditions and customer services throughout its service life (15 years for automobiles, 25 years for planes, 35 years for railway equipment) require the ability to repair, replace, control and memorize

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[2] The concept of "intelligent transport systems" (ITS) is widely used to characterize their effect in terms of their application in transport systems.

[3] As a driver, pilot or conductor, as a user and as an operator and manager of transport solutions, etc.

the relevant technology that must be followed. However, how can we attain this, considering that the technology takes 5 years to develop before it can be manufactured (the standard length for the development phase in transport industries[4]), for vehicles that will be manufactured in the next 10 years and must then be maintained for an additional 15 years? This results in a total cycle time of around 30–40 years. In 2050, how will we maintain vehicles designed in 2015? What about the availability of spare parts coming from an IT technology designed decades before?

The technologies that are more "traditional", with respect to *energy*, on the one hand, and to *structures* and *materials*, on the other hand, are also evolving spectacularly in such a way that the term "revolution" is also relevant even if it concerns longer cycle times.

In the energy domain, techniques used for converting thermal energy into mechanical energy to propel vehicles are following their progress, owing to very elaborate modeling that enables three-dimensional (3D) simulations of transient phenomena in fluid dynamics and thermodynamics: engine combustion, injection and breathing, air flows, heat exchanges, etc. This improved control of energy conversion processes enables us to gradually converge toward ultimate energy efficiencies, the physical asymptotic limits imposed by the Carnot principle in thermodynamics. Parallel studies on gas kinetics and their link to fuel formulations provide solutions for the optimization of the quality of the gas emitted by exhaust pipes and for sizing devices for the after-treatment of gases.

Similarly, progress is also taking place in the ability to size structures, to analyze and optimize their vibratory and acoustic behavior, their dynamic and crash behavior and their thermal and electromagnetic performance resulting in solutions that are lighter and yet increase their resistance.

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[4] This time widely depends on the type of technology as well as its "depth" (in terms of impact on the overall architecture of a vehicle). Introducing innovations with regard to the onboard software does not require the same R&D time that is required to completely recast a vehicle's rolling platform.

With regard to materials, besides detailed studies on improving the properties of "traditional" metals, new technologies are emerging in the field of nanotechnologies[5] and "smart" materials in relation to shape memory and adaptability. They can be applied to composite and multifunctional structures in assemblies, as well as to devices that generate or store energy, namely electrical[6] (fuel cell membranes, batteries, supercapacitors), to methods for gas treatment, to sensors and actuators, to filtration elements, etc. They also enable the performance of more traditional techniques to be strengthened such as high-strength steels.

In particular, these technologies improve the intrinsic performance of vehicles: their ability to resist loads, making them lighter, their energy and environmental efficiency and their reliability. They also entail profound modifications to motorization, drivelines, transmission components (gear boxes, clutches, converters, rotors, etc.), vehicle structures (platform, wheel base, bodywork, chassis, frame, cabin) and driver compartments.

The term "revolution" can also be used in the domain of design methodologies because of the deep-rooted change in the creative process, the design of modern vehicles, with the objectives of making them lighter, reducing their energy demands, increasing their reliability and their ability to guarantee a high level of service quality.

Because of their intrinsic potential and also owing to their combination, these diverse revolutions in ICT, in energy systems and materials, bring in a whole set of elementary rupture solutions that can be phased in order to gradually improve the operational performance of vehicles. Merging them together cannot be separated from designing transport solutions, which includes the design of associated services as well as the design of transport vehicles. It entails new needs for the progress of vehicle development methods, for industrialization procedures and in the organization of professions, the

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[5] They enable matter to be processed and shaped up to nanometric scales.

[6] Storing fuels such as natural gas or hydrogen, in gaseous (at high pressure) or cryogenic (at very low temperature) form, requires highly technical tanks, which also benefit from the results obtained from revolutionizing materials.

expertise of which is necessary to design, produce, commercialize, maintain in operation, and for end-of-life recycling (cradle-to-grave).

New professions have emerged to control the different phases of the developmental cycle: {design–testing–validation}. These cycles are generally orchestrated on the basis of the Technology Readiness Level (TRL) index which measures a technology's degree of maturity and its ability to be incorporated into a product being developed (Figure 2.1).

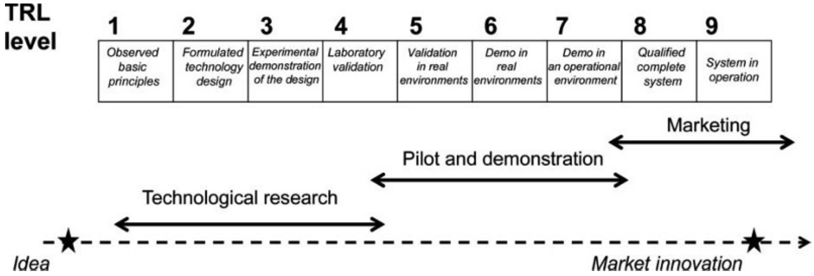

Figure 2.1. *Stages for the development of technologies according to the Technology Readiness Level (TRL) scale*

The set of professions mobilized enables the development of a range of products (and services) to be developed, particularly for automotive and aerospace industries, based on the set of components and elements that shape a number of vehicle platforms: they can be potentially modified into several variations in order to cover the diverse requirements set out by users in current (or future) markets. Architects integrate solutions and work with "systems engineers" who bring in the system elements that constitute the vehicle. Together, they negotiate interface definitions and specifications: fixing and assembly points, dimensions, structural performance and communication protocols for the circulation of data on vehicle networks, energy exchanges (mechanical, electrical and electronic, pneumatic, hydraulic, etc.).

A multifunctional approach enables us to design and organize the vehicle parts that provide several functions by integrating them into the same components that are subject to multiple requirements.

Human–machine interfaces (HMIs) are a completely vital example. They ensure the relationship between a machine and its operator (pilot, driver, etc.) by connecting the array of technologies, which will enable communication, perception and action: these technologies can be divided between technical systems, on the one hand, and the ability of humans to measure, understand, act and interact with integrated automatisms installed in the machine that will interact with them, on the other hand. They consist of displays, commands and cockpit elements, which are, in a way, the vehicle's core.

Specialists in human sciences (ergonomists, knowledge engineers, psychosociologists) must work alongside engineers from different technical disciplines in order to guarantee the best integration with respect to the humans being placed as controllers: this is a matter of developing the ability to control "simplexity", which can be translated as "making the understanding and use of complex systems simple"[7].

The resulting vehicle is designed according to performance specifications based on the detailed analyses of uses and has several variants in order to cover the diversity of market demands. The actual performance of the final vehicle depends on how the steering operations for its development are articulated during project cycles, which are subject to rigorous chains of operations and actions from various professions. These cover engineering (architects, design and engineering offices, those responsible for synthesis and testing, etc.), "purchase" functions (which ensure contractual relationships with various providers), "quality" functions and those for industrial methods; they also include other supporting professions, which play a vital role even if they are often little valued (management of technical data, approval, data processing support, etc).

Executing processes from upstream (from the idea and initial concept) to downstream (final validation tests according to the client use cycle) now follows formal and strict rules, which are in line within all the parties involved into the vehicle design and development, either in the company, or its partners, providers and subcontractors. It also

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[7] A. Berthoz (*Collège de France*) developed the notion of simplexity extensively [BER 09].

involves a number of professional tools: computer-assisted design, virtual prototyping, computer simulations and models, calculations, hardware-in-loop[8] (HIL) tests, "packaging"[9], and verification and validation tests for use. It is impossible to avoid following these exact rules when specifying complex architecture for future vehicles, which take, and will take, solutions on-board that have only recently been mastered. Some examples are as follows:

– hybrid energy architectures (for example combustion/electric);

– hybrid material architectures (for example composites or composite/metal combinations);

– "X-by-wire" devices that are electronically controlled (for example "brake-by-wire", electronic control for braking, "steer-by-wire", electronic control for steering, or "drive-by-wire", electronic control of actuators at the driver's post, etc.).

This approach to multifunctional and multiscale integration (from component to system, to function, to finished vehicle) is also supported by tools for job-sharing, for distance communication and for sharing knowledge. They require specialized professions to adapt to the job as well as being able to be more available in order to serve the projects they are involved in.

These experts are involved at all scales of the product's complexity: localized but with a wide geographical reach[10], tied to projects as a contractor, provider, or partner, they cover a wide range of professions and knowledge that are constantly evolving at the same rate as the technologies they use, by forming a network of competences constantly being stimulated, with the aim of maintaining and developing it.

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[8] This is a testing method that combines physical modules (for example an electronic processor and sensors) and real-time computer simulation.

[9] Packaging concerns the work carried out on the design of subsystems, while guaranteeing their intrinsic design (its scheme) in addition to satisfying all the operational restrictions related to the operating environment (thermal restrictions, acoustics, energy interfaces with adjacent systems, etc.).

[10] Nowadays, networks of expertise cover the entire planet, involve competences that are distributed over all the continents, constantly linked to each other in real time by appropriate tools for communication.

The human aspect in this technological evolution must be highlighted. In all cases, humans are always central to vehicle design and industrialization: they are the operators who set up innovative solutions for vehicles that benefit from the latest available technology. However, humans are also the final subject that must be provided with sustainable means of transport:

– as a client, passenger or driver involved in the cost, performance, safety and comfort of their vehicle;

– as an agent in order to guarantee service and management operations associated with usage during the (long-lasting) lifetime of these vehicles;

– as a resident living close to the roads and infrastructures used by these vehicles, who must be protected from negative environmental impacts caused by vehicle gas and sound emissions;

– as a road user, who shares the same infrastructure as vehicles that have different performances, sizes and destinations, and who is therefore confronted with this coexistence in secure operating conditions.

Figure 2.2 summarizes technologies for future vehicles. They illustrate the diversity of competences and professions required to create and develop them.

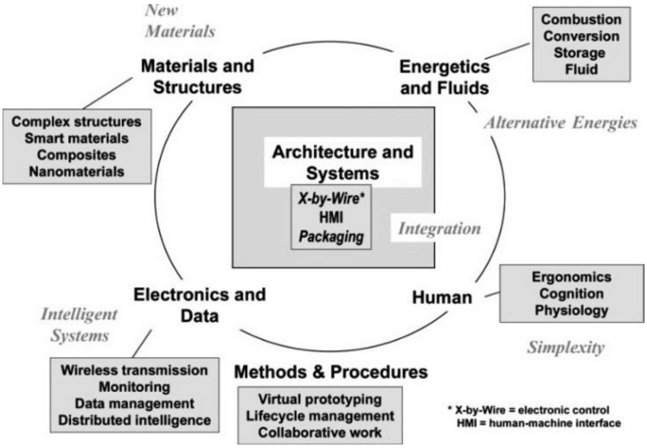

Figure 2.2. *Main key technologies for future vehicles [FAV 13]*

2.2. Combustion engines

Automobiles (cars, freight) are a leader in terms of depolluting combustion engines which have, for the last 20 years[11], monopolized most of the resources for research and development in industry. Industrialized countries have prescribed voluntary regulations to deal with the problem of air quality, in particular for metropolises. These regulations are based on the measurement of polluting gas emissions according to either roll or engine benches[12], using very accurate measurement cycles and with working conditions which are chosen for their assumed representativeness of real working conditions. Figure 2.3 shows the evolution of the regulatory limits in Europe for cars with diesel engines. From Euro 1 regulations (1992) to Euro 6 regulations (January 2014), the limit values have thus been decreased by −82% to −97% depending on the pollutant for this type of vehicle.

Similar regulations have also been imposed in the US (US-EPA norms) and in Japan; they were precursors to the motion that progressively involved other types of vehicles ("TIER" norms for "off-road" vehicles – construction equipment, tractors, marine and industrial motors, etc.) and other world regions. These limits resulted in values that are gradually converging toward global world harmonization (WHSC World Harmonized Steady state Cycle, stabilized by engine hot start, and WHTC World Harmonized Transient Cycle, transient with both hot and cold start), with distinct emission limits depending on the engine technology[13] and the power of the vehicle. The reduction in limit values correlates with the evolution of the measurement cycles for pollutant emissions in order to strengthen the operational efficiency even further. This entails an increase in the difficulties encountered to satisfy them, and in the importance of modifying combustion engines technically.

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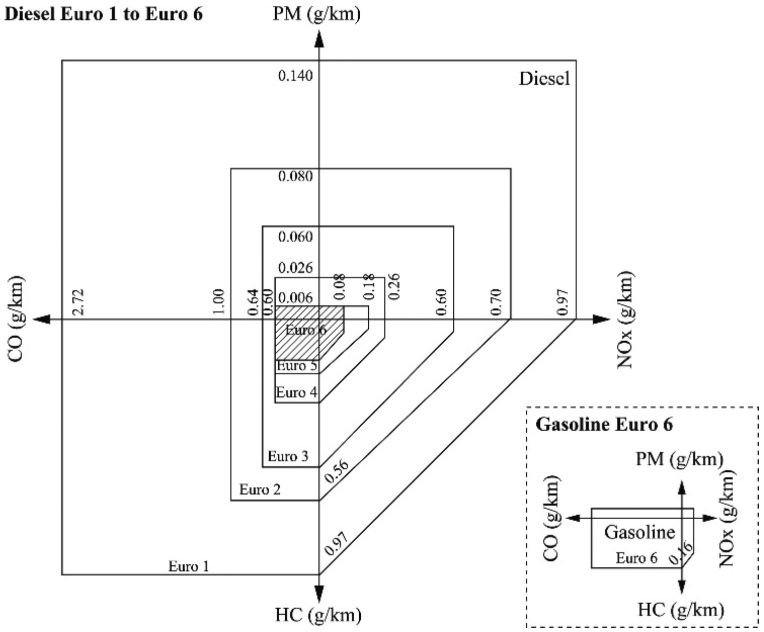
[11] Euro 0 regulations date back to 1990, it has gradually evolved to Euro 6 (2014) to cover the gas emissions that affect health directly: carbon monoxide (CO), nitrous oxides (NOX), particles (PM), unburnt hydrocarbons (HC), non-methane hydrocarbons (NMHC). They do not include CO_2, which is not directly toxic, and which was not discussed in 1990.

[12] Roll bench for cars, engine bench for industrial vehicles.

[13] The main distinction separates spark ignition engines (Otto cycles), which operate on gasoline, and combustion engines (Diesel cycle), which operate on diesel.



a) b)

Figure 2.3. *European regulatory limits for gas emissions (in g/km) for different types of regulated pollutants emitted by cars: nitrous oxides (NOX), unburnt hydrocarbons (HC), carbon monoxide (CO), particles (PM). a) Evolution of values from Euro 1 to Euro 6 for automobiles with diesel engines b) Values for Euro 6 for gasoline automobiles*

For cars, the decrease in gas emissions correlates with the increasing complexity of technologies. It is possible to confirm that the enforcement of Euro 5 regulations on January 1, 2011 did, in practice, solve the issue of particle emissions related to new vehicles. Effectively, it fixes an emission limit which implies that particulate filters (PFs) have to be installed in all new diesel engine vehicles. Euro 6 has even more demanding requirements, and engines must in addition use a combination of most of the technologies identified for depollution:

– solutions related to injection and combustion (pump-injectors, common rails);

– optimizing internal aerodynamics and the shape of the combustion chamber;

– improving supercharging systems (fixed turbo-supercharging with controlled “waste gates”, variable geometry turbo-supercharging, etc.);

– recycling exhaust gases (“exhaust gas recirculation” (EGR))[14];

– exhaust gas after-treatment using devices that reduce the quantity of nitrous oxides and oxidation devices or particle filtering[15].

The different systems illustrate the diversity, as well as the complexity, of necessary technologies[16]. Their assembly and integration enables the requirements for depollution performance to be fulfilled, while allowing near-optimum energy efficiency (that of the Carnot principle). By partially separating the phase of mechanical energy production[17] from the gas treatment phase[18], the designer provides himself with the means to simultaneously deal with research on maximum energy efficiency (and therefore decrease in consumption), depollution of burnt gases and minimization of noise. These objectives all need to be met and may otherwise lead to contradictory technical solutions.

Similarly *for industrial vehicles* – trucks and coaches/buses (European norms Euro 0 to Euro 6), regulations on gas emissions have led constructors to develop, step by step over the past 25 years, increasingly advanced depollution technologies for engines. They have been applied to the vehicles currently being marketed in Europe and as a result, the limit values for pollutants have been reduced to

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[14] Principle behind EGR: part of the exhaust gases are reintroduced in the engine’s intake after they have been cooled. The effect is to reduce NO_X emissions by means of lower combustion temperatures.

[15] Exhaust gas after-treatment technologies:
– Reducing NO_X => selective catalyst reduction (SCR),
– Reducing Particles => {diesel oxidation catalyst (DOC), or diesel particulate filter (DPF) or particulate catalyst (PM Cat)}.

[16] For example, SCR devices that reduce nitrous oxides in heavy trucks from exhausts now have an additional tank for aqueous solution consisting of 32.5% urea, required for their use (*AdBlue* is the commercial brand).

[17] Transmitting combustion loads to {piston-rod-crank} moving parts.

[18] Motor breathing at intake and exhaust gas after-treatment.

values close to zero. From 1990 to 2014, reductions of 98% (NO_X) and 97% (particles) have been obtained. They are accompanied by requirements that now impose the number and size of particles to be controlled, in addition to a good maintenance level for devices during the operational time, depending on the operational conditions: these are taken into account in validation tests and in the limit values, and are imposed by the installation of on-board devices in the vehicle. These devices monitor the soundness of depollution systems by imposing adequate maintenance, and intervening by stopping the vehicle in case of malfunction and increased pollution levels ("on-board diagnostics" (OBD) system).

With current technology, particulate filters have a filtering efficiency of more than 90%, and can reach 99.9% in terms of number and 99% in terms of mass, for all particle sizes and in all working conditions (hot, cold, during fast accelerations, in towns or on roads, in case of failure of regenerating systems, etc). They require regeneration at regular intervals (an operation for the elimination of soot): this concerns the combustion at a temperature of more than 600°C of carbon particles caught by the filter, in order to prevent the filter from clogging and the exhaust counter pressure from increasing, which would be detrimental to the energy efficiency. Regeneration therefore needs assistance, which is provided by a set of coordinated devices: these include associating a catalyst with the exhaust, fuel additives, implementing regeneration strategies relative to engine control and a dedicated heating system in the exhaust. In these conditions, a heavy goods vehicle, meeting Euro 6 performances, must undergo maintenance every 100,000 km to evacuate non-combustible ashes, and the filter durability required lies between 500,000 km and 1 million km.

The actual gain in gas emissions from traffic is therefore the result of gradually putting vehicles into circulation with a gas emissions performance based on the technology used, which will depend on the date that they were put on the market. They must also be assessed according to their numbers present in traffic. The actual gain also depends on the maintenance conditions of vehicles during their operational life. Clearly, a modern vehicle that is provided with guaranteeing lower emissions of polluting gases, on the one hand, and sturdiness of depollution performances on the other hand, as well as maintaining them in good working order, cannot be compared to older vehicles, *a fortiori* if its maintenance is not properly ensured. Therein lies the key issue in the debate on gas emissions from road vehicles in a local context (nitrous oxides, particles, etc.). This debate is enlightened by the following elements:

– The report by CITEPA (the Interprofessional Technical Centre for Studies on Air Pollution) on the evolution of greenhouse gases and pollutant emissions between 1960 and 2010 in France, by branch of activity, mentions the following on the subject of transport: "gradually fitting catalytic convertors since the 1990s, followed by the enforcement of Euro 3 and Euro 4 norms for freight in 2002 and 2007, and of Euro 4 for cars in 2005, has enabled nitrous oxide emissions (NO_X) from transport to be reduced by 47% in 2009 in comparison to 1990 (representing 598 k.t)."

– Besides, *Agence française de l'Environnement et de la Maîtrise de l'Energie* (ADEME) recommends taking action on the rolling fleet of old vehicles, particularly diesel fleets that are not equipped with closed-loop particulate filters: cars and delivery vehicles in addition to captive fleets (taxis, buses, etc.) that travel in agglomerations.

– This opinion is in line with the 2012 report by the European Environment Agency (EEA) on the impact of transport on air quality[19]: renewing the vehicle fleet is a determining factor for disseminating better techniques. Old vehicle fleets still emit high levels of fine particles, especially diesel vehicles that are not equipped with closed-loop particulate filters. Modern technologies introduce pertinent solutions[20].

Committed studies sketch the future trends of internal combustion engines. They include:

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[19] www.eea.europa.eu/publications/transport-and-air-quality-term-2012.

[20] For clarification, freight fleets (veh·km) circulating in France in 2013 (including transit vehicles) are composed of 50% Euro 5 vehicles, 24% Euro 4, 20% Euro 3 and 6% older vehicles.

– increasing their energy density: down-sizing, lighter materials, increased pressures, introducing “flexible” systems[21] in order to adapt them to operational conditions at any point;

– improving the efficiency of combustion, which will be continued (by controlled self-ignition, by homogeneous charge (extended HCCI[22])), by incorporating more closely the search for joint optimization of the various objectives: energy yield, particle emissions, noise emissions, etc.;

– gradually introducing alternative fuels (biodiesel, hydrotreated vegetable oils, DME (di-methyl ether) and E95, ethanol, natural gas and {natural gas–hydrogen} mixes, etc.) which will be encouraged;

– optimizing devices for the after-treatment of gases, which will be adapted to the relevant fuels, while aiming to lower their precious metal content and simplifying their design;

– better control of energy waste and lost calories.

2.3. Environmental and energy efficiency

The search for energy efficiency is evidently not new, although it has been shaped by other factors (comfort or performance for example) depending on the type of transport. The energy consumption of vehicles has clearly been identified as a barrier that questions the sustainable nature of transport. This consumption results from a combined and interactive set of physical mechanisms in which the main intervening elements are the vehicle’s weight, its aerodynamic properties (shape, frontal surface, etc.), its suspension principles and the related friction[23], the driveline yield, and, naturally, the operational conditions, particularly speed and its variations.

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[21] These systems are related to injection, distribution, cylinders and compression ratio.

[22] Homogeneous charge compression ignition: this type of engines combines the performance of spark ignition engines with that of diesel engines.

[23] Ground contact ({wheel–rail} for rail modes, {tire–road} for road modes), floating for transport on waterways, flight for air transport, etc.

Rail transport generally has a reputation of being environmentally efficient, for both good and not-so-good reasons. One of the main good reasons is the low rolling resistance of {iron–iron} contact, a keystone for rail transport, which entails a lower demand in energy in order to maintain a given speed, in comparison to their road equivalent for which {tire–road} rolling friction is greater (in particular due to tire deformations, which on the other hand provide a better ability to adhere to the road). Another reason is the lower aerodynamic drag of trains when they consist of linked carriages or wagons which are "shielded" by the tracting carriage and placed in its wake, in comparison to road hitches, the length of which is limited by regulations[24]. A third reason is the fact that they generally use electricity. This argument has already been discussed and it was shown that it has a much more limited reach, and is sometimes erroneous because of "well-to-wheel" system considerations and energy mixes depending on the world region being considered. Moreover, rail uses thermal energy in some countries (for example Diesel in the United States).

Air transport does not deny the necessity to solve both energy and environmental questions. New-generation airliners exhibit a significant improvement in energy performance in comparison to previous models, especially in terms of consumption per passenger seat, owing to intense pursued efforts on architecture (making cells lighter, aerodynamic refining, etc.) and motorization[25].

Trends for new *road vehicles* have been observed over the past two decades for which the consumption decreases by up to 1–2% per year. The impact of fuel cost and the public environmental objectives in terms of CO_2 naturally make it a priority in the current day. For medium-term objectives, constructors aim to maintain these trends, which are nonetheless conditioned by the maintenance of the vehicle's intrinsic qualities (for example safety), satisfying regulatory

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[24] In the wait for convoys that travel on roads by being linked together, either physically or virtually, in the context of ultimate concepts, see Chapter 5.

[25] An Airbus A340-600 is under 4 l/100km per passenger seat with a load factor of 80% [GOU 11].

requirements (namely that of gas[26] and noise emissions), and cost control for exploitation (particularly for energy cost). The high sensitivity of a vehicle's consumption to its use is also noteworthy. A remarkable way in which consumption can be reduced is by driving at a moderate speed (which significantly decreases aerodynamic losses, which increase exponentially with speed), by using the optimum engine speed for powertrain energy yield [27].

In a traditional long-haul, heavy-duty *truck*, for an average use cycle including road and urban phases, and driving on uneven ground, energy can be separated between losses due to the engine's overall thermodynamic yield (around 58%) and propulsion work (42%). This includes aerodynamic drag (10%), tire–road rolling contact friction (10%), transmission losses (2%) and losses due to work during ascents (14%) or accelerations (6%). Constructors are still aiming to reduce consumption significantly, by approximately 1–2% per year for predictable perspectives, through on-going in-depth studies which include:

– improving the energy efficiency of motors (in particular, through the more efficient use of thermal and kinetic energy produced);

– recycling waste energy to make it useful (thermal losses linked to exhaust gases, thermal losses linked to breaking or slowing down, etc.) and transforming it into mechanical or electrical energy;

– optimizing vehicle aerodynamics for various profiles;

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[26] Respecting regulations on gas emissions clearly involves the aspect of CO_2. It is coordinated by thresholds imposed on constructors, known as Corporate Average Fuel Economy (CAFE), introduced in the United States in 1978. It imposes a maximum average consumption for the entire set of automobiles sold by a constructor during the year. This regulation has been adapted to Europe. In 2009, the European Union imposed stringent standards for the levels of CO_2 emitted by new cars, equivalent to 130 g of CO_2 per km (5.2 l/100 km) in 2015 and 95 g of CO_2 per km (3.7 l/100 km) in 2020 (Regulation No 443/2009). The 2009 regulation also planned for the Commission to revise "the procedures for implementing the long term objective of 95 g CO_2/km between now and 2020, in order for it to be attractive in terms of cost-benefits". On July 11, 2012, the Commission made its proposition public, confirming the 95 g CO_2/km objective for 2020 and establishing procedures with which this objective should be met.

[27] It will be shown (in Chapter 5) that the exploitation systems for roads play an important part in this issue.

– decreasing the energy consumption of tires;

– correcting the use of energy by the driver and/or driving automations.

All the possible paths are being investigated in order to recover as many lost calories as possible by recycling them in order to transform them into useful energy (waste heat recovery). Technologies are appearing that transform lost calories into electricity (thermo-electricity) or that reinject them in the form of useful mechanical energy, according to a variety of thermodynamic cycles (such as the Rankine cycle), and involve cooling loops as well as very complex materials and structures.

Research on automation used for energy optimization is currently an important topic. Research consists of implementing on-board "adaptive commands", in order to minimize the risks of poor energy use and to optimize its management. These automations either concern the driver (as driving aids for economic driving) or the vehicle's on-board systems: motorization, breaking, air conditioning, storing intermediate energy, etc.

The demonstrator *Optifuel Lab* from Renault Trucks (Figure 2.4) illustrates these tendencies. When it was developed (2008–2009), it enabled the consumption to be decreased by 13% in comparison to the best vehicle on the market at the time, owing to the incorporation of a set of around 20 technological solutions related to {tractor/semi-trailer} convoys. For a typical working cycle, the diesel consumption of the vehicle, with 40 metric tons full load, thus went from 30 l/100 to 25 l/100 km (approximately 1 l/100 km for each useful metric ton transported[28]). This gain is the result of the specific benefits of each solution in comparison to the technology initially used, which is replaced "run-of-river"[29]. However, it is also the result of combining them when integrating them in the completed vehicle, in which there is a coupling effect between technologies which have been modified

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[28] A convoy with a total rolling weight of 40 metric tons usually carries approximately 26–28 metric tons of payload. Its empty weight is 12 metric tons (current value 2013).

[29] All other things being equal.

and which leads to the final consumption performance (gains are not added by integrating, but are combined):

– deep aerodynamic alteration of the front and (especially) back in order to minimize turbulent airflows energy by re-attaching the skin's boundary layers, obtained with diffusers, screens and spoilers, "boat tails"[30];

– minimizing equipment losses and electrifying accessories in the kinetic chain (supply systems and cooling systems, steering, air compressors, dynamos);

– modifying tire structures and treads;

– introducing economic driving aids to help the driver anticipate and adapt his/her driving (adaptive cruise control, assisted gear change).

Figure 2.4. *Prototype truck with a low energy consumption, by Optifuel Lab [REN 09]*

These continued efforts will also encompass making vehicles lighter[31]. The on-board energy will also have to be managed more

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[30] The introduction of some of these aerodynamic innovations in marketed vehicles is subjected to adapted European regulations on the weight and dimensions of trucks (European Directive 96/53/EC -- *Weights & Dimensions*) and is expected for 2015.

[31] The gain from a weight reduction of 100 kg is estimated to be 8 g CO_2/km for a European sedan car from 2013.

efficiently and must be distributed between the vehicle's on-board producers and users, by combining abilities for intermediate storing (electric or mechanic), which enables it to be assigned for the benefit of good immediate use[32].

With regard to *making vehicles lighter*, research aims to improve the performance of the multipurpose materials and assemblies used to create the structure of the vehicle. The specifications must be satisfied simultaneously with the improvement of the safety behavior (crash), while maintaining the required comfort level in terms of acoustics, dynamics and temperature. The properties of traditional metals, such as high-strength steels, are also still being improved[33]. Aluminum, which is easily profiled, and even magnesium, in combination with plastic materials and composites capable of providing great diversity, are gradually being incorporated into the redesigned vehicle architecture, with the ambitious objective of making vehicles significantly lighter (although at a cost which must be controlled[34]). Researchers are also currently searching to increase and rehabilitate the use of biogenous materials, such as natural fibers.

Evolutions such as these involve eco-design approaches that widen "cradle-to-grave" considerations in terms of material impact, by leading it to closing the loop "from grave-to-cradle". In addition to research on minimizing the weight of vehicles, prescriptive measures must be applied to the substances used, for decommissioning and recycling, and for the lifecycle's carbon footprint[35]. For example, the European Directive on scrap vehicles[36] banned four heavy metals

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[32] It is also possible to consider recovering the buildup of energy during downhill phases and reallocating it to uphill phases, or heating the coolant in order for it to later return its calories by transforming them into electricity, etc.

[33] Their performance is still in progress, owing to new set-up procedures (such as hot stamping).

[34] To still be marketable, the maximum additional cost which is acceptable for cars for each kg gained is 3–4 € (in 2012 economic conditions).

[35] Decommissioning a Renault Premium truck which weighs 6,602 kg (designed in the 1990s) leads to the following classification: 5,482 kg recycled, 433 kg of energy recovered, 689 kg of unrecovered material eliminated (Renault Trucks 2009).

[36] European Directive 2000/53/CE of September 18, 2000 on scrap vehicles introduces major issues from an environmental point of view. It sets quantified objectives that must be reached by January 1, 2015 at the latest.

(cadmium, mercury, lead and chrome VI) from being used in light road vehicles (<3.5 t). The European Registration, Evaluation, Authorization of Chemicals (REACH) regulations cover the registration of chemical substances, their assessment, authorized and restricted use for vehicles. It imposes certain substances used in the automotive industry to be traceable, such as phthalates, refractory ceramic fibers and chromates.

The carbon footprint of materials can also be predominant in some industrial processes: for example, the additional energy cost of producing aluminum instead of steel. It is also appropriate to avoid the use of multimaterials serving the same function, to choose materials that can be benefit from existing sorting/recycling systems, and to mark pieces in such a way that their components can be identified. Designing while taking into account end-of-life decommissioning implies that reservoirs and tanks are easy to drain, that fastenings are easily accessed and in limited numbers and that precautions are taken for systems containing gases, fluids and explosives. Disposal is relevant for complex components and multicomponents (seats, dashboards, etc.). Most of the unrecovered mass consists of residue from crushing.

It seems that the gradual and massive introduction of electricity as the energy vector for guaranteeing on-board functionalities has been programmed to optimize the *management of on-board energy*, as will be discussed in more detail later.

The link between energy efficiency, fuel consumption and CO_2 emissions exhibits different aspects:

– It ensues directly from the carbonaceous molecule content of fuels. For given energy contents, hydrocarbon chains that emit higher quantities of CO_2 are the ones which are the most carbon-intensive (have the highest number of carbon atoms per molecule). Therefore, methane gas (CH_4), the simplest hydrocarbon, which is the main constituent of natural gas, emits less CO_2 and proportionally more water (H_2O) than chains that are more carbon rich (such as ethane C_2H_6, propane C_3H_8 and butane C_4H_{10}.).

– The reduction in consumption is proportional to the reduction of CO_2 emissions for a given fuel and technology.

– Depending on the type of engine and thermodynamic cycles used, the energy yield that transforms thermal energy into useful mechanical energy may differ very significantly, and consequently the consumption. Therefore, combustion in diesel engines is superior, in terms of efficiency, to combustion in spark ignition engines or Otto cycle engines (in other words, gasoline engines or some natural gas engines).

One effect can therefore be partially compensated for, or emphasized by, another. Diesel engines consume less fuel than gasoline engines due to the physical phenomena involved in combustion mechanisms; they use a fuel that is more energy rich and they also emit less CO_2[37]. Their advantage is in part mitigated by the complexity of technologies that have to be implemented in order to reduce their particle and nitrous oxide emissions. Natural gas engines use an amount of fuel comparable to that of gasoline engines, but the carbon content of the fuel makes them more advantageous in terms of CO_2 emissions. However, this advantage must be reconsidered due to the fact that methane is a powerful greenhouse gas, as has already been mentioned, and that the inevitable "well-to-wheel" leaks in the methane cycle must be perfectly controlled to attain the full benefit. Finally, gasoline engines are still pertinent solutions owing to their relative simplicity and robust technologies for depollution. Besides, they use a fuel that is found in relative abundance in refineries.

In total, the CO_2 emitted by vehicles result from combinations of previous factors related to motorization, and forces acting on vehicle structures, chassis, compartment, bodywork, etc.

Each year, the French Environment and Energy Management Agency (*ADEME*) publishes a ranking for new cars sold in Europe

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[37] One liter of diesel fuel weighs 0.85 kg and produces 2.6 kg of CO_2 in combustion. One liter of gasoline weighs 0.74 kg and produces 2.28 kg of CO_2. Both fuels produce around 3.35 kg of CO_2 per kg. Their energy density is different (40 MJ/L for diesel, 34 MJ/L for gasoline).

according to their CO_2 emissions[38]. It includes a comparison of CO_2 emissions (g/km, CO_2 rating, bonus/malus), a comparison of fuel consumption (urban, extra-urban, combination) and information on pollutant emissions. According to data from 2012, the performance of cars is still improving. The European average for CO_2 emissions has decreased by 50 g of CO_2/km in 16 years and by 30 g of CO_2/km in the last 9 years.

For example, in 2011, France ranked as the third most "virtuous" country with 127 g of CO_2/km, behind Portugal and Denmark. It had exceeded its 2015 objectives stipulated by the European compromise (set at 130 g of CO_2/km). The next step of the European calendar is an objective of 95 g of CO_2/km by 2020[39], and a goal set between 68 and 78 g for 2025. In Europe, 12.8 million vehicles marketed in 2011 had an average value of 135.7 g/km for CO_2 emissions, which was 4.6 g CO_2/km less than in 2010 (−3.3%), according to preliminary data provided by the EEA that analyzes the data from member states[40].

2.4. Hybridization and electrification

2.4.1. *Vehicles*

The term "hybridization" is widely used to refer to systems that combine the properties/functions of two technologies. In the domain of transport vehicles, this term is especially used to refer to the energy systems of vehicles that combine thermal motorization with other types of motorization, most often electric (the term hybrid vehicles generally means thermal-electric hybrid vehicles). Thermal-hydraulic,

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[38] www.carlabelling.ademe.fr.

[39] It was fixed to 147 g CO_2/km in 2020 for new lightweight commercial vehicles compared to 203 g CO_2/km in 2013.

[40] For comparison, the vehicle performances in terms of energy (Challenge BIBENDUM Berlin 2011) were the following:

– for petrol vehicles, over a 300 km cycle at a speed of 60 km/h, the consumption for a production vehicle was 4.8 l/100km (127 g CO_2/km) and 3.7 l/100 km (99 g CO_2/km) for a prototype.

– for electric vehicles, the consumption was 16 kWh/100 km (or an equivalent 1.79 l/100 km), therefore 72–80 g CO_2/km depending on the European "mix".

thermal-pneumatic or thermal-mechanic hybrids also exist[41]. However, it should be noted that there may be some confusion due to the term "hybridization" as it is used for other applications in the field of vehicles: for example, complex structures that combine materials, such as metal and plastic, are called metal–plastic hybrid structures, and their assembly is qualified as a "hybrid assembly".

Electrical vehicles have been around ever since vehicles were first designed, but the contemporary problems have reorganized their position entirely. All types of vehicles with urban connotations[42] are now being addressed. Fleets of power-assisted bicycles, motorized two-wheeled vehicles (scooters), cars, buses and delivery vehicles are developing quickly. China, Japan, the United States and Europe are especially active in the market.

With regard to *hybrid vehicles*, the Prius was introduced in 1997 and has been remastered several times since. It was with this vehicle that Toyota popularized hybrid cars and succeeded in gradually and extensively introducing them to the world market from Japan[43]. Other constructors followed gradually. By the end of 2009, more than 2 million hybrid cars had been put into circulation. Hybrid technologies now concern all types of vehicle (cars, trucks[44], buses,

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[41] Mention must also be made of the existence of a system's first use (in motor sport competitions, for example) for storing kinetic energy, such as inertia wheels. Their basic principle is that the kinetic energy of the moving vehicle is transferred to a rotating mass when breaking; this energy can be stored in the wheel and recovered according to demand.

[42] The proven potential of electric vehicles is not limited to urban applications. It can address any frequent short distance transport (and may concern most rural trips).

[43] Toyota sold over 1 million in 2012 alone.

[44] A light-weight truck weighing 3.5 metric tons, the all-electric Fuso Canter E-Cell (2011) is equipped with 40 kWh Li-ion batteries, it has an autonomy of 120 km and takes
10 h to recharge (with a 200 V source).
The hybrid truck MAN Metropolis (2012), is an electric adaptation with the prolonged autonomy of the MAN TGS 6x2-4, is equipped with a 203 kW electric engine and includes a thermal engine with a 3L cylinder capacity and a power of 150 kW to recharge a Lithium-Ion battery with a storing capacity of 105 kWh. It has a payload of 14 metric tons.
An urban truck weighing 10 metric tons uses around 1 kWh/km and requires a 150 kWh battery for a 150 km autonomy.

construction machinery)[45]. In 2011, the United States was the largest market for hybrid vehicles and represented more than 2.15 million cumulative sales[46].

Since they were first introduced into the American market in January 2011, more than 110,000 rechargeable electric and hybrid vehicles had been sold in the United States by July 2013, double the progress of "classic" (non-rechargeable) hybrid vehicles. Another interesting fact is that the penetration rate of this sector is nearly three times the rate of that of hybrids in the first three years after their introduction into the American market[47].

Market sectors for vehicles with electric systems include vehicles that are entirely electric (which have a single propulsion engine operating on electricity, most often stored in batteries[48]) and thermal-electric hybrid vehicles. For the latter, the thermal engine runs on traditional fuel and the other engine is electric. The batteries are capable of supplying the electric engine with energy and therefore of complementing or replacing the thermal engine for more or less long-lasting time periods depending on the technology. The "link" between the two engines varies according to the driving phase. The electrification rate associated with the functions fulfilled by electricity depend on the technical choices and give rise to subcategories of hybrid vehicles termed Micro, Mild, Medium and Full Hybrid. Some vehicles can be electrically recharged by connecting them to the electricity network (the "grid"); these are rechargeable hybrid vehicles[49]. For those hybrid vehicles which use electricity as their main constituent, they are provided with a small internal combustion engine, or some other form of on-board secondary energy source,

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[45] Thermal-electric hybridization also has uses in rail and ship industries.

[46] The International Energy Agency (IAE) published a report through IA-HEV, its branch for technology and programs for hybrid and electric vehicles, which takes stock of sales made in 2011.

[47] EC-Electrification Coalition quoted by AVERE France July 2013. In terms of operational costs, the EC study confirms that plug-in hybrid electric vehicles (PHEV) are already profitable and competitive in comparison to "classic" thermal and hybrid vehicles.

[48] Abbreviations EV and BEV (electric vehicle, battery-electric vehicle) are used.

[49] Abbreviations HV, HEV, PHEV and EREV (hybrid vehicle, hybrid electric vehicle, plug-in electric vehicle, extended range electric vehicle) are used.

connected to a generator in order to recharge batteries, thus allowing the vehicle's autonomy to be significantly increased; these are called range extender electric vehicles (EVs). The on-board voltage varies (up to 600 V and over) and requires specific technologies and safety procedures. Neither the architecture nor the concepts have yet been stabilized because the best configurations are largely dependent on the mission profiles and the use cycles, and only several variants are thus able to satisfy the wide variety of needs.

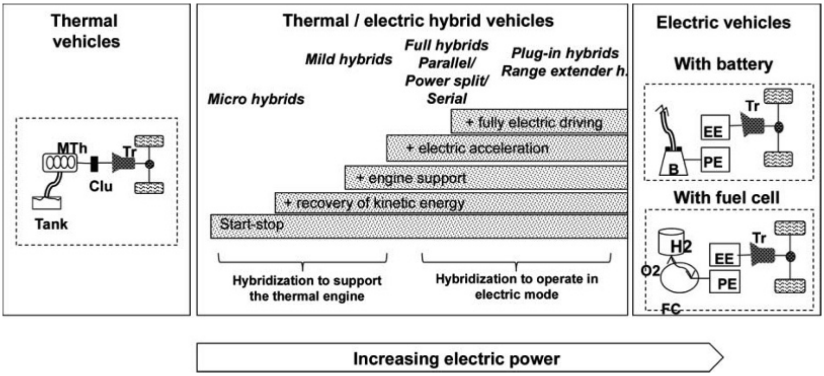

Figure 2.5. *Classification of VEH hybrid vehicles, from "fully thermal" to "fully electric" [ERT 11]*

All the configurations for hybrid motorization which have been applied to road vehicles are therefore subject to being put on the market in the future. Figure 2.5[50] puts forward a possible classification method, ranging from mostly thermal solutions (left) to all-electric solutions (right). Between them, hybridization combines and incorporates the following elements depending on a variety of architectures:

– thermal motorization (no matter what fuel is used[51]);

– electric motorization;

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[50] ERTRAC 2011 – *Expert group enabling technologies – Hybrid solutions in road transport.*

[51] G-CITY is a vehicle that runs on natural gas and electric traction, presented by GDF Suez, and received the prize for innovation in 2012 at the *Salon des Maires et des Collectivités Locales* (France).

– transmission (mechanical and/or electric, etc.);

– systems for storing electricity (battery(ies), supercapacitors, etc.);

– management systems (converter, controls and electronic power).

The accurate sizing of elements (such as capacity of thermal engines and battery capacity[52]), and the successful integration of assemblies, must enable the need for autonomy and performance to be satisfied without burdening (too much) the operating costs.

HEV vehicles have a certain number of additional functionalities in comparison to traditional vehicles. The following list presents the features obtained from lowest to highest gain increase:

– optimizing the management of energy for electric accessories;

– switching off the engine when inactive, with automatic restart (Stop & Start);

– recovering energy when braking (regenerative braking);

– electric support for traction or booster (motor assist);

– full electric operation, also called “zero emission mode” or EV drive.

Their autonomy in this mode varies with the electrical storing capacity that they take on-board (equally dependent on the possibility of recharging the battery via the grid).

The place of hybrid vehicles on the market in time can also be questioned: is it a temporary transition toward fully electric solutions? Or is it a lasting solution? It seems that in the future, technical solutions will come in consecutive waves that will introduce increased levels of on-board electricity, while maintaining the benefits acquired by the previous wave in terms of performance and autonomy from the

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[52] Some vehicles are provided with two types of batteries: one for energy demands, the other for power demands (power demands are equally satisfied by a supercapacitor).

user's point of view. Starting with stop-and-start and followed by regenerative breaking, boosting and electric modes with thermal support to extend the range (range extender).

Hybridization therefore allows the energy required by the vehicle to be managed more efficiently, and to be available at any point for real-time demands and respective capacities of thermal and electric motorization. It reduces thermal losses (when breaking, slowing down, etc.) and uses motorization at its most efficient operating level. Figures 2.6 and 2.7 show the principles of recovery, storing and reuse of energy for a hybrid vehicle during a cycle consisting of an acceleration phase, followed by a deceleration/stopping phase.

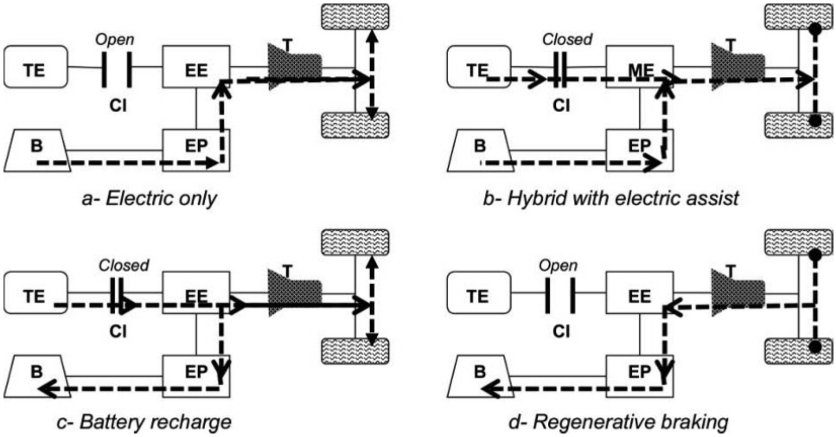

Figure 2.6. *Principle of energy flows in a hybrid driveline for a vehicle's acceleration–deceleration cycle: the thermal engine (TE), the electric engine (EE), the electric power management system (EP) and the battery (B) ensure that the propulsion energy is efficiently managed, according to the cycle phase, by means of the clutch (Cl) and transmission (T)*

The decrease in a hybrid's fuel consumption in comparison to traditional thermal vehicles depends on a range of considerations. It must be approximated by taking into account the fuel consumption and the consumption of the initial on-board electricity (if a rechargeable hybrid is being considered). The decrease in consumption is approximately 20–30% for urban use, the most favorable environment due to the profusion of {acceleration–

deceleration} cycles. The most pertinent hybrids to these conditions are extended range EVs. The benefits diminish when used on roads, and the most pertinent hybrid to this case is therefore the rechargeable hybrid. Hybridization is accompanied by the ability to reduce noise when in electric mode. Moreover, the thermal engine satisfies current regulations on gas emissions.

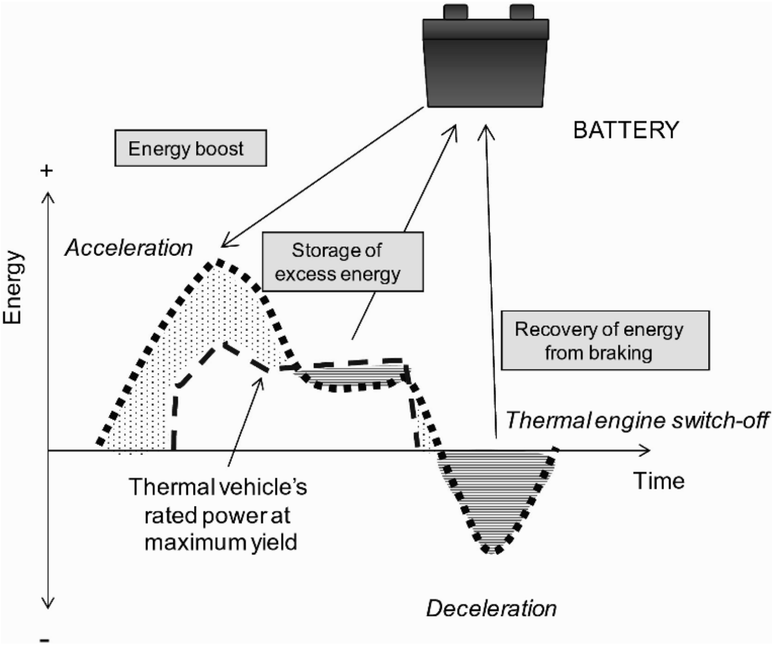

Figure 2.7. *Supply of thermal energy (- - -) and electric energy (. . .) for an EHV in a typical cycle consisting of acceleration followed by deceleration and stopping, according to the phases described in note* [53] *(Volvo)*

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[53] Succession of cycles:

– Phase 1: at start-up, only the electric engine is active and is supplied by batteries. This mode is active for low speeds as well as for breaking and stopping. During deceleration phases, the kinetic energy produced by the vehicle's movement is directly transformed into electrical energy, which is sent to the batteries. The thermal engine is completely inactive. The vehicle does not emit any gases.

The general economic equilibrium of solutions incorporates procurement costs and operating costs (and namely reducing the cost of energy used) and remains a challenge. Minimizing the procurement cost of solutions is vital to change the current situation. However, the feedback obtained is not sufficient to highlight global economic interests clearly. It includes:

– a more favorable nominal energy cost (electric) than the one for equivalent thermal fuel;

– economizing the energy in operation (due to partially recovering losses);

– lower maintenance costs than for traditional solutions;

– privileges addressed by public policies to electric or hybrid vehicles (see Chapter 5).

Work still needs to be carried out in the field of systems for energy storage, transmission, modularity of hybrid architectures and safety. Questions related to integration into the electricity network and guaranteeing access to recharging for prolonged autonomy according to need are a fundamental issue.

Rechargeable hybrid vehicles ("plug-in hybrid" electric vehicles (PHEVs)) correspond to a specific hybridization mode. The batteries can be fully charged by connecting them to electricity networks prior to travel and are gradually discharged according to their working cycle. If the battery is flat, the vehicle behaves like a normal vehicle as long as there is fuel in the tank: from the point of view of the user, autonomy is therefore guaranteed. Batteries designed for this type of vehicle can be charged either while the vehicle is operating via the thermal engine or while it is inactive on the network via a recharge station or even via an adapted socket at the individual's home. It should nonetheless be noted

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– Phase 2: during acceleration, both motors are solicited in order to provide combined motor power for fast accelerations or for going uphill.

– Phase 3: for constant movement, at a constant speed, the electric motor is inactive. The vehicle is propelled by the thermal engine alone, which operates in the regime corresponding to maximum yield. Simultaneously, the surplus motor energy provided by the thermal energy is used to recharge batteries by means of a generator (the electric engine is also an electric generator).

that the on-board electrical energy is limited in comparison to the energy provided by fuel in traditional tanks: liquid fuels cannot be compared in terms of energy density (Figure 2.8)[54] .

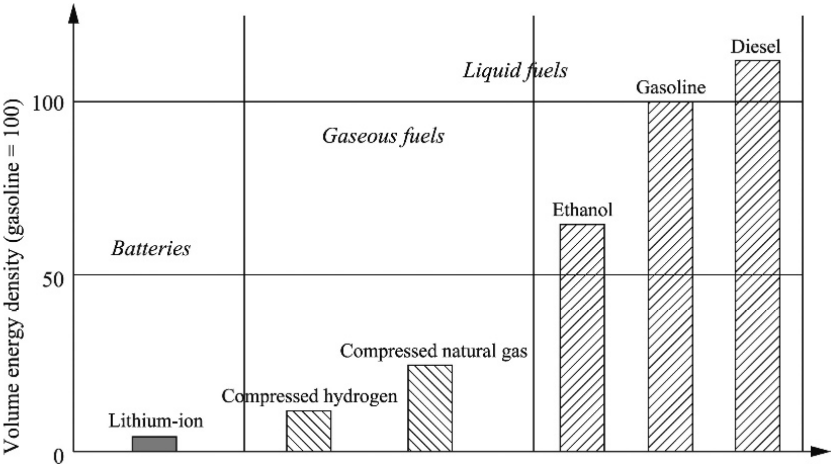

Figure 2.8. *Volume energy density for different types of fuel [TOY 11]*

2.4.2. *Batteries*

The electrochemical systems able to store electrical energy are divided into two families: accumulators (or batteries) store energy by transforming it from chemical energy, whereas supercondensers (or supercapacitors) store energy by a purely physical principle[55].

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[54] In 2011, an electric vehicle needed a battery weighing 2,500 kg in order to have the same amount of energy as a diesel vehicle with 50 l of diesel fuel on board.

[55] Accumulators consist of two electrochemical pairs, two electrodes immersed in an electrolyte. As soon as reduction or oxidation reactions occur, in which electrons are swapped, the ions produced move in the electrolyte. In order to have a higher stored energy, a significant number of electrons must be produced in addition to a reaction which associates strong oxidizers with strong reducers. The electrochemical process must also be entirely reversible and the materials must have a low mass or molar volume.

Super-condensers consist of a double electrochemical layer located at the interface between an electrolyte and a polarizable electrode that has a large specific surface. Applying a potential difference to the device's terminals entails ionic storage of charges at the two electrode-electrolyte interfaces, which behave in the same way as

Batteries consist of unit cells encapsulated in modules that guarantee their physical integrity and allow them to function as autonomous systems connected within the architecture of an electrified vehicle. This modular approach covers all vehicle constructions, from the smallest to the biggest, from small two-wheeled vehicles to trans-oceanic ships, using the same basic component.

Batteries are used to store and re-deliver on-board electrical energy. Research on the best solutions has produced successive generations of batteries with the aim of minimizing their faults: costs that are too high, energy densities that are too low (and hence batteries that are too heavy) and insufficient, variable or unpredictable lifetimes. For use in vehicles, the following material combinations are the main ones to have been kept: lead and acid (Pb-acid), nickel-metal-hydride (Ni MH) and lithium-ion (Li-Ion). Performances are determined by their energy density (expressed in Wh/kg), often attractive in laboratory studies, but modest and, in particular, irregular in real working conditions, owing to the variety of technical and physical constraints, temperature and working environments. The real values (expressed in Wh/kg) are in the order of 20–50 (for Pb-acid), 45–80 (for Ni MH) and 70–200 (for Li-Ion). These values must be compared to that for gasoline (12,000 Wh/kg)[56]. Power is another battery characteristic which determines their ability to provide or store energy quickly. Two different technologies used in cells of equal energy density can exhibit very different performances in terms of power (Figure 2.9). However, a battery can be expected to have a better performance in terms of either energy (for autonomy) or power (for recovery from breaking or recharge time), depending on the part it plays in the general architecture of the electrified kinetic chain. Some

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two condensers placed in series. Super-condensers are characterized by a specific energy which is 10–20 times lower than that of accumulators, but their specific power can be up to 10 times higher than that of lead batteries.

[56] This gap is narrowed when the energy efficiency of electric motorization is considered, and which is in the order of 85–90%, that of thermal motorization is around 30%.

arrangements use both type of batteries in the same vehicle: one for energy and one for power[57].

Li-Ion batteries are currently most successful owing to their performance. The positive electrode is made from lithium oxide (Li MO_2, where M can be one of several possible metals), and the negative electrode is made from carbon, graphite or titanate. Lithium ions are displaced by the positive electrode and "forced" into the matrix of the negative electrode until saturation is reached. The phenomenon is reversible. However, with each cycle repetition, it appears that fatigue happens because of mechanical and thermal stresses in the structure, which gradually reduces the charging and "forcing" capacity of ions, and which damages the cell's performance.

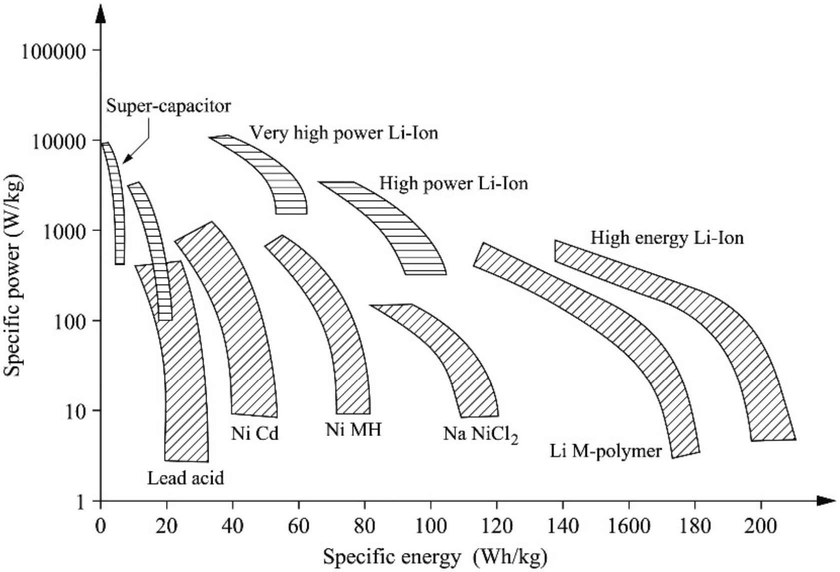

Figure 2.9. *Performance of different battery technologies (specific energy/specific power – cell level) [DEG10]*

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[57] In the second case, super-capacitors (or super-condensers) can also be used; they are quickly charged and discharged and are adapted to stop and go or "opportunity charging" configurations (fast charge–discharge cycles).

Numerous paths lead to the improvement of lithium batteries and current technology is developing fast:

– new material couples (such as Li-Si, Li-S, Li-Air and Li-organic);

– increasing the active surface and structuring materials at microscopic scales – or even nanoscopic ones[58] (which has positive effects on the storing capacity, the life span, power, but which also rapidly results in an increased cost);

– reducing mechanical stresses (by managing the demands related to power, temperature and equilibrium between cells more efficiently).

These evolutions can initiate highly innovative industrialization processes (namely to "sculpt" microscopic structures). Laboratory studies give hope of achieving spectacular future improvements (by a factor of 10) by means of several candidate technologies.

Other types of batteries are also possible, including hot sodium batteries such as ZEBRA batteries, which require a working temperature of around 300°C. They have a high energy density (currently ranging from 120 to 180 Wh/kg) but their use is limited because of their working conditions (which require regular use and operating cycles). This type of battery also self-discharges spontaneously over time.

Given the options currently being investigated, it seems likely that the performance of batteries will continue to improve quite quickly. Some estimates predict the price of storing electricity to go down by 60% between 2009 and 2020, and/or a 20% increase in their capacity, and/or an improved reliability for operation, by minimizing scatter. However, progress will depend on the ability of industrial investments to reproduce the solutions discovered in laboratories, and the solutions marketed will have to achieve a certain level of sustainability.

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[58] Graphene electrodes enable an energy density of 500 Wh/kg to be reached in laboratory studies.

It is also important to mention the aspects linked to safety risks associated with batteries, which are capable of generating redhibitory restrictions for both operation and storing[59].

2.4.3. *Constraints for recharging*

Batteries are slow to recharge and their capacity is limited. Both of these factors have inhibited the general use of electrical vehicles. A vehicle that can be recharged as easily as a thermal vehicle will still be a utopic concept in the foreseeable future. This impossibility not only concerns batteries, but also the recharging infrastructure associated with it. All the major players in the field are working on designing the battery which has the fastest recharge time (while still being sustainable, etc.). Achieving higher energy densities must be accompanied by the decrease in internal resistance for the transfer of ions, control of the risk of major incidents (such as battery fires) and cost. With regard to the supply networks (the “grid”), it must be able to resist jolts resulting from new connections – those of thousands, and then of millions, of vehicles extracting powers equivalent to dozens of kW for quick recharging[60]. The connection must ensure the electricity transfer until invoicing, as well as the transfer of necessary data to provide good management with regard to the network and vehicles.

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[59] Two incidents occurring in Li-Ion batteries led to several Boeing 387 Dreamliner planes being immobilized in January 2013 and the coverage in the media and the impact on the economy were considerable.

[60] To clarify this point, the available power in a 220 V 16 A plug allows vehicles to be fully charged in 5–8 h (cars or small commercial vehicles); the higher the charging intensity (the higher the number of moving electrons), the shorter the charge time. With a 200 A plug, it would therefore be possible to charge the battery in under an hour, and to charge it to 50% of its nominal power in 20 min. For fast recharge stations, the time to recharge a battery to 80% of its power ranges from 5–15 min, depending on the model. However, if the battery is charged too fast, the lithium ions will not have time to change back into their original form on the graphite electrode, resulting in the formation of a metallic lithium layer. There is therefore a limit to the battery’s intensity, which must not be exceeded. Alternatives are being studied in order to allow lithium ions to be incorporated faster (a thin titanium oxide sheet, for example). It will then be possible to fully charge the battery in 5 min.

Future systems for recharging will be able to use contactless technologies either static or (possibly) dynamic (see Chapter 5). In the meantime, the solutions currently in use (use of cables and connectors) have not yet reached the required level of standardization for mass implementation. This concerns the installed power, the intensity and type of current (the latter can vary from 16 A single-phase alternating current to 63A three-phase power connections), the type of connection, etc. Several standards are still competing[61]. No matter what standard is adopted at a European level, all the stations installed, or yet to be installed in the next few years, should be capable of being equipped with them. A serious alternative has already been used for some time for some heavy-weight urban vehicles: the system of changing batteries enables standard exchange to be performed in minutes and could be extended to cars[62].

From 1990 to 2000, hopes were put in *fuel cells* which combine hydrogen[63] with oxygen in the air. These hopes were lowered in the following decade. Hybrid vehicles which use hydrogen fuel cells are not immediately achievable, unlike hybrid vehicles which use batteries. However, fuel cells[64] themselves have demonstrated interesting potential and are completely compatible with hybrid architecture, in which they can replace thermal engines as they play a

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[61] In 2013, discussions on type 2 (T2) or type 3 (T3 and its different versions 3a, 3b and 3c) charging plugs conferred on the charging system's electrical performance and safety. The two connection systems can equally be universally used for both single- and three-phase at 16 A and 32 A. The 63 A caliber is only used for vehicle connectors as the cables used for this level of current, corresponding to fast recharging, are permanently fixed to the station. No plug sockets will therefore be installed in infrastructure for 63 A currents.

[62] Companies Renault and Better Place have studied and partially implemented (in Israel and in Denmark) a solution consisting of exchanging batteries, named Quick-Drop. One of the factors slowing down its implementation is the lack of standardization, namely for batteries.

[63] Hydrogen can either be provided to the vehicle by infrastructure or (alternatively) produced by using on-board fuel by means of a "reformer" embarked on the vehicle. In the latter case, the reformer transforms fuel into hydrogen and CO_2, and the overall performance (in terms of sustainability) is poor.

[64] The cell is based on a membrane which guarantees exchanges between hydrogen and oxygen (or air) in order to provide electricity and water. It is incorporated into a stack which combines all the necessary functions: monitoring, cooling, conversion, etc.

similar part. Conversely, fuel cells are fragile, costly and their operating strength has not been established[65]. On the other hand, the management of on-board hydrogen in addition to storage tanks needs to be improved. The question of hydrogen availability (as a compressed gas or as a cryogenic liquid), or infrastructure provided, has not been made particularly clear in agendas. The expiry date for the appearance of motorization that combines fuel cells, as well as the speed with which they are rising in power on the market, remains strongly dependent on the set-up of hydrogen systems based on renewable resources.

2.5. Energy solutions

Sustainable transport demands that the carbon content of energy used by a vehicle (or more generally, its greenhouse gas potential) be reduced. It is clear that renewable energies are the focal point of discussions, and how they could be used on a large scale is at the heart of the debate. Figure 2.10 illustrates this.

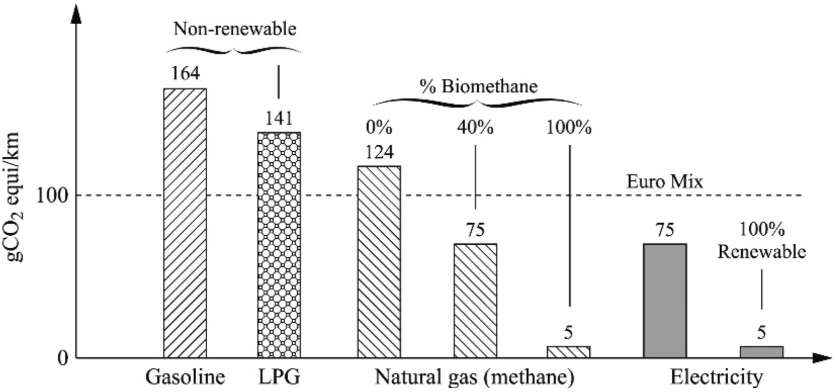

Figure 2.10. *"Well-to-wheel" analysis (in gCO_2 equi/km) for different types of energies, cars in segment C, NEDC cycle [TOY 11]*

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[65] In 2013.

2.5.1. *Fuels (refer to the glossary for alternative fuels)*

Thermal motorizations which use fossil fuels are the worst in terms of CO_2. Gasoline and diesel (and kerosene, etc.) are generally produced from crude oil: sustainable transport demands that their use be strictly monitored.

For natural gas from fossil origin:

– its combustion in thermal engines has undeniably important advantages in terms of CO_2 compared to gasoline or even diesel;

– its direct impact, in terms of greenhouse effects, is still to be assessed in detail due to methane potentially leaking into the atmosphere and resulting in significant greenhouse effects.

Using biomethane (if available) for vehicles[66] is therefore virtuous as it avoids sending the gas straight into the atmosphere and plays a part in the natural carbon cycle.

As has previously been mentioned, the performance of *electricity* varies greatly depending on how it is produced. An EV can sometimes generate a carbon footprint which is higher than that of traditional vehicles (gasoline or diesel), if electricity is produced using fossil energy (as coal or natural gas) and because of the overlay of yields (from that of the power station to that of the vehicle's batteries).

As for *biofuels*, they offer a varying range of possibilities in terms of energy for transport depending on their origin, their production procedures, their physical characteristics and chemical composition. The main properties that are likely to make them distinguishable are as follows:

– at vehicle level, their energy efficiency (in comparison with gasoline or diesel), their compatibility with vehicle technologies in terms of use and maintenance;

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[66] This being said, it is easier and more pertinent to use biomethane when available for immobile set-ups rather than for transport.

– at infrastructure level, the possibility of having to provide dedicated infrastructure, which may require considerable investment;

– from an environmental point of view, their equivalent CO_2 balance sheet, their ranking in terms of gas pollution (regulated pollutant, noise, smells, etc.);

– their surface footprint, which is an important economic and environmental parameter[67,68].

There are several approaches possible for using these very diverse fuels in engines[69].

One of the possible actions is to adapt the biofuel by formulating it so that it is compatible with current engines and designed to function on oil derivatives according to rigorous technical specifications: this strategy is currently dominant. Even though it is not the best in terms of energy and environmental outcomes, it has a considerable advantage: the carbon footprint of traditional vehicles is significantly reduced.

The other possible action is to modify the engine (and possibly its supply, and even storage, system: pressurized tanks, for example) in order for it to operate on nominal biofuel. This strategy allows fuel to be produced locally and is adapted depending on the specific territorial ecosystem[70], although it then requires an entirely new system to be set-up in the relevant territory; moreover, it raises

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[67] Every year, one hectare of ground produces up to 4,500 l equivalent gasoline of biogas, or 2,900 l of liquid fuel, depending on the crop and production method used. For example: 3,300 l of ethanol from sugar cane, 1,500 l of ethanol from wheat, 1,400 l of biofuel from rapeseed ([VOL 12], *W-to-W analysis update,* 2006 (JRC, EUCAR, CONCAWE)).

For example, each year, one hectare of land allows a car (depending on its weight) to travel between 15,000 and 80,000 km, or a fully loaded highways truck to travel between 5,000 and 13,000 km, depending on the crop [FAV].

[68] It is possible to produce about 200 l of ethanol from one metric ton of wood. Trees, particularly species with a fast growth rate, such as willow or pine, thus have the potential to be a considerable source of biofuel.

[69] It should also be noted that important studies aim to use biofuels at least as a partial substitute to kerosene for aeronautical uses.

[70] Based on a production unit connected to a supply pool for either cultures or recycling of specific waste.

problems for constructors in the maintenance and guarantee of vehicles.

The most reasonable strategy is to combine significant proportions of biofuel with nominal fossil fuels, introducing it at a rate that does not change the overall performance of the {motorization/fuel} couple. Although it is not spectacular, it is nonetheless truly efficient.

Biofuels in the "oil category" are mainly used in two important ways:

– crude vegetable oils can be directly used in diesel engines. They can be used either pure or mixed, but if an important share of oil is used, then the engine will have to be modified, namely because of the high relative viscosity;

– biodiesel (also called diester in France), consists of vegetable oil esters including methyl (EMHV) and ethyl (EEHV) esters. Their molecules are smaller and can thus be used as a fuel (sulfurless, non-toxic and highly biodegradable) for diesel engines.

Biofuels in the "alcohol category" mainly include:

– bioethanol, obtained by fermenting sugars and capable of replacing gasoline and its derivatives: ethyl-tertiary-butyl-ether (ETBE), biobutanol (or butyl alcohol);

– methanol[71] obtained from methane and capable of being used as a partial substitute for diesel or, in time, for a certain type of fuel cells.

Bio-DME (CH_3-O-CH_3) is a specific example of a fuel category that may yet be developed further. DME is produced by dehydrating methanol or directly synthesizing black liquor or other renewable raw materials. Compared to standard engines, diesel supplied with bio-DME offers a similar yield and has a proven advantage in terms of noise levels and particle rate. Replacing fossil diesel with bio-DME enables 95% CO_2 emission to be cut. DME is a gas but condenses to a liquid when it is under a pressure of 5 bars. It can therefore be

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[71] Specific precautions must be taken when manipulating methanol, which is toxic to humans.

conditioned in liquid form in a lightly pressurized tank similarly to liquefied petroleum gas (LPG) [VOL 12].

2.5.2. *Emerging solutions*

It has been noticed that a number of potential solutions are developing in parallel: energy systems in vehicles exhibit architectures and a selection of energy vectors that have been preserved[72] which is truly diverse. This diversity concerns each of their components, as well as the arrangement of the final assembly, and integration as whole in a viable set-up for vehicle movement. For each vehicle, these systems include: fuel(s), engine(s) (thermal or electric), the driveline (including transmission), control systems and strategies, energy supply and storage.

The environmental and economic performances associated with variations have been widely glorified by the media, but it is difficult – even illusory – to establish a definite, objective comparison.

Effectively, the actual performance, in terms of sustainable transport, has to be measured according to a reference which combines all categories (well-to-wheel, cradle-to-grave), the geographic scale (local/global), timescale (short term/long term) and uses (for example urban/interurban). Some measurements deliberately highlight and advocate a combination of innovative technologies that cause vehicles to be considered in the rupture of technology. Others, on the other hand, aim for fast success on the market, by progressing in small steps, and do not require a major evolution in the acceptance of users or investments.

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[72] The set-ups for hybrid drivelines previously mentioned combined several on-board energies:
– the engine can run on gasoline, diesel or natural gas,
– secondary energy can be electric or hydraulic,
– fuel storage can be either liquid or gaseous.
Dual-fuel can be quoted as another example and is a thermal motorization that simultaneously combines diesel and natural gas (compressed or liquefied). This assembly aims (at the cost of increased complexity) to optimize the entire system, while benefitting from the virtues of each one.

No single solution seems to stand out as being the only pertinent one in medium and long terms. Traditional energy solutions from oil or fossil gas, and the less traditional ones based on biofuels (including biogas), or based on electric and hydrogen systems, result in a range of solutions for which the future is difficult to predict. Depending on the alternatives considered, the investments required are very different and must be interfaced with other aspects, technologies, complexity, demands for coordinating multiple players, administrative implications and acceptance on the market. Energy systems that require specific infrastructure must demonstrate their key advantages compared to systems based on the slow evolution of existing infrastructures. Both approaches are possible and will be specified differently according to the market, the national options for energy mix and their distribution between uses for transport and other energy consumers. The trend will still be to find long-lasting results in terms of lowering CO_2, minimizing energy losses and decreasing sensitive pollution (which is also economically pertinent).

2.6. Noise emissions

2.6.1. *Overall vehicle noise*

Improving the acoustic quality of transport is one of the steps towards truly sustainable transport. Noise emitted in the environment clearly disturbs the neighboring inhabited areas in particular, and its effects are now well known. Criteria for acoustic quality have been established near roads, railways and airports, and regulations have been set up that relate either to emissions from sources (vehicles) or to the reception on road developments, transport infrastructures and associated urbanism.

Noises originating from aircrafts and road vehicles focus studies on controlling the noise level emitted by vehicles even if other types of transport are subject to targeted concerns (high-speed trains, freight trains during the night, dock work, helicopters, etc.). A variety of physical mechanisms are involved in producing vehicle noises. Noise sources can be classified according to their sensitivity to design or use parameters. For land transport (road and rail), the following are identified:

– mechanical noise (due to kinetic chains: engines, transmissions, gear reductors);

– rolling sound emission: {tire–road} contact noise or {wheel–rail} contact noise;

– aerodynamic noise, which becomes dominant at high speeds (in the case of high-speed trains).

For planes, it is possible to identify two main noise categories: engine noises and the sound of flow on the cell and fuselage[73].

For road traffic, now consisting almost exclusively of vehicles with thermal engines:

– noise from mechanical systems is the dominating source of noise and discomfort in situations where the vehicle speed is low or moderate and for transient speeds (acceleration and high engine-running speed). These situations correspond to urban roads (where speed is typically limited to 50 km/h), roundabouts and access ramps to faster roads;

– rolling noises are the dominating source of noise and discomfort in situations where speed is faster (arterial roads and highways), in suburban and rural areas. It can also predominate in areas of moderate speed depending on the state of the road surface (which correlates strongly with noise)[74];

– other various noises are also a potentially dominating source of noise and discomfort in situations linked to behavior or diversified use (brakes and retarders, doors, cut-out, handling, etc.)[75], for residents living besides distribution and service roads.

The players affected by aims to lower noise and discomfort are therefore vehicle manufacturers and their original equipment

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[73] The IROQUA network (*Initiative de Recherche pour l'Optimisation acoustiQUe Aéronautique*) provides a detailed overview, www.iroqua.fr.

[74] For example, this is the case for old urban centers where "medieval pavement" type road surfaces are being preserved or imitated.

[75] Noise connected to improper behavior or to random sources (doors, loading, bad maintenance or vehicle "DIY"), which are not covered by technical regulations, are a particularly detrimental aspects of vehicle noise.

manufacturers, tire manufacturers, road manufacturers and users themselves, who by behaving as a good or abusive citizen, determine the acoustic quality of their materials during use and maintenance.

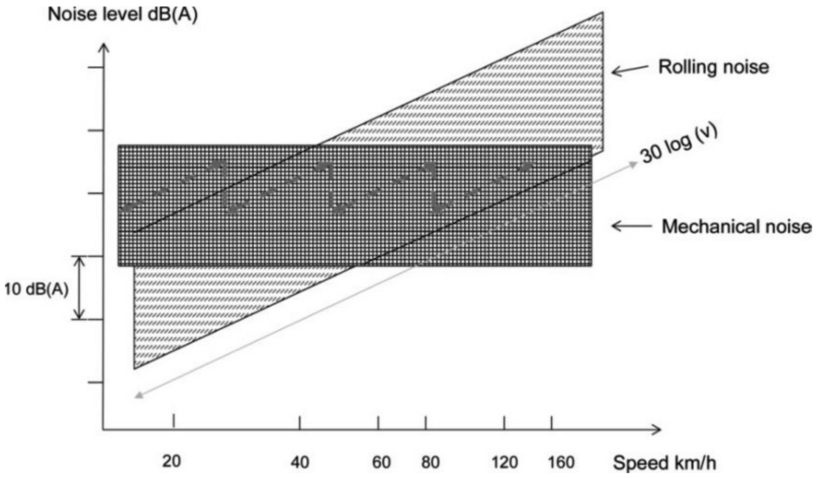

Figure 2.11. *Noise emitted by a road vehicle, respective ratio of mechanical and rolling noise*

Figure 2.11 shows the ratios of mechanical and rolling noise emitted by a road vehicle into its environment according to its speed:

– for a given engine, mechanical noises vary with the engine regime and the engine charge[76]. By changing gear, it thus sweeps a range of noise levels varying between 10 and 20 dB(A) according to dynamics for the entire range of gears in the vehicle;

– the rolling noise varies with the vehicle's absolute speed[77]. It depends on the tires and the road surface. For a given tire, noise levels

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[76] Variations in mechanical noise (expressed in dB(A)) is in the order of $\{a+40 \log_{10} (n)\}$, where a is a characteristic constant for motorization, and *n* is the engine speed (expressed in revolutions/min for example). If the engine is "charged" (for example when accelerating or when going uphill), the sound level increases by a few dB(A) for a given engine speed.

[77] Variations in rolling noise are in the order of $\{b+30 \log_{10} (v)\}$, where b is the characteristic constant of the {tire–road} couple, and v is the speed (expressed in km/h, for example).

are located within a wide range of values depending on the road surface (a difference of 15 dB(A) is typical between “silent” road surfaces (of pervious asphalt type[78]) and “noisy” road surfaces (or urban paving type surfaces)).

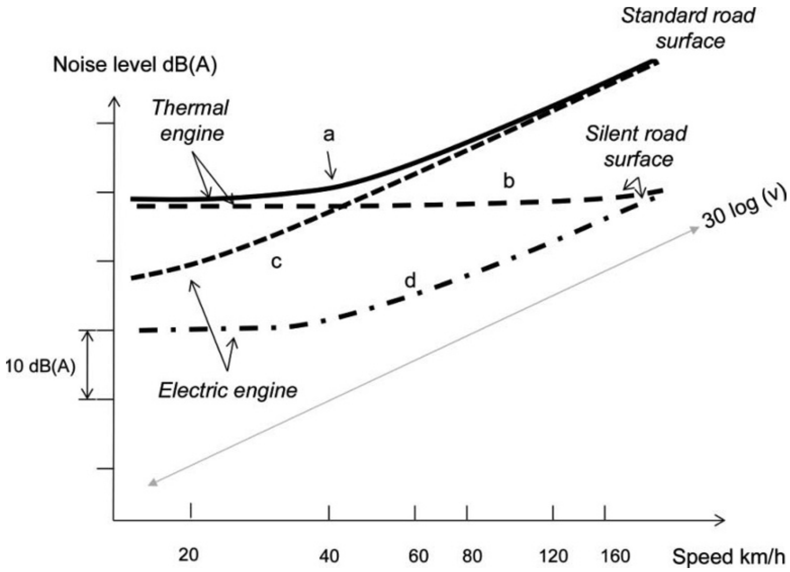

Figure 2.12. *Overall noise emitted by a car as a function of speed, according to its engine and the road surface. Unit: weighted decibel A (dB(A)) [FAV 13]*

Figure 2.12 shows how the overall noise from a road vehicle, the “sum”[79] of its mechanical and rolling noises, varies with speed. It shows:

– the noise emitted by a vehicle with a traditional engine on a noisy road surface (curve a) or on a silent road surface (curve b);

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[78] This type of road surfacing contains open pores within its structure and not only minimizes rolling noise, but also absorbs the mechanical noise reflected at the level of the vehicle’s underframe. It also has proven advantages in terms of road adherence and safety on wet roads. Unfortunately, it requires significant maintenance and is particularly affected by freezing.

[79] The decibel is a logarithmic unit, the “sum” of noises is obtained by logarithmically combining decibels and not by simple arithmetic addition. The total noise is therefore the logarithmic superposition of mechanical and rolling sounds.

– the noise emitted by a vehicle with an electric engine on a noisy road surface (curve c) and on a silent road surface (curve d).

2.6.2. *Noise reduction*

Reducing the noise emitted by vehicles requires action to be taken on the vehicle and its various systems. Transport equipment manufacturers have been identifying and analyzing noise sources for a long time, as well as minimizing emission levels, both internally (to improve on-board vehicle comfort) and externally (for the environment). The technical work carried out makes it possible to follow the regulatory evolution of primarily road vehicles and aircrafts.

However, controlling the acoustic emission of a vehicle still requires important efforts, even though spectacular results have been achieved in the past three to four decades, and which, in some cases, led to some of the previous current technical solutions to be completely requestioned[80,81]. The method consists of eliminating, or treating, the most highly emitting elementary sources[82] as a priority. However, every time progress is made in lowering noise, secondary sources appear which in turn become primary sources. Each subsequent effort must therefore treat a higher number of sources which are equally important. Moreover, the first decibels gained are the least difficult for a given elementary source. The difficulty and cost of treating each additional decibel both increase strongly and quickly result in technical impossibilities. Finally, noise reduction is involved in other objectives, namely lowering consumption, greenhouse gas emissions and sensitive gas pollution. These

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[80] This is the case for airliner engines, which have gone through spectacular evolutions in only a few decades for (namely) acoustic reasons.

[81] The acoustic characteristics of some transport solutions have made them completely redhibitory, even though they have some technical advantages. Commercial supersonic planes such as Concordes, or the Aerotrain, levitated by air cushions, created by the company Bertin can be given as examples.

[82] For a given vehicle, each noise source (such as the engine) can be broken down into elementary noise sources (see, for example, Figure 2.13).

objectives are often incompatible with each other and result in contradictory solutions.

As a result, it is necessary to find solutions for noise reduction that are technically feasible, economically acceptable and remain efficient for the whole use cycle (for the vehicle's entire life time). The "silent design" approach is used and is a process which is widely practiced in the transport industry, even if studies are still required to improve tools and technology further. The process involves:

– the development cycle ("V cycle"[83]), collection of technical and acoustic specifications, work on components, vehicle systems and vehicle synthesis;

– acoustic treatment (preventive, curative);

– models and simulations to understand low-, medium- and high-frequency systems, resetting and experimentally characterizing through metrology and signal treatment, to identify acoustic systems;

– finally, choosing and optimizing concepts for vehicle architecture and systems.

This approach results in hierarchizing the most emerging sources, in intervening on excitation (geometry, geometric tolerance, mass, stiffness, surface state), in treating acoustic and vibratory energy, transfer and radiation (by insulating, damping, absorbing) and, eventually, in eliminating the source itself.

The most effective method is to act at the source (on generating phenomena), although it is naturally limited by the principles of physics itself. As shown in Figure 2.13, motorization is an extremely complex system which involves combustion, impacts, friction, pressure, rotations, and other phenomena inside mechanical, hydraulic and aeraulic mechanisms, with intervening electronic systems for

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83 "V cycles" allow a design methodology to be used based on specifications from client requirements. Starting from the top left of the "V" and sloping down the left branch, the objectives are separated in to sub-objectives for each component, down to the most detailed level. At the end of the design phase, the right arm of the "V" is followed up: the components are reassembled, the assembly is tested and the performance is compared to the objectives and validated.

command controls. Serious efforts need to be rolled out in order to understand all the effects involved in emitting, transferring and radiating both vibratory and acoustic energy within motorization systems.

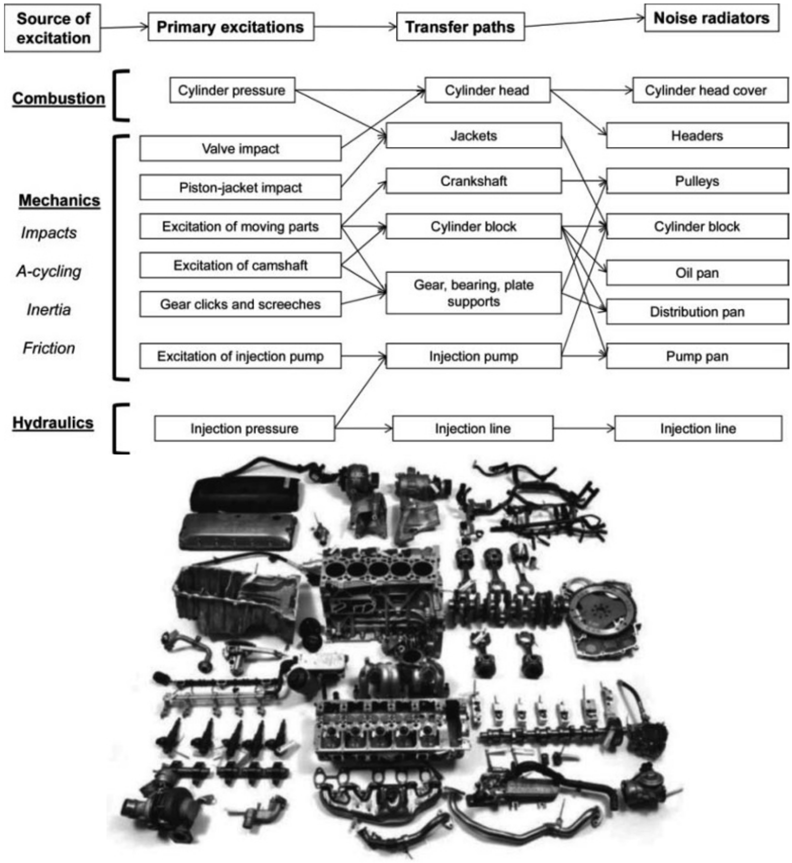

Figure 2.13. *Analysis of the elementary "engine block" noise sources in a thermal engine, with respect to its different layers: excitation of source, internal transfer of vibro-acoustic energy, external vibratory and acoustic radiation (based upon a Renault Trucks engine)*

When these actions alone are not enough, specific acoustic treatments must also be undertaken, which intervene in the external acoustic propagation and which can be delicate to implement. For example, "encapsulating" the engine consists of "locking it up" in a cocoon that prevents its sound from radiating straight into the outside environment by using principles of acoustic insulation and absorption for incident energy. The outside environment is thus (partially) insulated and protected. The sound attenuation value for engine noise is in the order of −5 to −10 dB(A) depending on the context. This solution is widely used (at least partially) for different types of recent land vehicles, yet also raises problems for integration and optimization, namely due to its thermal consequences (monitoring and evacuating calories generated by the engine must be controlled). The solution can also be very costly.

All noise sources (engine, exhaust pipe, intake, etc.) are now involved to roughly equal extents in the acoustic outcomes. They must all be reworked in order to lower noise levels or reduce scatter. The additional cost per decibel gained is estimated to be 1% of the vehicle price and increases rapidly. Treatment requires specific acoustic technologies for support and multifunctional integration: materials to insulate, absorb and dampen more effectively, and, eventually, techniques to actively control noise[84] (such as silent exhaust pipes). The evolution of material technology and that of mechatronics will lead to new solutions. For now, however, conventional vehicles are not expected to undergo spectacular breakthroughs with regard to improvements in noise performance[85].

2.6.3. *Noise regulation and its impact on noise environment*

Since they were first introduced in Europe in 1970[86], the limit values set by regulation, for sound emissions from road vehicles put into circulation, have been lowered, in steps, by 8 dB(A) for motorcars

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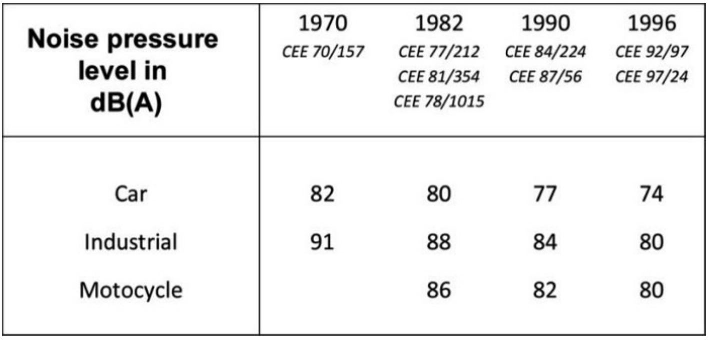
[84] Actively controlling the noise gathers a range of techniques that use electronics to ensure control and optimization. The most emblematic one consists of generating and modulating the noise created (through the use of loudspeakers for examples) so that its phase is opposite to that of the noise it aims to minimize.

[85] This may be different for new vehicle concepts using alternative energy.

[86] European Directive CEE 70/157. Measurement conditions concern the noise measured when a vehicle, in full acceleration, passes by on a standardized road surface.

and 11–15 dB(A) for industrial vehicles (Figure 2.14)[87]. As the decibel (dB(A)) is a logarithmic unit, this implies that the sound power[88] emitted by the vehicle (measured in conditions of full-acceleration on a track with an approved surface) has been divided by a factor ranging between 6 and 20 depending on the case considered. It should also be noted that, for reasons that do not depend on technical ones, motorcycles are authorized to have the same regulatory sound level as a truck, which is higher than that of a car. The reasons for this laxity regarding motorcycles are considered by the author to be completely unfounded.



Noise pressure level in dB(A)	1970 *CEE 70/157*	1982 *CEE 77/212* *CEE 81/354* *CEE 78/1015*	1990 *CEE 84/224* *CEE 87/56*	1996 *CEE 92/97* *CEE 97/24*
Car	82	80	77	74
Industrial	91	88	84	80
Motocycle		86	82	80

Figure 2.14. *Time evolution of regulatory noise levels (dB(A)) for European road vehicles when put into circulation (the year that they were introduced and the reference for the relevant European Directive is given)*

The acoustic performance obtained in regulatory conditions for new vehicles (which are therefore well maintained) concerns

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[87] Due to the psychosensory characteristics of hearing, a difference of 3 dB(A) (representing an incredible amount of work from a technical point of view) is just about detectable. A reduction of 10 dB(A) only results in dividing the noise perceived by 2. It is therefore easy to understand the challenge faced by designers: the difficulties that need to be overcome in order to lower the acoustic energy by half (to reduce the noise by 3 decibels) are poorly rewarded (in terms of perceived benefit) in the field of minimizing discomfort with respect to noise pollution.

[88] The acoustic power level of the source, Lw, expressed in decibels, is found using the base 10 logarithm of a noise source's power P, compared to 10^{-12} W which is the reference power: $Lw = 10 \log_{10} (P/10^{-12})$ The acoustic power of common traffic vehicles is of the order of only a few fractions of a Watt within the audible frequency spectrum.

mechanical noise in particular: it does not entail the same level of progress in terms of the noise level emitted by traffic, such as they are perceived by local residents. Effectively, real progress has been observed in the emission of mechanical noise (engine, gearbox, axle, etc.) but has been partially shadowed by the concurrent emergence of noise from tire-road contact. Other elements (volume and composition of traffic, age and evolution of vehicle fleets, lack of maintenance or poor use of vehicles) also play an important part [SAN 01]. In real traffic, the noise emitted by a "tinkered" motorcycle, which exceeds the noise emitted by a conventional vehicle by 30 dB(A), can therefore make as much noise as 1,000 traffic vehicles.

Specific regulations for tires have also been introduced, in the wait for regulatory values to be issued for road characteristics (which, as already mentioned, greatly affect noise from traffic).

Besides this in-depth work on drive-by noise, it is necessary to highlight the regulations that concern other types of noise: idling noise, pneumatic blow-off noise, slowing-down systems or restriction of urban traffic. A specific noise certification procedure is also being enforced to certify the noise levels originating from loading and unloading trucks during night-time deliveries.

From 1980 to 2000, the efforts made to meet regulations have resulted in a significant decrease in the noise emitted by vehicles during real working conditions. At moderate speeds (<60 km/h), at which mechanical noise dominates, the progress accomplished is typically a noise reduction of around 5 dB(A) (cars) and of up to 8 dB(A) (trucks) for fleet averages. Similar to gas emissions, noise emission in real traffic is mainly triggered by old vehicles or/and vehicles that are not well maintained or well used. At higher speeds, the decrease becomes less distinct over a time span of 20 years: at these speeds, the dominant noise is rolling noise and is directly linked to the type of road surface.

An improvement of the ambient noise has not generally been able to counterbalance the increase in noise associated with the general rise in traffic.

The next targeted deadline for regulations in Europe has been discussed for many years by stakeholders, and finally, it was decided to introduce a new directive that will impose an additional decrease of 2–3 dB(A), coupled with an important change in measurement conditions so as to better represent real traffic conditions. For lawmakers, the future stage could indeed be an important turning point in terms of the trends from the past stage by targeting classes of noise, use and context more clearly:

– on the one hand, tire-road contact noises will be catered for specifically, as they have become dominant in most cases of noise pollution. The recent awareness of its importance should help the introduction of quieter solutions. For tires, new technological breakthroughs, relevant to structure and tread, gives us a glimpse of interesting possibilities. For road surfaces, some formulations are proving to be particularly promising (for minimizing rolling noise, as well as for absorbing mechanical noise…)[89]. Prefabricated road works will be used in certain specific urban uses. On this topic, public authorities may also take on more initiatives (or pertinence) than in the past in terms of soundly choosing road surfaces for urban acoustics (for example by avoiding the generalization of paving – which are particularly noisy – in sensitive urban areas).

– on the other hand, future regulations will consider a better reference for urban traffic conditions and the specificity of urban vehicles. Vehicles which are dedicated to urban use effectively have engines which are of great interest in terms of acoustics, with regard to mechanical noise:

- they either partially or fully use the electric mode: hybrid vehicles and EVs possess engines that emit moderate noise levels when operating in their electric mode,

- or they use quieter combustion when operating in the thermal mode: natural gas buses and smoother combustion emit −2 to −4 dB(A) in comparison to its diesel equivalent,

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89 Whether tires or road surfaces are concerned, obtaining the “best compromise” is a nagging issue: how can some characteristics (in this case noise) be improved without damaging others (safety, rolling friction, wear, acquisition or maintenance costs, etc.)?

- or they have a "low noise" mode[90]: the vehicles can operate according to two different mappings, they include a conventional road mode and a quieter urban mode (but with a decreased dynamic performance due to the engine being muzzled).

In general, public authorities have started to employ a more global approach by developing an integrated method which simultaneously encompasses vehicles, infrastructure, operation, use, behavior and areas to be protected, which could be a turning point from past decades. Approaches such as these emerge in the case of specific applications, for example in controlling the noise of night-time deliveries (see Chapter 5).

2.7. The intelligent vehicle: "safe-smart-secure"

No matter what the transport mode used is, safety does not only rely on the vehicle's intrinsic safety; it also relies on the conditions under which it is inserted into the environment, traffic, infrastructure, operating protocols and above all on human behavior. In Chapter 1, it was seen that, depending on the world region, roads are by far the most lethal and provide alarming results. However in Europe, these results are gradually improving at a rate close to political objectives (reducing by half the number of deaths and serious injuries in 10 years).

Between 1980 and 2000, constant work has been undertaken on vehicle structures, and has drastically improved their ability to protect passengers in case of crashing (secondary safety), although this results in a heavier bodywork[91]. In the 2000s, developments permitted this trend of overweight structures to be stopped with the introduction of automations and regulations that reinforce vehicle performances, with

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[90] This is the case for the delivery truck by Renault Trucks in the FIDEUS project (2008). Passing from one setting to another was decided by and activated by the driver, with the help of a control placed under the demonstrator's steering wheel. The result was a reduction of ~6 dB(A) in passing-by noise in real operation.

[91] Over this time period, improving crash safety, and improving comfort (in particular acoustic comfort), have entailed an increase in the weight of European motorcars of over 100 kg.

respect to their ability to avoid accidents (primary safety): higher performance braking systems, maintaining stability, maintaining trajectories, etc.

Due to the huge newly developed potentiality of vehicle control systems interfacing with human behavior, safety will continue to improve with the coming age of “cooperative systems” and integrated safety: focus will be put on their introduction. Gradually, these systems will interface and intervene with the driver. The list is extensive: examples include emergency braking, maintaining a safe distance, maintaining trajectory, assisting maneuvers and parking, automatic light adjustment, assisting with viewing blind spots, night vision and identifying obstacles (by means of enhanced reality), detecting vulnerable users[92], etc. These efforts are made possible by combining and articulating “ITS” technologies[93] (covering on-board vehicle systems, driver assistance systems, infrastructure management, organization of mobility and logistics) and “non-ITS” technologies (covering energy on the one hand and materials and structures on the other hand). The coordinated combination of these technologies could potentially significantly improve the efficiency of transport, fuel consumption and its effects on the environment, and traffic security and safety. Their cross effects can lead to results that are already spectacular in the present day and even more so in the long run (for example, the complete elimination of risks related to road safety can be given real thought).

In this context, *humans hold a privileged position*, and a vehicle must be provided with all the functionalities and interfaces that are liable to facilitate human intervention and ensure that humans are always in control; whether the person in question is a professional or not, whether they are a driver (or pilot), as well as other operators (who guarantee vehicle maintenance and repair, fleet management and organization of transport), they are and will be “on-board”[94], central to

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[92] Pedestrians and two-wheelers.

[93] Intelligent Transport Systems (ITS) is a term used for the concepts brought to vehicles and their interaction with the external environment by information and communication technologies.

[94] The appearance of vehicles without drivers, or drones, does not exclude these aspects from being discussed, quite the opposite.

an increasing amount of information and control systems, which they will supervise and understand in order to activate the best actions required. The tasks of driving, piloting and intervening, working on-board, communication, transport management, networking with clients and providers in the mobility chain or logistics chain have all increased demands on humans. For vehicle designers, these demands must be included in specifications sheets to ensure ergonomics, comfort and risk prevention against tiredness and loss of vigilance. They require man–machine interfaces that have been adapted to human requirements:

– from vehicle to human: interfaces consist of displays, screens, indicators providing visual information and also acoustic information, or different "haptic" sensory information (vibrations, pressure, etc.) via the driver's (or pilot's) various sensing devices;

– from human to vehicle: interfaces consisting of various types of commands with which the driver can control actions on the vehicle, and the consideration of the driver's decisions, which are shared to an increasing degree with on-board command systems.

Integrating commands and organizing the information exchanged between the vehicle, driver and outside environment in the form of driving aids (or piloting aids) is a priority issue for vehicle designers (who must resolutely give thought to simplexity). In general, satisfying human expectations is the key to successfully integrating ITS technologies into vehicles and associated services and to obtain the performances targeted in terms of transport safety and security. We must split a number of requirements between humans and machines which relate to maintaining vigilance, knowledge of the vehicle's environment, the detection of risks, making the right decision and executing it in order to drive economically and safely. In critical situations, how do we distribute the roles between machines and humans and allow the latter to regain control and to steer towards the right decision? To what systemic extent should roles be separated and responsibilities allotted? These are both crucial questions which are relevant to sustainable transport.

Besides its qualities in terms of energy and environmental efficiency, tomorrow's vehicle will therefore integrate functionalities for safety, adaptability and resilience (Safe-Smart-Secure), which will result in an equal number of complementary attributes, and are the trademark of future vehicles. The following chapters will discuss these characteristics, and it will be seen that they can be adapted at the level of transport systems in their entirety, thus becoming one of mobility's characteristics.

2.8. Sustainable vehicles and transport

The characteristic traits of vehicle evolution, in the context of sustainable transport, are largely demonstrated by the present example of motorcars. They are highlighted thus:

First of all, the *energy* question, which involves an element of movement (the *trans* in transport), brings about underlying trends:

– optimizing the energy yield of devices that transform initial energy (thermal, electric, etc.) into motor energy;

– minimizing the energy losses by not only working on the vehicle (making it lighter, various types of friction), but also by working on its operation[95];

– distributing the energy demands more effectively between different on-board "consumers" and "producers";

– using renewable energies, whether the "vector" is electrons or organic molecules;

– using energy with a lower carbon footprint;

– increasing the ratio between payload and unladen weight.

Over time, these trends have appeared in a very wide variety of versions, which can raise hopes and disappoint, depending on the

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[95] Reducing the vehicle speed effectively restricts aerothermal losses linked to aerodynamic friction. Reducing the number of stops and accelerations limits "tribo-thermal" losses in braking systems. Keeping the motor at its optimum operating level increases its energy efficiency due to the Carnot thermodynamic principle, etc.

market evolutions of energy and vehicles. The danger is that the numerous proposals and initiatives will not be able to accompany the implementation of pertinent industrial and economic procedures, which would result in the collective inability to provide long-lasting solutions for our environment.

Then comes the structural assembly of *material*, which provides the ability to carry (the *port* in transport). It requires more sophisticated materials for high-performance and lighter vehicles, which demand supply and evaluating procedures to be reconsidered. If the search for some of the raw materials used in high-technology components are sourced in increasingly distant locations, recycling them at the end of the chain, from end-of-life vehicles, is also possible and may become profitable. This includes:

– mastering the design of various assembly patterns (for example modular design, or composites);

– implementing evaluating procedures;

– developing the potential of more biogenous "natural" materials.

This type of vehicle has great *intelligence* (which can bring the *sustainable* dimension into transport). The intelligence equips and innervates all the on-board components and ensures the coexistence between these components and humans, who are the on-board pilots placed in a driving and monitoring "cockpit", in the wait for the latter to withdraw (or to be *ipso facto* withdrawn?) from their prerogatives. This intelligence, which is now mainly distributed between humans and machines (vehicles, on-board systems, connected external systems), means that the vehicle is considered as an element of a system that is more complex: the transport system. This aspect opens a new chapter in sustainable transport (see Chapter 5).

For cars, solutions to be put on the market in 2020 are already part of the constructors' roadmaps. They are therefore the solutions that result from strategies for producing decarbonized and clean vehicles[96],

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[96] Therefore, the new-generation Citroën C3 permitted a decrease of 10%, in comparison to the older model, in the consumption of the built-up engine, 5 dm^2 in aerodynamics (in terms of S.Cx, where S is the frontal surface, and Cx is the penetration coefficient in air), 100 kg in mass, 10% of rolling friction [MAC 11].

which is the answer to triple optimization: adapting vehicles and motorizations, adapting alternative fuels and partial or full electrification. Gasoline engines use increasing levels of technology, have been "downsized" (compacted by making cylinders smaller and increasing the energy density) and are little affected by Euro 6 regulations. This is not the case for diesel engines, for which the relative requirements in terms of nitrous oxides and particles are very high in comparison to Euro 5. Due to the rising cost of after-treatment, they will no longer be competitive with gasoline, unless they maintain their intrinsic advantage in terms of consumption. Introducing electricity gradually into the architecture of cars in order to provide on-board energy is currently a work in progress. It provides complementary performances and results in a wide range of partially hybrid vehicles. As for EVs and rechargeable hybrid vehicles (HR), it is necessary give them some support in order for the market to take off, starting with the development of infrastructure. It should also be noted that the diversity of fuels that can be used in thermal engines, enables us to contemplate the gradual introduction (yet partial, given available resources) of biofuels for this type of motorization.

After 2020, solutions will have to be searched for by any means possible in order to reach the voluntary objectives related to greenhouse gas emissions, which may be required of automobiles[97].

With regard to the *transport of goods*, thermal motorization should keep on playing an important part in interurban transport. Fossil diesel oil and – increasingly – "renewable" diesel should maintain their position as the dominant fuels in the next few decades. Natural gas and biogas are mainly used at "regional" levels in compressed form in urban areas. In their liquefied form, they can supply interurban corridors. One of these replacement fuels, DME, is an attractive niche candidate as a medium- to long-term fuel: better "well-to-wheel" energy efficiency and "CO_2-neutral" if produced from biomass. Applications which use electricity in various forms should gradually be deployed for urban transport. This is already widely the case for

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[97] In France the program "voiture à 2 l/100 km" (car consuming 2 l/100 km) aims to reach CO_2 emissions equivalent to 50 g CO_2/100 km (2013).

urban buses and could be the case for “last kilometer” delivery vehicles.

Finally, it should be noted that supplying infrastructure and on-board storing abilities is a key point for developing electricity. As for hydrogen, implementing its production/storage/distribution system is a complementary gamble (or an alternative to electricity) and is a prerequisite if its set-up is being contemplated. Only the future can say to what extent the two systems – electricity and hydrogen – are compatible in the same markets.

The same analysis can be applied to other types of vehicles and other transport modes (land, nautical or air). However, they can provide opportunities as well as specific constraints that cause their applicability to change. The discussion here will limit itself to aircraft, for which the question necessarily outlines flight weight and implies inevitable technological choices. Electric planes that operate on batteries are not an option, given their dead weight. Supplying them with energy by means of on-board photovoltaic cells is not an option either, given the surface that is beyond the conceptual solutions that have been tested on prototypes[98]. For the foreseeable future, planes will still be provided with engines that use liquid fuels, given the current state of technologies and according to realistic predictions[99]. Their potential to lower consumption (long-haul flights) is limited to a predictable 20–40% by carrying out important work related to making planes lighter, aerodynamics, motorization and operation. In the immediate future, the fuels used will most likely be predominantly fossil fuels[100]. This is bad news for sustainable transport.

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[98] The prototype plane, Solar Impulse, which operates only on electricity supplied by photovoltaic cells, was designed by Bertrand Piccard and is emblematic.

[99] Refer to the summary on “bigger but less greedy planes” by Futura Sciences in www.futura-sciences.com/magazines/espace/.

[100] A long-haul plane’s “full and complete” trip loaded for one single flight with 310,000 l, equivalent to 263 metric tons of fuel, requires crops of 241 ha for wheat or 1,006 ha for beetroot to produce the equivalent amount of agro-fuel. Agro-fuel has a lower energy density and a higher average on-board load and therefore lowers the plane’s autonomy significantly. As a result, the drag caused by lift is increased and inevitably further degrades the overall balance [KIE 11].

Chapter 3

A Systemic Approach to Transport Schemes

Understanding and setting up the conditions for sustainable transport must be based on the ingredients that constitute them. One of the main constituents has just been analyzed: road vehicles. Vehicles are one of the building blocks that we are now trying to assemble, before integrating them, so as to reach the project targeted: sustainable transport. Here, it is necessary to construct not only vehicles, but also the infrastructure and modes of organization: building blocks and their assembly.

This chapter presents the author's interpretation: transport has strong territorial characteristics, in terms of the geographical establishment of its infrastructure, in terms of diversity of origins and destinations and in terms of land coverage and environmental impact. Organizing any form of transport involves corridors consisting of infrastructure, platforms and connectors, vehicles and rules for operation. Similar to water in a hydraulic circuit, or an electron in an electric circuit, circulating flows (of people or goods) have conditions attached, imposed by sizing and the layout of each element in the overall infrastructure by means of “adapting its impedances”[1]. Understanding this system is a fundamental point for sustainable transport and enables it to grow.

3.1. Transport corridors[2]

All transport modes guarantee transfers from a departure to an arrival. This cycle involves several kinematic phases that the vehicle undergoes between its starting and finishing points. These phases are combined with the corresponding infrastructure.

Figure 3.1 shows a the basic relationship between a vehicle’s kinematic cycle in a corridor between two stopping points (above), and the way in which the associated infrastructure is structured to optimize the corridor’s output, requiring the terminal parts to be split. For the same nominal flow, the ends of the corridor occupy an area of land that is larger by far than the space occupied by the nominal fast section.

Schematically, it is possible to identify the following:

– Nominal speed cruising sections (continuous section), in which transit is allowed to flow as fast as possible for working conditions that guarantee a certain level of service quality (in accordance with the modes concerned and the state of infrastructure)[3].

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[1] This acoustics and electronics terminology expresses the work to be done in order to facilitate energy transfers across interfaces between two systems that must exchange energy.

[2] This section concerns all transport modes. However, non-terrestrial modes (air and maritime) have specificities that will not be discussed here. These specificities are due to constraints that are weaker in the environment that they move in during their cruising phase, distant from land on a 2D surface (sea), or in a 3D volume (air) medium.

[3] For example, urban road infrastructure in France can be classified according to their urban status, into urban expressways, arteries, distribution streets and service roads. They can serve traffic calming zones (speed limit of 30 km/h), or “meeting zones” (where the speed limit is 20 km/h, and where various flow modes mix, including the pedestrian mode). They are accompanied by appropriate speed limits. The French urban infrastructure management center, *CERTU*, provides town maps that show these attributes.

– At each end, starting or finishing zone, and docking and parking zones, vehicles are allowed to stop in order to load and unload, and are interfaced with the neighboring space (which ensures storage, exchange, service, etc.).

– Intermediate sections for gathering speed or slowing down to allow vehicles to link up with the two other configurations. The speed here is more moderated and is lower than the nominal speed so as to lower safety risks linked to operation (due to the proximity of stopping zones), and also the environmental impact on the region being crossed (the infrastructure is usually located in inhabited areas).

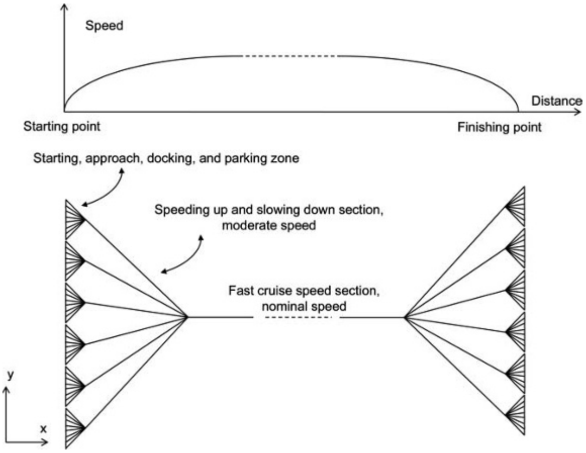

Figure 3.1. *Typical speed cycle for a transport vehicle with respect to the distance between starting and finishing points (above), and diagram of the infrastructure connected to ensure nominal output (below)*

Local service is therefore carried out at low speeds, which are cancelled at stations in order to ensure that people and goods are exchanged at the interfaces between the corridor and end platform. The occupation time for the parking area is at least equal to the time necessary to load and/or evacuate the vehicle (transshipment). The time taken therefore specifies the size of the end access infrastructure. The longer it takes to complete transshipment, the more the end infrastructure will be solicited and required to receive and allow vehicles, needing to travel at nominal speeds in the continuous section, to park. To optimize transport, it is therefore necessary to appoint specific sections of infrastructure at the ends, and therefore surfaces, land and site coverage: the corridor is thus multiplied into elements that become even more numerous as parking time grows longer. For a given corridor, the number of sections is directly proportional to the ratio between nominal and end flows.

This effect can be illustrated by a few examples:

– A high-speed railway line, of Train à Grande Vitesse (TGV) type, ensures a capacity in the order of 12–15 convoys per hour, representing 12,000 passengers each way[4]. At the end of the line, the flows are split by rails and a set of points that distribute them in stations depending on the platforms available at that point in time. The station's ability to exchange and the line's output capacity are closely related. The approach zone, where trains gain speed or slow down, requires multiple rails to be assigned and managed, and receive and co-manage trains according to their successive arrival, and it harmonizes transport flows (passengers, goods) as much as possible. Land is rare and costly, and its use must, therefore, be rigorously assigned and optimized. The stop time for a TGV in a terminal station is approximately 30 min to allow for passengers to disembark on arrival, the train to be prepared for the next departure and passengers to embark before departure. The "output" of a terminal platform is, therefore, two TGVs per hour. A minimum of six platforms is required to guarantee the capacity of a track in one direction.

– Motorway toll plazas are sized in order to distribute traffic during busy times. A motorway lane has a capacity of approximately 2,000 vehicles per hour per lane[5] (approximately one vehicle every 2 s). There are 5–10 tolls in each nominal lane[6] (corresponding a station stop time of 15 s per vehicle).

The need of available space in order to ensure (slow) exchange flows at the ends of each fast infrastructure section also goes hand in

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4 A double TGV Duplex transports approximately 1,000 passengers. The length of the train set is 400 m.

5 According to [BOT 91], the hourly flow for a 3.5 m wide lane is 14 000 cyclists or 19 000 pedestrians, in comparison to 2 000 cars. I aded the ref in the biblio.

6 Introducing electronic road pricing has enable the size to be lowered as tolls operate faster (stopping is not required).

hand with the spatial requirements needed to ensure the storage of transit. These spaces simultaneously allow exchange flows at the interface between corridors and local regions to accelerate, and guarantee the connection and distribution of flows from point of origin to destination, regardless of whether it concerns the transfer of users (at multimodal stations, at airports, etc.) or of goods (transiting within a logistics center). These places are certainly not idle in terms of mobility. On the contrary, they play a vital role in connecting transport modes, and make sure that starting and destinations points coincide. These spaces must therefore be sized according to the needs in terms of facilities (loading, unloading, storage, transfer, etc.). They must also be sized in order to ensure mobility services linked to connecting transport modes (travel information, ticketing, sorting and transferring logistics, etc.), as well as the local services connected to the region being served (consumption, meeting spaces, purchase, etc.).

The actual output of a given transport infrastructure therefore depends on both the capacity performance of the continuous section, and the performances at each end where it interfaces with the regional environment and with the points where the flow is interrupted. The performances, in terms of operating output, are hence imposed by the lowest-performing section of the entire arrangement.

Figure 3.2 shows a diagram of the three types of corridors:

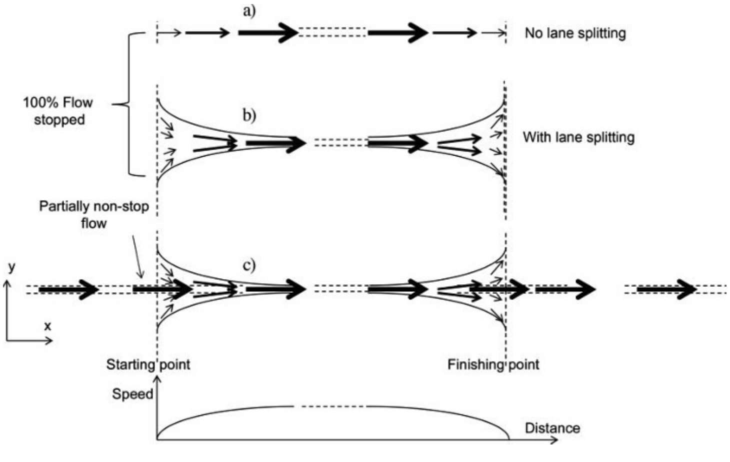

Figure 3.2. *Different types of transport corridors. Arrows represent vehicle speeds*

– For corridors of type (a), continuous infrastructure includes a series of stations and disruptions (red lights, stops, etc.), which are imposed by operation: it therefore guarantees both nominal flow (in which vehicles move at their nominal speed), and stopping at stations or in compliance with road signs. The kinematic behavior of a vehicle is conditioned by the infrastructure's nominal characteristics as well as by the presence of the previous vehicle. These constraints impact the dynamic behavior of all vehicles and shape the output capacity of infrastructure in continuous sections, and the output is therefore limited.

– For corridors of type (b), continuous infrastructure (along which vehicles move at their nominal speed) is enclosed on each side (upstream and downstream) by zones that allow the flows in parallel sections to be split in order to guarantee end servicing. These zones are "buffer" zones that make sure that vehicles are managed during their starting and approach phases, as well as when they are parked. They are systematically connected to the exchange area (the platform) thus making sure that transshipment operations can be carried out. The output of infrastructure is the same as for the nominal infrastructure, as long as the buffer zones are of sufficient size.

– For corridors of type (c), a combination of the first two types, the connection areas are attached to the continuous infrastructure in several places, thus locally guaranteeing stopping points, managed in parallel, for part of the flows without greatly impacting on the continuous infrastructure's nominal performance (if integration has been designed correctly).

By managing corridors, the aim is to optimize the transport capacity by maximizing the flows per infrastructure "unit" (in particular, per unit cost of investment and operation[7]), while maintaining the objectives for safety, security and service quality. In particular, the main sizing factors are:

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[7] All the costs (internal and external) should naturally be included, in particular, those associated with environmental impacts.

– the output capacity of infrastructure in a continuous section, for a given operating speed;

– the station stopping time, and thus namely the boarding and/or unloading rate of people or goods[8]. The station output rate itself depends on the architecture of vehicles, their internal movement, their openings, their docking height and length, and the architecture of the platform or the station, their capacity in terms of reception and evacuation, maintenance, traffic and storage;

– the number of diversion and gates;

– rules of operation.

In the case of roads, empirical relationships (called "traffic laws") correlate instantaneous flow rate with instantaneous vehicle speed; as the amount of traffic increases, the speed decreases from the maximum speed permitted by the infrastructure's nominal characteristics. For example, the output rate of an expressway, with a speed limit of 130 km/h, reaches its maximum for a vehicle flow speed of approximately 60 km/h (the output rate is therefore approximately 1,800 veh/h/lane)[9]. It should be noted that this capacity rapidly collapses if saturation is reached. For other types of roadways, the nominal capacity is lower, and is especially low if the road operates at a local level and/or if it must meet quotas from regulations that impose speed restrictions and stops (such as traffic light regulations). An urban road with an average flow speed of 15 km/h reaches an output rate of 500 veh/h/lane.

Another example is the operational output rate of a railway line managed in paths and sections. This centralized operational structure allows a frequency of 3–4 min on a standard line, equivalent to 20 trains/h/way for a passenger train. For a goods train, the frequency is approximately 5 min. For a high-speed train (HST), going at the maximum working speed (approximately 300 km/h for TGVs), the output rate is tangibly lower (12–15 trains/h/way). With Duplex double train sets, which take approximately 1,000 passengers aboard,

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[8] Rechargeable electric vehicles now impose their own time and parking restrictions.

[9] Many traffic engineering books discuss the subject of traffic laws. For example, the reader may refer to [COH 00].

this provides an output rate of 12,000–15,000 passengers per hour and per way. As has been discussed previously, stations should have sufficient dimensions to cater for these passenger flows.

As a consequence, infrastructure is usually split at each end in order to respect the equilibrium between the corridor's capacity in the nominal section, and its capacity at each end. This is done in such a way that vehicles can distribute themselves as they arrive into as many removals, thus allowing the separate flows to be homogenized at the interface with the flows in the continuous section (Figure 3.3).

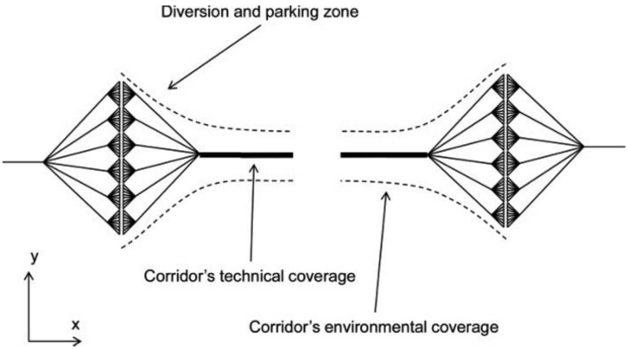

Figure 3.3. *Diagram of a corridor with its technical site coverage, environmental coverage and terminal service areas*

This architecture has several impacts on the land:

– Corridors themselves need land to ensure the supply of infrastructure (civil engineering, substructure and platform, networks for drainage, sign posting, energy, etc.) and safety[10]. Placing traffic streams in parallel next to each other needs to be separated by a certain distance, which appreciably influences the width covered.

– In diversion zones, where speeds are lowered, the site coverage can be very high due to several overlaps. Of course, this is the case for road and rail corridors in urban areas, for which diversions immobilize very large areas. It is also the case for ports and airports.

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[10] One high-speed train line mobilizes at least one track width covering 40 m (including 14 m for the rolling platform) [SNC].

– The land immobilized by exchange platforms (bus and railway stations, airport terminals, ports, areas for logistics, etc.), through which passengers and goods transit, have a surface area and a capacity (for docking vehicles, welcoming users, storage, maintenance, etc.) directly linked to the area of and the activities in the regional space that they serve, or else to their transit capacity. The same is true for the relative constraints of sizing a metro platform (as well as its access corridors, etc.), a car park for a shopping center and its access infrastructure, etc.

– Beyond the technical and administrative limits of corridors, important surface areas, in relationship to zones crossed, are affected by noise levels[11,12] and by the local pollution generated by traffic[13]. Maintaining these levels within the acceptable limits implies restrictions for the supply and operation of corridors[14]. Reciprocally, creating and operating corridors deteriorates the zones' environment from an ecological and economic point of view.

It should also be noted that traffic lights induce the same effects on the cycle length as terminals, due to the interruptions they impose (during the red phase): slowing/stopping/restarting, and requires the infrastructure's site coverage to be increased (failure to do so will result in the appearance of traffic jams, depending on the vehicle density). Introducing automations for vehicles and infrastructure could noticeably change these relationships in the future, by increasing the infrastructure's performance in terms of output flow. They have considerable potential. Projects to build new infrastructure may be avoided by using existing corridors more efficiently, as their working

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[11] The acceptable noise limit at the boundaries of residential areas (set to 65 dB(A)) concerns a 150 m zone on either side of an urban motorway with a flow in the order of 5,000 veh/h [CER 80], which is 10 times its technical coverage.

[12] The instantaneous "acoustic footprint" associated with a single road vehicle traveling at cruising speed is approximately 6,000 m^2 : this is the area of land subject to sound levels more than 65 dB(A) due to the noise that the vehicle emits into the surrounding environment [FAV84].

[13] It is also important to remember the effect of breaks, the impact on landscape, on the run-off water, etc.

[14] Noise screens along roads and rail infrastructures are one of the numerous possible examples. Another example consists of the management procedures used for air traffic (take-off and landing) near airports.

conditions will be improved with regard to flow and vehicle density, while improving safety performances (see Chapter 5).

3.2. Transport mode, effective velocity and distance traveled

A transport mode's performance and its efficiency depend on a great number of design, use and operation parameters, for both vehicles and infrastructure.

One way in which this performance can be characterized is by quantifying the time required to travel a given distance. A simple representation of the major transport modes for people is shown in Figure 3.4.

Two blocks can be identified: that of more specific "short distance" urban and suburban movement and that of more specific "long distance" interurban movement.

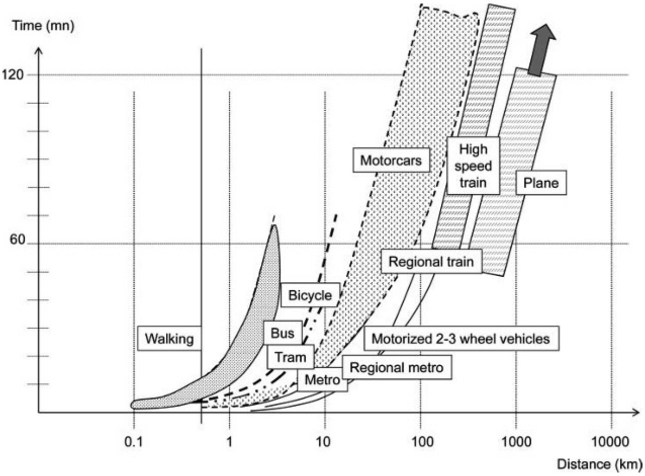

Figure 3.4. *Relationship between time (linear scale) and distance traveled (logarithmic scale) fordifferent transport modes for people [FAV 13]*

For short distance, following the modes:

– Mild or "active" modes, walking, bicycles with or without motor assistance (or assimilated, scooters, for example), which permit short trips. Walking is the only pertinent mode for trips below a certain distance. All trips start and end with walking[15].

– Motorized private modes (motorized vehicles with two to three wheels, small private vehicles with urban characteristics, cars) and public modes (buses, trams, metros, express regional trains) cater for intermediate distances. In 15–30 min, they allow passengers to travel across the urban space of medium-sized agglomerations. The distance traveled depends on the mode (vehicle, associated infrastructure, working conditions). Due to their different respective performances, these modes are more often complementary rather than in competition with each other. Linking them allows the variety of urban trips to be covered, at both small and big scales.

For long distance, the modes correspond to motorcars, express trains, HSTs and planes. In 1–2 h, they allow territories of different scales in the European space to be crossed, ranging from 100 to 1,000 km (counties, regions, states). For distances more than approximately 1,000 km, planes are nearly exclusively the transport mode of choice, in order to link international hubs from which a chain of (several) other mode(s) leads from the point of origin to destination.

Within certain limits, the transport time depends relatively little on the total distance that separates the starting point from the destination.

Firstly, for a given transport mode, time is directly dependent on distance, although the relationship is not linear; factors linked to scale and environment must be taken into account as they impose rules of operation for corridors, discussed previously. Even though the continuous section of the corridor is efficient, the end approaches quickly deteriorate its performance and significantly affect the distance traveled, even more so for short trips: for both long and short trips, the approach to airports and entering stations, in addition to the searching for a parking space, generate imponderable delays and can (quickly) compromise the performance of short trips even further. Overall (Figure 3.5), for a given distance traveled, the transport time

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[15] Naturally, there are specific cases relevant to people with reduced mobility.

increases when the displacement scale decreases[16]. Time is a base logarithmic function of distance for large scales of time values. It doubles when the distance between start and end points is multiplied by 10. A relationship can be used and is written as $T = 30 \log_{10}(D)$, where T is the duration in minutes, and D is the distance in kilometers, according to which it takes 30 min to travel 10 km, 60 min to travel 100 km and 90 min to travel 1,000 km. Of course, when traveling at cruising speed in a corridor, the time is linearly dependent on the distance for a given mode.

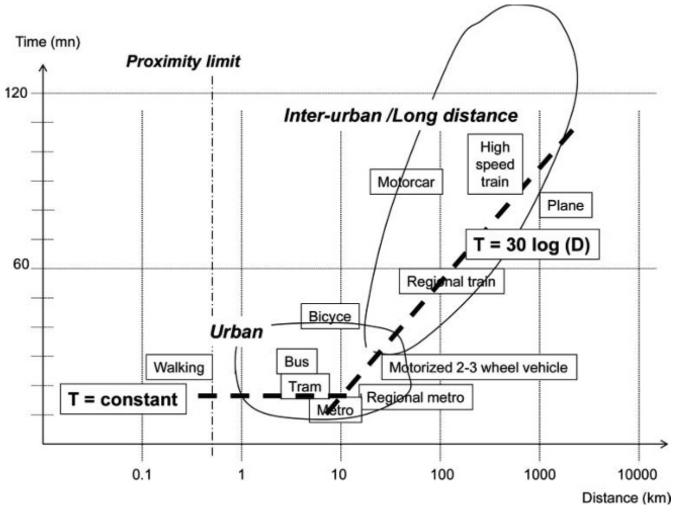

Figure 3.5. *Simplified typology of the relationship between travel time and distance traveled, for the transport of people [FAV 13]*

Time then continues to elapse when passengers transfer from one transport mode to another at the same transfer platform. The total time required to complete a trip between point of origin and destination is therefore the sum of the times for different transport modes used, plus the waiting and transfer times at junctions. The performance of linking trips between starting and end points involves breaking loads between

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[16] For long distances, it is possible to travel 500 km (plane), 200 km (express train) and 80 km (car) in 1 h. For peri-urban, a 50 km approach to the city is possible in 1 h (train and regional metro, car). For urban areas, it takes 30 min to travel (in terms of "effective" distance) 10 km (metro), 6 km (bus), 3 km (bicycle) or 1–2 km (walking).

transport modes and meeting platforms, no matter what form they take (car parks, stations, terminals, logistics center, etc.). Here, the interfacial elements are vital, as they can quickly ruin the performance of transport modes if poorly adapted. The characteristics of these interfaces (including the interface between a transport mode and a platform at both entrance and exit, and the platform itself) depend on geometrical, physical and numerical conditions[17]. The conditions for adapting transport modes, and their interoperability, must be defined and optimized for the characteristics of these interfaces.

This important aspect is shown in Figure 3.6, exemplified by a chain consisting of four transport modes used to go from the point of origin O to the point of destination D. The first mode travels at a low speed and takes a time T1 to reach the platform, from which a second, fast mode leaves after a waiting time of T2. Times T1, T3, T5 and T7 are the times taken by each consecutive trip to reach its destination. Times T2, T4 and T6 are the transfer, or access, times between modes; the total performance between origin and destination is highly dependent on how well the different transport and transfer stages are interconnected, more so than on the (nominal) pure performance of the modes involved.

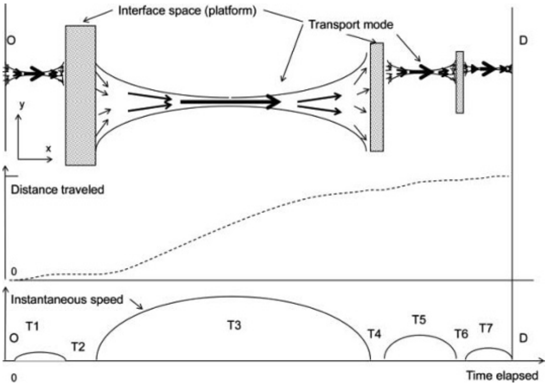

Figure 3.6. *An example of the evolution of instantaneous speed for an {origin–destination} trip involving linked transport modes*

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[17] Numerical conditions refer to the ability to exchange the correct travel information in real-time, which shapes the transfer quality related to the platform.

The subject of how best to combine modes to optimize a trip is illustrated in Figure 3.7. It represents a passenger making an intercity "door-to-door" trip from Lyon to Brussels. The two cities are 750 km apart. This trip requires[18] a minimum cumulative time, which varies between 4 h 30 min (by plane) and 7 h 30 min (by car), with an intermediate performance of 5 h and 30 min (by taking the direct TGV). Here, the time taken by each transport mode and transfers is included. The relationship between distance and time depends on the modes used and transitional transfer times, and depends very little on each mode's cruising speed performance. It is also noteworthy that the travel time can potentially be highly scattered for a combination of one or several modes between origin and destination, and depends on:

– the closeness of the points to platforms that provide access to main transport modes;

– the transfer performance of platforms;

– the frequency of services (for public modes) (in this case planes, direct HSTs or with transfers to connecting trains, land-transport modes for short-distance urban trips, etc.)[19];

– traffic congestion conditions (for private modes or in public infrastructure, especially in urban and suburban road systems);

– imponderable operating factors (weather, strikes, various incidents).

The problem with platform transfers (within platforms and at their interface with transport modes) is that it requires users to be "autonomous". Users include people, for whom walking is widely practiced within platforms. However, some user categories (people with reduced mobility) need means of accompanying substitution to be provided and may call for equipment and services to be adapted in order to make it possible to transfer them. A comparison of this issue can be made in the transport of goods and is more general. The

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[18] Trips undertaken in 2013.

[19] Bearing in mind the possibility of break downs or unforeseeable circumstances (strikes, natural disasters, etc.), for which the various solutions are not resilient to the same extent.

transport of goods is not (currently[20]) provided with the ability to be autonomous; it requires transport and handling means, involving a central organization for these operations and accompanying or steering operators (drivers, delivery men, etc.).

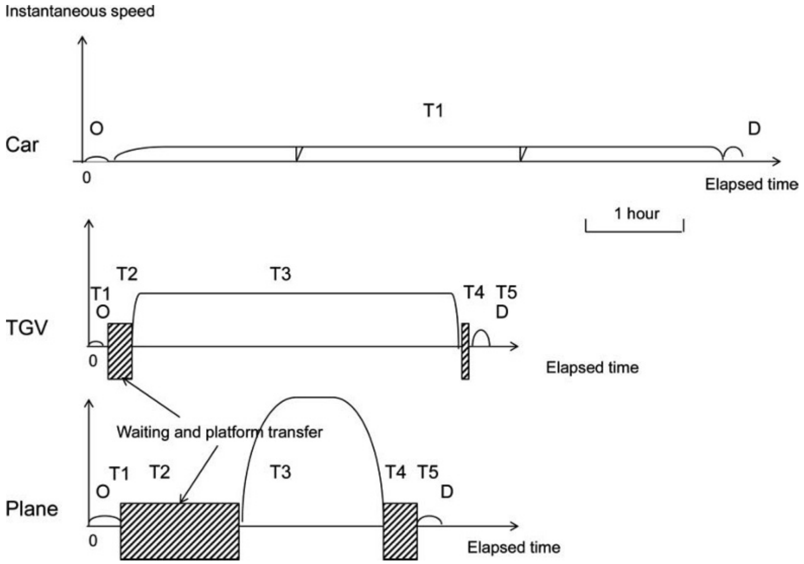

Figure 3.7. *Comparison of the cycles for different means of transport for a single person to travel door-to-door between Lyon and Brussels*

Taking this into consideration results in making general recommendations for platforms and intermodal transfers (access, movement within the platforms, control procedures, welcome methods, storage capacity, etc.), to the same extent as for transport modes themselves (vehicles, infrastructure and working conditions). The goal is to design and use the entire transport system effectively, so as to allow the practices for sustainable development, which demonstrate the best results in terms of efficiency, environmental and societal impacts. It is therefore also crucial to design the connections in transport systems well, in addition to their sections. The care put into minimizing time and improving connection ergonomics within

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[20] While waiting for robotic solutions to be used, which will make them autonomous.

platforms and interchanges will directly benefit transport from point of origin to final destination, thus improving the quality of mobility. The effectiveness of this type of action can be estimated and must therefore be added to the gain expected from increasing the pure nominal speed of a transport mode in the sections. The marginal effect of the latter may prove to be highly disappointing in terms of travel time if it is compared with the action's cost, which is considerable and even colossal[21].

3.3. Articulating modes and scales

Different transfer modes can be articulated and interconnected through the means of exchange platforms, in order to cover the different scales of territorial space in an organized manner. The principles of organizing in such a way may be relevant to the displacement of people or goods and are shown in Figure 3.8:

– In (a), the first transport mode serves the local territorial fabric by finely innervating it, thus making sure that local transport is drained. This mode is almost exclusively the road mode as all origins and destinations in a territory are serviced by roads (with exceptions). The term "last kilometer" service is often used, even if it can refer to a wide variety of distances in practice, ranging from several meters to dozens of kilometers.

– In (b), a second transport mode takes over. It is faster in continuous sections, permits larger output rates in order to mass previous flows, and the sections between stops are longer.

– In (c), following the tendency of shifting to possibly greater scales, another mode takes over. This third mode also allows reaching higher levels of performance (massing, distance, speed) in comparison to the previous one.

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[21] It is possible to arbitrate between potential mobility solutions by estimating the general cost (which is the sum of monetary cost of travel, plus the cost of saved (or lost) time (time x time-value)). The value allocated to time (for example €10 or €20 per hour for the user) is a determining factor in choosing the solution. It would therefore be possible to compare mobility solutions against each other.

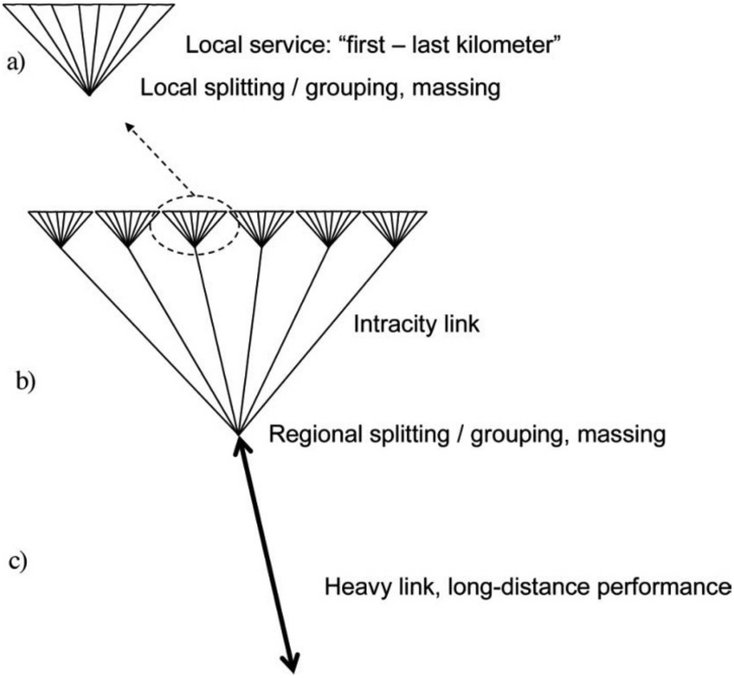

Figure 3.8. *Principle of connecting transport modes to cover different territorial scales*

The entire territory is thus innervated by juxtaposing infrastructure and transport modes that guarantee coverage. In the area covered, leaving from any origin can service any destination by stacking the relevant scales. Figure 3.9 demonstrates this organization.

With regard to innervating the ends of corridors or junctions from one scale to another, or between modes, it assumes the existence of a fine local network that is sized to permit:

– the distribution of vehicle flows and the adjustment of their speed from nominal corridor vehicle speed down to zero to the station, according to the model in Figure 3.1;

– the assurance of exchange flows expected within the platform.

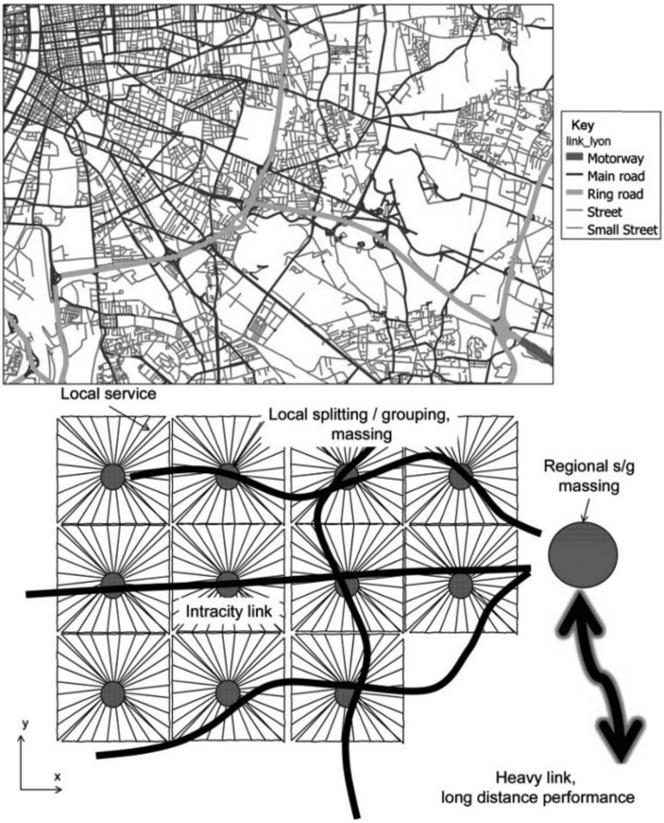

Figure 3.9. *Draining territory by a transport infrastructure network; a) road network with road hierarchy; b) network represented by mixed modes and exchange platforms for different scales*

Junctions are not symmetrical for two different transport modes (for example rail on the one side and road on the other): Figure 3.10 shows the exchange between one rail corridor and five road corridors.

The junction will not be symmetrical for two different transport modes (for example rail on the one side and road on the other): Figure 3.10 shows an interchange between one railway corridor and five road corridors.

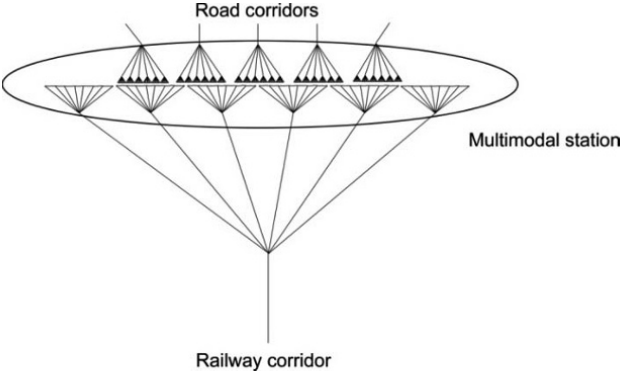

Figure 3.10. *Junction between transport modes*

Any thoughts on the implementation of solutions for sustainable transport are based on the framework of following transport networks:

– Infrastructure: this includes corridors (their core consisting of sections that allow flows to travel at nominal speeds, and their ends are finely innervated by terminal sections to allow parking), as well as exchange platforms.

– Vehicles, regulated according to their specific rules of operation.

This framework includes networks for different transport modes; roads are the main and generalized structuring element in territories and other networks (railways, waterways and airways) are superimposed onto this base. Platforms ensure connections between different mode combinations and different geographical scales (local, urban, regional, international, etc.).

3.4. Transport scenarios

The framework previously described forms the basis of transport services. They can be optimized by taking into account another "systemic" layer: that of organization, which involves different levels of capability:

– observation: the ability to acquire and process data (mobility needs in a territory, locating moving entities, people, goods, infrastructure capacity, etc.);

– prediction: the ability to establish, simulate and assess scenarios and to measure the costs and advantages;

– governance: ability to implement funding, management and decision-making procedures.

The objective is to develop modes of organization that competently optimize the characteristic indices of sustainable transport: ensuring mobility and service quality while minimizing the environmental impact and optimizing efficiency.

The approach is exemplified here by the concept described below, starting with a territory. The aim is to analyze the customs, with regard to mobility, and to test the benefits predicted, obtained from optimizing the organization modes alongside the best use of the territory's framework for its transport network. Figure 3.11 shows this territory at a given geographical scale (for example at the scale of a district, commune, etc.). It is broken down into meshes identified by an {x, y} reference (Figure 3.11(a)). Two territory meshes are considered, M_I and M_J, and will be studied from the perspective of people (termed transport "users") mobility. For a given time period (for example from 08:00 to 09:00 h on a working day), a certain number of users in mesh I will travel to mesh J (Figure 3.11(b)). Different transport schemes, inherent to this demand, will be analyzed.

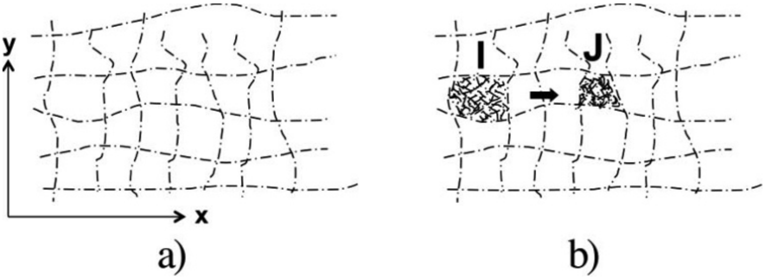

Figure 3.11. *Mesh for a territory using an {x, y} geographical reference*

3.4.1. *Scenario 1: private transport*

In the first scenario, every user behaves independently by using private means of transport. Figure 3.12 shows all the users moving in the geographical and time window considered:

– Figure 3.12(a) shows their original (mesh M_I) and final (mesh M_J) geographical positions.

– Figure 3.12(b) shows the individual scenario for each user, who moves from their point of origin to their destination in an autonomous way, by means of a private vehicle (typically a motorcar).

– Figure 3.12(c) shows each user's itinerary; in practice, they must use the infrastructure that specifically allows them to go from M_I and M_J (typically roads), which they share with other users who are moving along the same itinerary during the time slot considered. Among the different possible combinations of infrastructure, the itinerary is chosen by each individual according to various criteria: distance, time, probability of traffic congestion, etc. The users traveling alongside the individual being considered originate from the same mesh M_I and are traveling to mesh M_J in the same time slot.

– Figure 3.12(d) shows that other users from different origins and/or going to different destinations also use the same infrastructures at the same time.

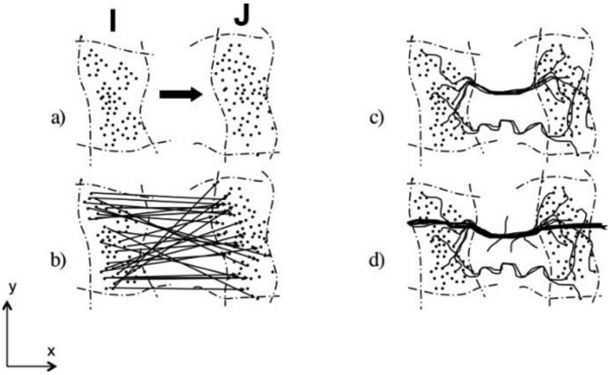

Figure 3.12. *Individual users traveling between two territories over a given period of time, using private modes and road infrastructure*

3.4.2. *Scenario 2: organized public transport*

The second scenario introduces a layer of organization. It consists of taking advantage of the ability of coordinating collectively to combine mobility needs on the one side, and transport offers on the other. Figure 3.13 shows mesh M_I divided into smaller geographical districts, S_{I1}, S_{I2}, …, S_{In}, which will guide the implementation of this organization:

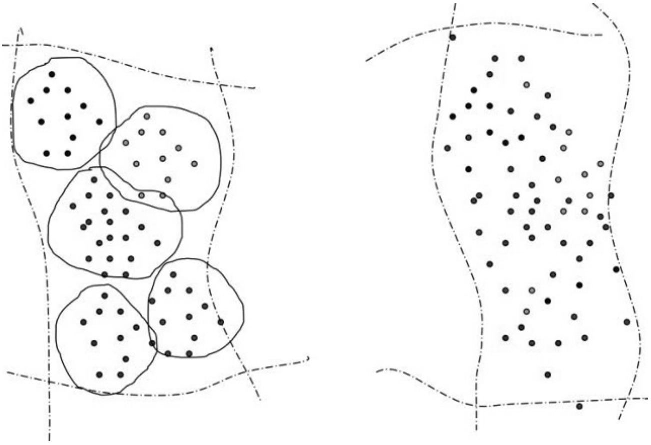

Figure 3.13. *Structure for a mesh of locally managed geographical districts by grouping users*

As shown in Figure 3.14, a center of gravity is defined for each of the districts S_{Ii}, which will be simultaneously the district's point of attraction and its point of connection with other connected districts; in particular, it permits starting and arrival user flows to be organized outside the district (Figure 3.14(a)). Transport going from a point of origin to this center of gravity, for each user within the district, can be achieved in two ways: either by organizing "round" (Figure 3.14(b)) or "pendulum" individual transport (Figure 3.14(c)). Organizing rounds implies that the approach is collective and uses a motorized road vehicle (with exceptions). Examples include school buses, mail rounds or collection of household waste. Pendulum individual transport relies on personal initiative and uses individual modes (usually walking for the movement of people, or often a mode on wheels for the transport of goods).

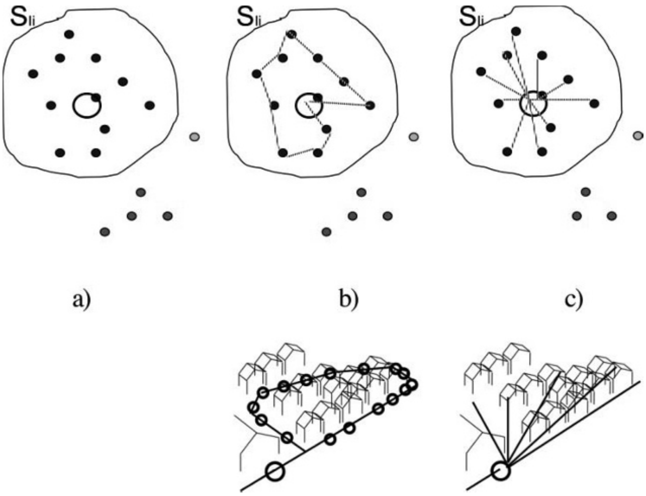

Figure 3.14. *Structure for local organization of transport within district S_{Ii}, in round mode (b) or in pendulum mode (c)*

At the next intermediate territorial level, a second transport mode can be imagined to link the centers of gravity or of concentration in the various districts S_{I1}, S_{I2}, …, S_{In}. This transport mode allows the district's transport needs, with regard to the nearby or faraway environment, to be integrated into a level of massing[22], which makes it more efficient. Districts can thus be linked to nearby districts via paths connecting the centers of gravity point by point. It guarantees links between the district's geographical area and neighboring districts, or platforms providing access to a variety of other transport modes. Organizing the chain of points well, involves transport infrastructure, vehicles and operating modes that are pertinent to guaranteeing it effectively. It also requires the implementation of interface infrastructure (station, platform, car parks, etc.) at given points, which

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[22] Here, massing is defined as concentrating a higher transport capacity on the same type of vehicle and/or the same transport system. The system or vehicle is thus made more efficient in terms of cost (energy, economic, resource immobilization) per unit transported.

allows vehicle parking and a fluid transfer (loading/unloading) of people (or goods). It also requires the ability to manage associated data.

At still higher territorial levels, another transport mode serves other meshes in the territory, and its performances are more pertinent to the distance, speed and operating requirements implied by the scale. This mode is also connected to the previous mode by means of one or more communal stations, which provide a platform for transfers. These stations must be sized accordingly so as to guarantee output rates and a service quality, which are compatible with the needs related to the capacity permitted by modes and required by serviced territories.

Figure 3.15 shows the following different levels:

– Figure 3.15(a): the intermediate transport mode passes within mesh M_I by connecting the districts in the mesh, via a round mode.

– Figure 3.15(b): the transport modes in this mesh interact in order to guarantee transport at three different scales: from a microscopic scale (in this case, a local round) to the scale of movement between meshes (in this case, a heavy mode), via an interchange station that gathers several transport modes that differ from each other to varying degrees.

– Figure 3.15(c): with regard to the mesh M_J, connected to the same heavy mode, it is also connected to other heavy modes by an interchange station. These other heavy modes serve and innervate mesh $M_{J,}$ and are structured in a similar way to those in mesh M_I.

– Figure 3.15(d): an interchange station links other heavy modes somewhere along the heavy mode, which covers the variety of needs for long-distance mobility.

The scenario for organized public transport therefore bases itself on a hierarchical structure that uses interconnected transport modes, linking different territorial scales, from local to global scales.

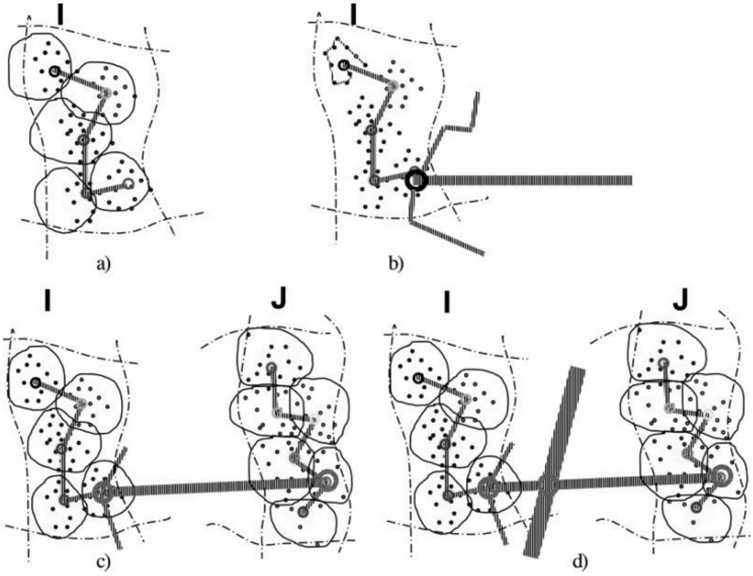

Figure 3.15. *Example of the way in which massed transport modes are articulated for each territorial scale, between "origin" and "destination" meshes*

3.4.3. *Comparison of the two scenarios*

From the user's point of view, both scenarios are capable of ensuring the mobility required. However, they both imply two very different underlying choices in terms of organization and mobility market. Their respective performances depend on a set of complex parameters and interactions, some of which are determined by the infrastructure's characteristics, others by the cooperative ability to coordinate and organize the mobility demands or transport supply. With regard to the mobility demand, in Chapter 4 its characteristics and private and public dynamics will be discussed. With regard to transport, Chapter 5 will discuss how it can evolve by a combined effort on vehicles, infrastructure, organization and governance.

When the two scenarios are compared, a clear conceptual difference emerges. Private transport enables users to travel door-to-door by using road infrastructure, which is the only one to service all origins and destinations. Organized public transport involves the ability to articulate transport modes, coordinated at interfaces, with each mode being optimized in order to provide the best possible service at the relevant scale, from microscopic (local districts) to macroscopic (territorial or planetary) scales. Coordinating and juxtaposing these transport modes at different scales are a strategic challenge in terms of public policies, organization and equipping with vehicles and infrastructure, and all territorial and administrative levels (from local to global).

The scenarios can be compared by means of indices and indicators that permit their respective performance in terms of sustainable transport to be quantified or objectified:

– quantitative values: travel time, travel cost, required energy and resources (land, equipment, maintenance, etc.), gas emissions (CO_2, NO_X, PM (particles), etc.) and sound emissions (dB(A));

– qualitative values (comfort, flexibility, accessibility, acceptability, robustness, resilience, etc.).

For example, {origin; destination} matrices are broken down into the various meshes in Figure 3.11. In the given time slot, a number of individuals x_{ij} are transported from mesh M_l to mesh M_j. For the chosen scenario, it is possible to calculate the average value of parameters: their travel time t_{ij}, travel cost c_{ij}, emissions of CO_{2ij}, NO_{Xij}, PM_{ij}, noise emitted B_{ij}, etc. By integrating these values over the whole territory, the performance of a transport scenario in the territory can be assessed and can form a basis for the comparison of other organizational scenarios. Although these calculations can quickly become tiresome, they nonetheless provide the foundations for the quantitative comparison of different options, in addition to qualitative considerations.

Figure 3.16 illustrates how the two scenarios can be represented at the scale of the entire territory. The continuous lines represent the different levels of massed public transport corresponding to different territorial levels and their connections. The dotted lines represent the path of private road transport. Two pairs of points have been sketched to link the Origin O to Destination D: points O_1 and D_1 on the one side, and points O_2 and D_2 on the other. In this figure, organized mass transport exhibits similar performances to connect O_1 to D_1 and O_2 to D_2. On the contrary, the performance of private transport is completely different: trip 1, from O_1 to D_1, is four times longer than trip 2, from O_2 to D_2.

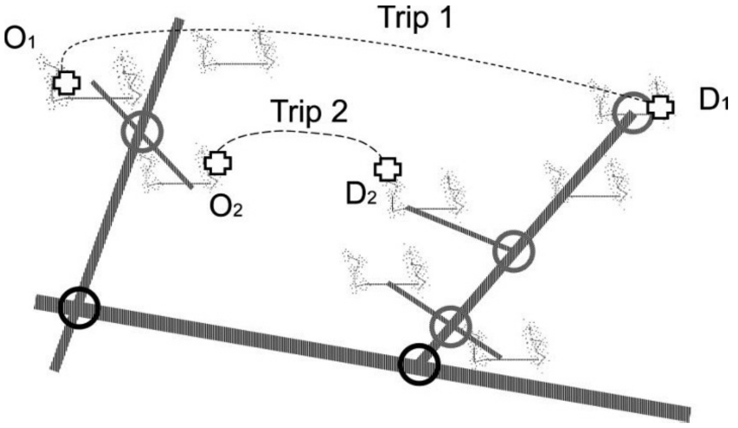

Figure 3.16. *Diagram of the how transport modes are structured according to scale, from local to global*

3.5. The transport of goods

The transport of goods lends itself to a conceptual approach analogous to that of the transport of people. However, there are several important and noteworthy differences:

– First, goods are not capable of being autonomous. They must be accompanied by the appropriate means (of transport) from start to finish, as well as during transshipment using specific operating, carrying and storage methods, etc.

– Second, the transport of goods is not (usually) a reversible process: each trip is a “single journey”, which accompanies goods in the circle of added value, from raw material to end user product.

– Third, other types of “one-way trips” concern the systems that manage waste evacuation and recycling, and containers, and containers (packaging, cases, containers, etc.).

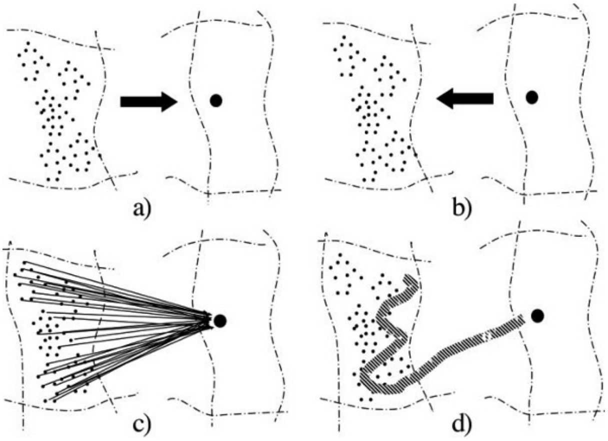

Figure 3.17. *Diagram of the transport of goods from provider to client*

Figure 3.17 shows applications for goods transports. The aim is to supply one industrial establishment from a set of providers (Figure 3.17(a)) or to service end users from a logistic depot or a shopping center (Figure 3.17(b)). The same directing principles are applicable; the first scenario (that of individual transport) is shown in Figure 3.17(c) and the second scenario (that of mass organized transport) in Figure 3.17(d).

For the latter case, complementary means of transport are articulated at different territorial scales, as shown in Figure 3.18:

– Figures 3.18(a) and (b), respectively, show round and pendulum modes at a local scale (“first” or “last” kilometer); vehicles used for rounds must have a larger capacity than those used for pendulum modes (for example a utility vehicle weighing 3.5 metric tons[23] instead of a car).

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[23] A total of 3.5 metric tons when fully loaded.

– Figure 3.18(c) shows an intermediate scale (here the example of a round using a vehicle with a larger commercial load capacity, a truck with a total rolling weight of 19 metric tons, with the aim to serve different local platforms on the one side and a grouping platform on the other).

– Figure 3.18(d) shows a global scale in which grouping platforms are interconnected by massed heavy road, rail and maritime modes, connected together at multimodal platforms, which guarantee that the different modes are articulated, and which are provided with the necessary handling means to transfer goods.

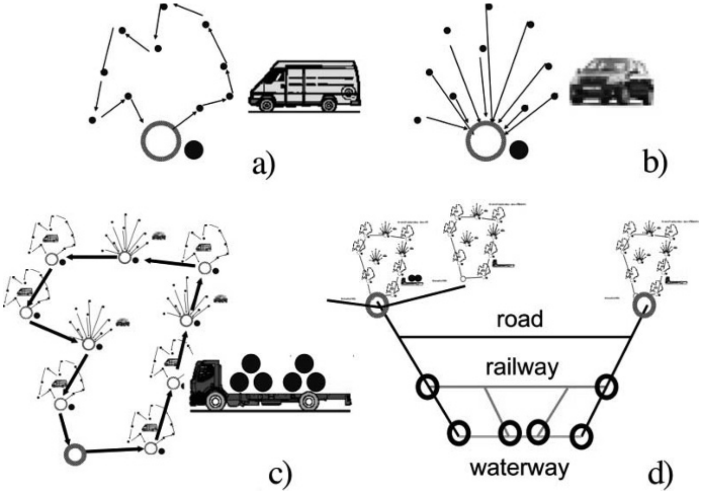

Figure 3.18. *Transport of goods, example of how it is structured at different levels [FAV 13]*

Figure 3.19 shows a diagram of this organization's different systemic levels. The local modes consist of road modes. Roads are also the main modes at intermediate scales, at which they complement railways, which can take over wherever they are present. At large scales, roads and railways can be replaced by waterways or airways, which are also the only possible transport modes for intercontinental scales. Figure 3.20 illustrates an example (movement of mail).

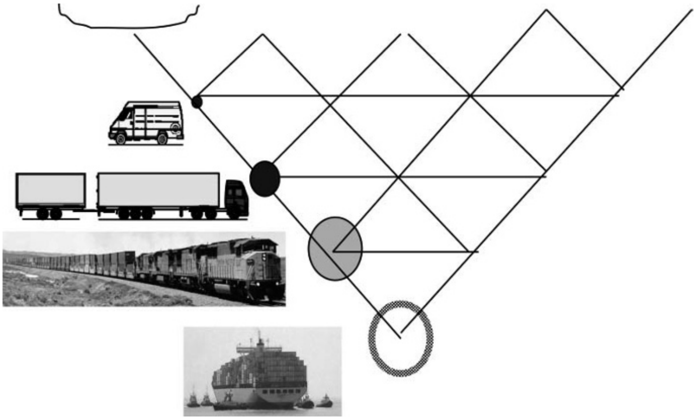

Figure 3.19. *Transport of goods, levels of massing from local to global [FAV 13]*

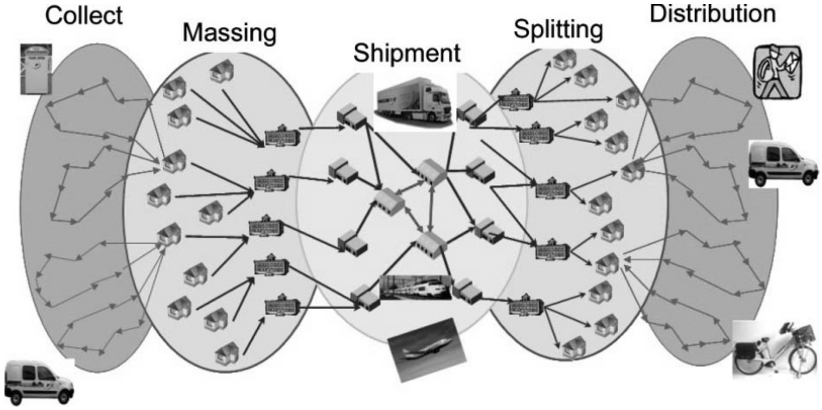

Figure 3.20. *Diagram of a "provider to client" transport scheme Organization of La Poste [LEN 09]*

3.6. The prospects for sustainable transport

This systemic approach to transport schemes highlights several characteristics of the way in which they are structured.

First, it is necessary to identify the *different territorial scales*. The radius of action for different transport modes, and structuring infrastructure into technical and administrative levels highlight that these scales must be read clearly, leading to solutions adapted to each scale level. Long-distance transport starts – and ends – with local adaptation, which must be compatible with the short-distance transport supplying local areas. Each scale is associated with a portfolio of modes that are preferentially adapted to it.

A second characteristic concerns the *close similarity* between diagrams for *the transport of people and that of goods*. Organizing them into a structure overlaps perfectly, even if there is a variation in the means that require, for example, specific vehicles or transfer processes, or particular operating modes for infrastructure. Transporting from an origin to a destination is performed according to the same diagrams for people and goods.

A third characteristic concerns the equal importance of *transport sections* (corridors) and *transport nodes* (platforms that provide transfers and connections). A transport section is aimed to output flows. The speed and density of these flows are related. The section is bound by two ends: transport always starts at some point to finish at some other point. "Some point" is a connection point, single interface point or a connector: buffer zones in which flows slow down and separate, mixing zones that need to be organized, meeting zones where something happens to enable the transit, transfer, draining and structuring of flows. The performance of these nodes determines the overall performance.

Finally, the variety of origins and destinations can only be covered by a combination of transport solutions that guarantee two functions: *local draining accompanied by global massing*. The combination's performance depends on the performance of necking points with respect to the outputs required (balancing offer and demand). In particular, it is necessary to suppress these bottlenecks, whether they are of technical, organizational or socio-economic nature, or whether they concern vehicles or infrastructure, sections or nodes.

In total, developing solutions for sustainable transport demands that these systemic relationships be well understood. The serviceability of transport systems is strongly controlled by the harmonious connection of its elements and by the fluidity and homogeneity of its interfaces. This overall juxtaposition defines their efficiency in terms of transport capacity (flows, speed, costs) between points of origin and destination. It also prepares for the objectives related to transport's environmental impact to be reached. Analyzing systems shows which scenarios are most pertinent to minimizing the associated energy costs, and gas and noise emissions, for each mobility unit satisfied (passenger.km, metric ton.km, m^3·km, etc.). As a result, the strategies that must be implemented to minimize the negative effects of transport in the context of rational transport are understood.

Chapter 4

Can We Organize Sustainable Mobility?

According to a theory known as Zahavi's conjecture[1], daily travel is made at constant travel time: the distance traveled is therefore a function of the speed of travel. With the acceleration of transportation performance, it is not the time spent on mobility that decreases, but rather the distance that increases. Although this theory is widely debated (especially in its social dimension), it is very widely used for examining the issue of daily (urban) travel and can also be adapted to the occasional longer mobility on longer (intercity) cycles.

Specialists in transport economics associate the issue of speed with that of travel time budgets to understand past trends and likely future inflections in terms of mobility; they find that the close correlation between economic growth and mobility is equivalent to a hypothesis whereby speed gains feed into the trend of increased distance traveled [CRO 12a]. In many developed countries, the distances traveled by private car are no longer increasing – not because total mobility has decreased, but because travel has shifted to faster modes such as high-

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[1] From 1970 to 1980, Yacov Zahavi published a series of works for the World Bank, which suggested that monetary and temporal transport budgets are consistent worldwide. From his conjecture, the average travel-time budget is approximately 1 h, and the average monetary budget is 5% for non-motorized households and 15% for motorized households. This theory, however, is controversial (see, for example, [HOU 06].

speed trains or airplanes. This would be a structural trend that could be interpreted by deciphering the history of modes of transport as a series of technological waves: with each new wave, a new mode of transport would increase its market share at the expense of market shares of other slower modes. After a certain level of development, this mode would, in turn, cede its place to another faster mode.

It is essential to understand mobility, its motives and its procedures in order to identify the actions that will help satisfy it by developing the means of this mobility: transport, with its attributes – vehicles, infrastructure, organizations, players, etc.

Similarly, this analysis opens up avenues to suggest solutions that do not concern transport as such, but that would result in moderation of the need for mobility, with its effects on transport. With an approach that is both microscopic and macroscopic, we dissect the status and trends of mobility in its societal context. We are led to touch on related fields such as spatial territory, public policies, industrial policies and consumer behavior.

As everything is connected, the complexity of these interactions exceeds the scope of this book because a comprehensive discussion would involve going into too much detail about each of the specific areas. We will limit ourselves by giving only a causal view of this much larger picture and discussing only certain aspects of it in detail. We will focus on what helps encourage sustainable transport. Transport can indeed become sustainable:

– either by changing its ingredients (vehicles, infrastructure, organization) in the context of a transport system, which we have already mentioned in Chapters 2 and 3;

– or by changing its “driving force”: the expectations in terms of mobility and the determinants of these expectations, which are covered here in Chapter 4.

4.1. Understanding mobility

The microscopic approach is illustrated in Figure 4.1. It represents the {space-time} evolution of one user among many users, observed over the course of a day, and his/her relationship with the movements he/she carries out or causes during his/her daily lifecycle. All occurrences of daily life are each punctuated by acts of movement, either of people or goods, in order to satisfy the needs of mobility or other individual needs. They result in acts of transportation. These acts correspond to individual or collective organizational choices, and also obey the rules of economic, organizational or functional order. Individual expectations and demands in terms of mobility result in pressure on the transport system. The use of a mode of transport affects the balance between individual freedom and collective organization. A user is alternately a motorist, a pedestrian, a neighbor of transport routes when at home or at work, a consumer of goods that must be transported and which the user wants at the right place at the right time, a witness to or user of “collective” transport modes. The user also has a task of which logistical needs must be satisfied. This also causes the intervention of professionals – craftsmen, delivery staff, etc. – who in turn use a means of transport to satisfy the request. This type of analysis highlights the contradictions that coexist in the same individual between different requirements. As residents, we are bothered by noise caused by other road users. When we become road users, we are hampered by congestion caused by other road users or by trucks transporting goods to deliver supplies to the home, to the office where we work or to the shops where we buy. This analysis also shows the possible impact of a change in individual behavior on transportation needs (for example changing purchasing habits and avoiding taking the car to go to the shopping center in the evening after returning home).

Figure 4.2 is a variant of the previous example. It illustrates, by spatiotemporal representation of trajectories in 24 h, the comparative mobility “performance” of two types of users: a cyclist and a pedestrian. It shows the relationship between mobility capacity and available transportation. The distance covered by walking is naturally less than that of a bicycle, let alone of motorized transport.

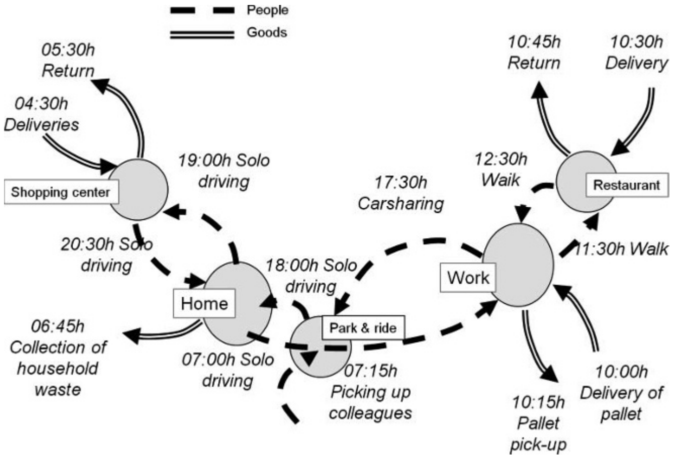

Figure 4.1. *Example of acts of mobility brought about during the day of an individual*

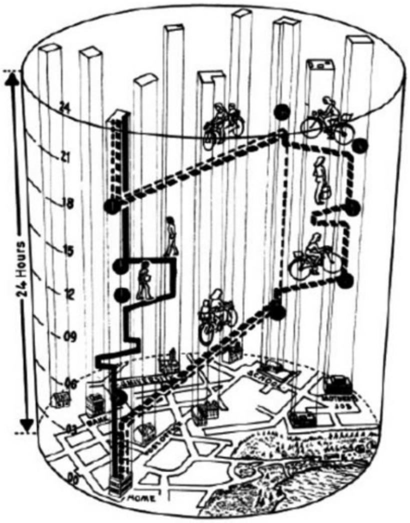

Figure 4.2. *Difference in action range between a pedestrian and a cyclist ([LEN 78], reproduced by Parkes and Thrift [PAR 80])*

These microscopic mobility analyses can highlight many features of individual behavior and requirements in terms of mobility. They apply, for example, to the establishment of specific requirements for the design of infrastructures or interconnections between transport modes, taking account of individual mobility characteristics of users (including people with reduced mobility). On a larger scale, they apply to the observation of social groups (same neighborhood/using the same infrastructure – the same mode of transport, etc.)[2].

The macroscopic approach, meanwhile, was developed to understand mobility on different territorial scales. It combines observations and simulations with a wide range of indicators. It arises from surveys and macroeconomic data from various sources relating to individuals, households, "institutions" (commercial/industrial/utility fields), infrastructure, urban planning and observed prices (transport surveys, "household" travel surveys[3], censuses, etc.). On the one hand, it enables us to establish the state of mobility in the neighborhood, town or territory. On the other hand, it can also project estimates for mobility in order to assess the consequences of decisions (political, economic and technological) compared with over-the-water trends. A detailed example of this is provided by the SIMBAD[4] project funded under the PREDIT[5] framework program: the project, including portions from previous works on the functioning of the Lyon region, highlights tensions between local and global challenges from observation of the operation of an urban area in terms of "weekly mobility" (related to work–life balance). The project arises from the mapping of housing, populations and households and of employment and economic activities. It measures goods' trade in the city,

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[2] For example, Hubert and Toint [HUB 02] published the results of a survey of 2000 Walloonians about their trips according to the type of day (school, holiday, national holiday) and their motivations.

[3] For example, the "household travel surveys" conducted in France, Lyon and Lille by CERTU.

[4] SIMBAD project – simulating mobility for sustainable urbanization (from the French: SImuler les MoBilités pour une Agglomération Durable), Economy and Transport Laboratory, LET-University of Lyon and Urbanism Agency of Lyon, in July 2009 and its development. The aim is to provide a tool for simulating policies that affect urban traffic to ultimately provide a relevant highlight of the economic, environmental and social impacts of these policies in an urban area over a span of 25 years.

[5] PREDIT – program for research and innovation in land transport (from the French: Programme de Recherche Et D'Innovation dans les Transports terrestres) – is a national (France) animation and R&D funding program in the field of transport, arising from the initiative of Ministries tasked with sustainable development, research and industry; of ADEME; of OSEO; and the National Research Agency.

exchanges related to the mobility of residents, transit traffic and trade flows with the outside world. It determines the distribution of traffic between peak and off-peak hours to take the impact of congestion into account. It produces an exchange matrix for the allocation of traffic between road networks and public transport. The results are used to estimate impact indicators of the transport system on environmental, economic and social dimensions. We can, for example, accurately estimate mobility costs for each group of households (according to income class and location) from the ratios of vehicle emissions units.

Urban sprawl issues and their impact on energy consumption and greenhouse gas emissions related to mobility, which are exerted on such a territory, are also included. In particular, the dominance of the car for suburban travel, the role played by public policy in terms of infrastructure, pricing of public transport, the issue of land policy and economic establishments; all these issues are to be taken into account to better understand the ingredients of mobility.

Other projects are aimed at other types of mobility (weekends, holidays, etc.) with the issue of air traffic increase and high-speed modes with respect to CO_2 emissions for industrialized countries. Long-distance journeys, which are less frequent but much larger consumers of fossil fuels and CO_2 emitters, are therefore also a very significant part of people's mobility. Figure 4.3 shows an overview of individual emissions related to traveling of the French. We can easily distinguish the differences between positioning and behavior, especially due to the differential use of the car[6] according to cities and territory sizes. *Mobility is related to commuting* structures and generates a significant proportion of CO_2 emissions. In 2008, it accounted for 57% of emissions for weekly local mobility[7] [LON 10]

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[6] Studies show a change in individual behavior. In particular, we note:

– a reduction in the use of cars in the city compensated by public transport and soft modes;

– but at the same time, a significant and upward trend of car trips in the periphery and outside of cities linked to the issue of urban sprawl.

Between two origin/destination points in the greater Paris area, 90% of journeys are made by car, compared to 35% within inner Paris [WBC 04].

[7] The average range of movement in Ile de France increased by 40% in 26 years (between 1975 and 2001) [BRO 13].

(followed by purchasing behavior). The highest CO_2 emitters for transport are “active young homeowners in a family where the couple are both earning, working full-time with a contract of indefinite duration, living in an area that is not served by public transport, and possessing two or more cars...”[8] [ORT 12]. In parallel, some of these “car captives” are at risk due to the large share of their income spent on transport: in times of economic crisis and increase in transport costs, they have a high risk of being in financial difficulty in the absence of real alternatives[9].

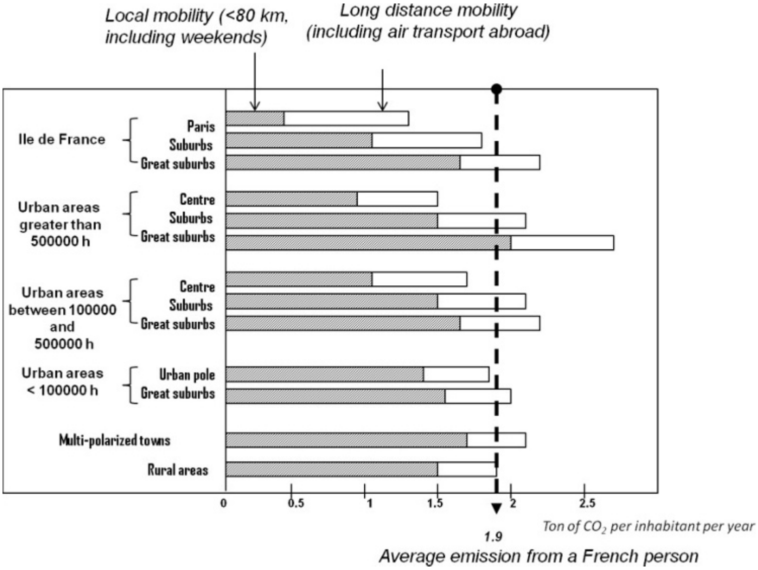

Figure 4.3. *Individual emissions of French inhabitants from traveling (metric tons of CO_2 per inhabitant per year) [CER 11c]*

4.2. Principles of sustainable mobility

It is imperative to question the sustainability of a mobility that would only increase. The review of sustainable mobility principles leads us to revisit both the objectives of mobility and the (transport)

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[8] In January 2013, the website www.recensement-2009.insee.fr published the results from INSEE showing the distribution of commuting in France in 2009.

[9] We have begun to define a “household vulnerability factor” for those who spend more than 16% of their income on transport [FAI 13].

means. Sustainable mobility has the virtues of maximizing efficiency combined with minimizing the negative effects in the multidimensional contexts of society, economy and environment. It concerns people and goods, daily and occasional, urban and intercity.

Let us start with the aims of mobility: we must therefore re-examine its rationale.

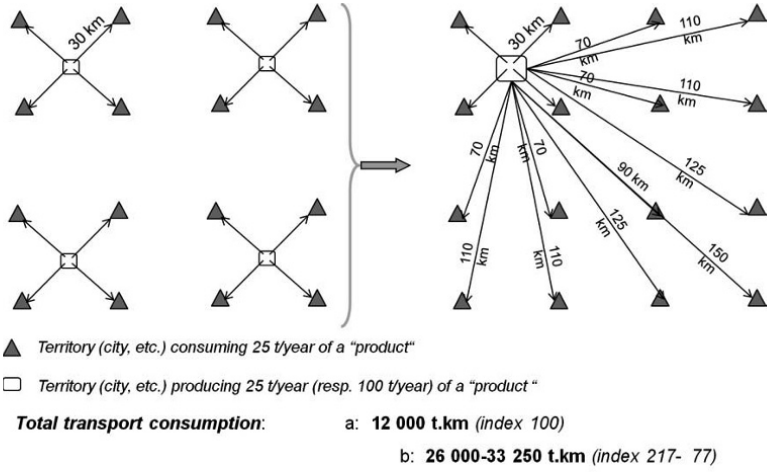
For people, we have seen that “urban” mobility (which includes the territorial basin of cities) is strongly linked to behaviors governed by commutes between home and work, bound from complementary daily behaviors, often associated to the former and scheduled according to a daily or weekly cycle (purchases of goods, transfer of children between home, school and recreational areas, etc.). This mobility is governed:

– on the one hand, by territorial locations of activities (housing, employment, public and commercial facilities), for which the rate of change can be very slow, in line with assignments and changes of land and construction of infrastructures;

– on the other hand, through uses associated with labor organizations or cultural behaviors for which the rate of change may be more significant and are sensitive to the costs and billing of mobility. The development of teleworking (working from home), tele-presence (remote monitoring), e-commerce (home delivery) are examples of these developments.

“Intercity” mobility of people is dominated by irregular professional or family reasons, as well as behaviors related to recreation and “travel”, punctuated by a seasonal or annual cycle. It is difficult to see how these reasons will reduce over time: global mass tourism only reaches a small part of the population in the long term, and its growth rates are spectacular outside geopolitical uncertainties. As for business travel, these are particularly related to the expansion of international trade and the business associated with it.

“Mobility of goods” is conditioned by the geographical location of production areas, transformation basins and final consumption basins of different types of goods, whatever their nature may be: primary materials, intermediate goods, consumer goods, etc. The rate of change is also very slow, in line with that of raw material deposits (agriculture, mineral deposits, energy resources, etc.), locations of conglomerates and heavy equipment (China, “the world’s factory”?), skills basins (Silicon valley (USA) for high tech, Arve Valley (France) for cutting, etc.), regional cheap labor and consumer basins (urban cities, particularly those in countries with high purchasing power).



a) b)

Figure 4.4. *Effect of centralization of sites relative to the consumption basin of mobility of goods [BT 67]*

For example, the simple calculation shown in Figure 4.4, taken from a pedagogical logistical economy exercise in the 1960s [BT 67], shows an aspect of industrial development: centralization can greatly increase the need for mobility of goods, so it directly affects transport. If we replace four local suppliers (Figure 4.4(a)) with a single centralized supplier with the same cumulative capacity (Figure 4.4(b)), the transport required to get these goods to the delivery area (here expressed in metric tons per km) is doubled. This reasoning can be transposed to all levels, from local to global. It can also be transposed to all platform facilities providing grouping functions or distribution of persons or goods: airline hubs, logistics platforms, etc.

Evolution of the mobility of goods is also linked to production practices, industrialization of merchandise and consumption. Here, various trends with contradictory effects become clear, which could change things significantly or substantially in the medium term:

– changes in cost of transport are naturally a major adjustment parameter, which can move quickly. However, the cost of transporting products is not usually the main cost of a product on the shelves (compared to the cost of production, marketing, packaging, etc.)[10];

– consumer choice for lighter products with greater technological content and the use of largely standardized products with easily reproducible motives modify product supply demands;

– decentralizable production means, which combine extensive use of digital and manufacturing processes for high tech (for example printing in 3D), could create new opportunities in terms of recovery circuits;

– "e-commerce", with considerable effects on logistics, experiences remarkable growth.

So, these are all aspects of a progressive and multidimensional logistic mutation.

What about means for mobility? We must seek more effective solutions, and this question is for transportation systems. Let us emphasize at the outset that different types of solutions exist, if only through the low rate of "filling" of vehicles for individual use, which could be improved. On notable trends, we are also observing a gradual decoupling of, on the one hand, personal possession of a car, and, on the other hand, its use. Accompanying the gradual shift of object-car to service-car is certainly an issue for future years. In developed countries, it is possible that from this point of view, we have reached

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[10] The cost of the "last mile" transportation of yogurt may be similar or even higher than the cost of transport over the whole production chain [RIZ 05].

"peak-car"[11]. As for infrastructure, their saturation is not imponderable. An operation introducing a rational dose of "intelligence" would significantly (even strongly) increase capacity. This feature helps reduce pressure on the need for new infrastructures. These now meet specifications demarcating those from previous decades (this is the meaning of activities related to "5th generation road"[12]). Implementation of public policies that ensure a coordinated combination of incentives and regulations to encourage the use of more virtuous modes is also on the agenda. The economic stakeholders are also required, their role is to strengthen and ensure the effectiveness of linking different modes of transport (interoperability and modularity) and thus promote the most relevant cross-references in terms of sustainable mobility.

4.3. Massification

The French term "*massification*", with a pejorative connotation and untranslatable into English, underpins a major underlying principle of optimization of sustainable mobility: it groups entities with the same mobility "intention" in order to maximize transport efficiency and minimize economic and energy cost. It is based on evidence that a single, correctly filled vehicle can do the same "work" as several under-filled vehicles. It also takes into account the fact that transport efficiency increases with size (of the vehicle and/or its load)[13]. It also

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[11] The point at which the car market (or car park?) begins to decline [MEY 12].

[12] The R5G project is supported in France by IFSTTAR and develops through various initiatives: FOR (FEHRL), reFINE (ECTP) and i-Mobility (ERTICO). A strong Franco-German cooperation emerges on this subject (2013).

[13] At a similar transport performance (for example, at same speed of operation), the amount of energy to carry a "useful" item (1 person, 1 metric ton or 1 m^3 of goods) is much lower if these elements are combined, "massified" into the same vehicle. This is due to the ratio between the {mass and/or midship} of the unladen vehicle and the {mass and/or volume} available for the vehicle to be loaded with goods. Given the laws of physics (regarding aerodynamic drag, rolling resistance, the mass of structure which is necessary to carry static and dynamic loads, etc.), these principles apply regardless of the mode of transport (land, air or water). They justify the search for solutions based on larger vehicles that can carry more with less energy cost per transported unit. For example, a fully loaded lorry carries eight times more useful load than a fully loaded car when compared to their mass when empty. The ratio is 1:0.35 for the lorry and 1:3 for the car.

increases with density of vehicles when they are organized as systems, managed such that they are coordinated and coupled (for example vehicles assembled in trains by real or virtual links). This principle addresses a variety of situations of use (people or goods); it applies to facilities, such as vehicles, and is available to each territorial or temporal scale. *Implementation of the massification principle*, where possible, leads to a considerable increase in the efficiency of transport systems. It implies, of course, associating entities to be transported for which the mobility project is compatible, with the requirements of effective massification: same origin and/or destination, time windows compatibility, transfer efficiency at the extremities according to modalities as discussed in Chapter 3.

Figure 4.5 illustrates this dramatically. It shows that between different combinations of vehicles to transport 75 metric tons of freight, the configuration based on “massified” vehicles (total authorized vehicle weight of 40 metric tons) emits nearly 10 times less pollutants than a combination based on 3.5 metric ton utilities vehicles and occupies 5 times (static) to 15 times (dynamic) less linear infrastructure space[14].

We must therefore understand massification as a general principle for improving the efficiency of mobility, which can be used at all territorial and temporal levels of the transport system:

– better filling of vehicles, tending toward saturating useful mass or volume. The benefit may be in the order of four (that is to say four times more efficient, which is four times less fuel per transported unit[15]);

– the replacement of a set of smaller vehicles by one larger vehicle, for which performance is improved for each transported unit[16]. The profit in efficiency can be important, in the order of 10 to give an

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[14] This effect is demonstrated in particular by ADEME, see IMPACT 2000 study.

[15] This is the case for a car with four occupants, compared to a car with one.

[16] This is the case for buses compared to cars or Airbus A380 “jumbo jets” compared to their smaller long-haul mail equivalents or “double-deck” rail carriages compared to single-level carriages. See also Figure 4.5.

idea[17]. The environmental benefit is yet more significant, but varies according to the impact indicators considered (gaseous emissions, noise, vibrations) [18];

– operating in convoys of coupled vehicles rather than isolated independent entities. The benefit is not only about energy efficiency (it makes gains on reducing aerodynamic drag of each vehicle due to its proximity to previous and/or following vehicles), but also and especially on operating efficiency (it optimizes the use of infrastructure, which can transfer bigger flows)[19];

– the allocation of necessary resources at the interfaces between vehicles, infrastructures and platforms (doors and doorways, rags, bridges, docks, pavements, corridors, airlocks, etc.). Indeed, the increase in efficiency of travel itself helps relieve transport corridors by increasing flow efficiency. It reduces environmental impact by linear path[20]. The counterpart of these benefits is an increased pressure on the exchange capacity at the interfaces, which in turn require more output. Massification pushes toward paying particular attention to these often overlooked elements;

– the parking and storage of vehicles and their loads, adapting them to larger vehicles or combinations (length, surface, etc.), but fewer and

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17 It takes a consumption of 1 l/100 km to the useful metric ton transported on a maxi-code truck, while the equivalent with individual cars is about 20 l/100 km. For a cargo plane, consumption of 90 l/100 km to the useful metric ton transported 2,000 km for a plane of less than 100 tons of maximum take-off weight (MTOW), it is 57 l/100 km for a plane of 250 tons of MTOW [DGA 13].

18 Emissions (gas, sound) from a large vehicle are substantially smaller than those of all small vehicles of similar technology which it replaces, but obviously higher than those of these small vehicles. For some environmental impact indicators, which are based on peak level rather than average level, the benefit is controversial. This is the case for acoustics, as it is the average energy equivalent that is addressed LeqA and LMAX as wrongly edited here. See original note with right characters. "This is the case for acoustics, as it is average energy equivalent that is addressed (Leq_A) (where massification is largely favorable), or peak noise (L_{MAX}) (where it is slightly "unfavorable) [FAV 84].

19 For example, a rail sees its rate doubled when operated with double rather than single train units.

20 Here, we mean the amount of pollutants emitted per unit length of corridor (for example number of gCO_2 h/km, number of gNOX h/km, sound power level Lw in dB (A) per linear meter).

of reduced impact (in terms of overall environmental footprint and land occupation).

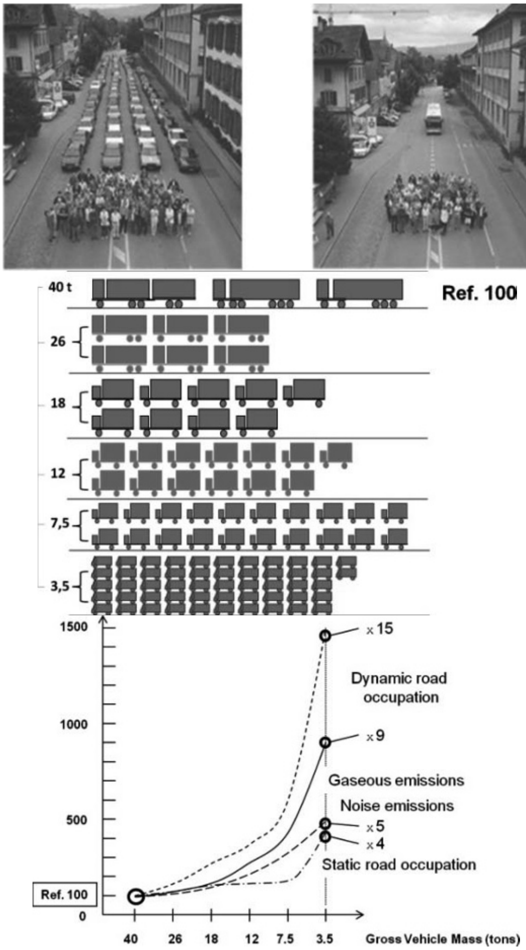

Figure 4.5. *Illustration of the principle of massification: (top) a bus provides transport equivalent to dozens of cars carrying only their driver; (bottom) the different combinations of vehicles each carry the same load (75 metric tons), but their impact (emissions, congestion) is very different, the best performance is the most massified vehicles [LUT 11a]*

The concept of massification therefore declines according to space (area, urban metropolis, interregional, international, etc.) and time (peak, off-peak, night, weekend, etc.), by looking at each place, at each time, and finding the best balance between the needs for mobility and the transport on offer to provide the means to satisfy them. When it comes to better filling of vehicles, assigning properly sized vehicles, operating vehicles and their infrastructures in a coordinated manner and facilitating exchange interfaces, the tools are different but the principles remain the same. Their full capacity requires the provision of useful information to make these tools fully operational, and it can be used by stakeholders whose involvement is required for implementation.

4.4. Developing, pooling and using data to attain sustainable mobility

We must especially exploit[21] the necessary information to make the most out of the potential effectiveness in sustainable mobility that we have just stated. However, these data are numerous, of various origins, and are produced and owned by different public or private providers.

A case of application dealt with extensively is *travel arrangements for a user* who consults, via the Internet or smart phone, a database of multimodal information[22]. This is likely to provide the best proposal to meet the demand in both economic (cost and travel time) and environmental terms (for example CO_2 footprint). The proper supply of theoretical (for example schedules) and circumstantial (actual state) content to information systems is essential here; it requires a structure for acquiring data that is open to providers of these data and is of great reliability. This opening is also necessary to enable the distribution of content via new media, including mobile media[23]. A number of multimodal public networks now have this type of feature, which facilitates the organization of journey sequences during the same trip, using multiple modes of transport to be linked between each other.

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[21] The usable data form deposits can be imagined like the operation of a mine: search, identification, extraction, separation, refining, densification, integration into the product, marketing.

[22] All modes of transport are likely to be addressed.

[23] Among many examples, let us cite the BreizhGo multimodal information system that provides the general public with all data related to Breton regional transport offers, including those of the “data warehouse” in the public domain of Rennes metropolis and the city of Rennes (France).

This problem of access to intermodal information is obviously closely linked with that of supply when tenuous: this is the case in the outskirts of cities or at night when the scarcity of public service makes traveling more delicate. It is not, however, summarized to that since there is also a problem of exchange in large centers (urban metropolitan hyper-centers, multimodal hubs, logistics platforms) where in contrast, the abundant information supply creates complex environments, through which we seek to optimize a path of travel.

A user of mobility services is a requester of “service-based” continuity, meaning the integration of all services that will be used during the trip. Beyond the mass of data that must be addressed at national or European level, there is no natural integrator. Who will provide this service to the user? We are very likely moving toward an initial link in local integration, then toward an aggregation of these links for a more global chain of service-based continuity[24].

A second case of application is that of the *carpooling stock market*[25], consisting of relating providers, on the one hand, and applicants, on the other hand, with carpooling solutions across a defined territory. These are essentially private initiatives (collective and individual). The constraints include abundance, sustainability and diversity of supply, quality and security assurance, usability, flexibility, reliability, pricing, payment and level of service. It involves well integrating them well to finalize a win-win solution for a given route between the provider, the applicant and the service provider by organizing it on a regular basis (including commuting). Careful organization of roles and rules of operation (property, administration relations, back-office, technical structure) is also a priority.

Carpool “dynamic” experiments[26] have been engaged and grow very quickly (Lyon, Grenoble, etc.). Subject to preregistration, a

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[24] Mobilis 2012, Vehicle of the future cluster.

[25] Unlike “car-soloism” where the driver is the only user, carpooling allows many to share the same car resource. Different websites offer carpooling services.

[26] This is a “real-time” carpool system, generally incorporating the following features: the ability to request or offer a carpool for immediate departure or within a maximum of 30 min, and real-time geolocation in order to achieve an optimal match [CER 09a].

journey can be offered almost instantaneously and is treated within just a few minutes (seconds?): organization of the service in real time and network is made possible due to a mobile telephone operator. Exchanges are fully automated and managed by the service.

In light of and beyond the applications already defined for which we just gave two examples, it must be recognized that the organization and operation of information on mobility intentions and potential means of transportation available to satisfy it are a key solution to creating conditions for sustainable mobility. They provide access based on the need for massification of flux of people and goods, coordinated with different transport modes (multimodality and interoperability), and mutualizing supply and demand. Here we recognize the attributes of massification, which we also discussed in Chapter 3. Instant consequences are the reduction of direct and environmental costs, and improvement and expansion of available supply means for mobility.

However, it remains beyond these principles to satisfy all the many actors (city, infrastructure and transport authorities, transport companies, transport users, drivers, operators and thus to find the ingredients for a successful and sustainable cooperation. This feature may require, on a sufficient scale of organizational complexity, a *governance structure* that implements coordination of efforts between public and private initiatives. The challenge is to finalize and develop them, while setting and enforcing rules on provision, ownership, operation and recovery of these data. The government is encouraging the emergence of this structuration[27].

In Figure 4.6[28], the cube represents all “open data” related to mobility and logistics systems, for which availability is required: availability and performance of different transport modes, schedules and real-time location of public transport, traffic, weather, parking, storage, delivery areas, carbon content of electricity, etc. Access to

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[27] In France, in 2011–2012, ADEME piloted the allocation of financial resources to support public-private partnerships to develop support services for mobility. This initiative has been a roadmap to guide a call for expressions of interest (CEI) on urban mobility, and another on occasional mobility.

[28] Roadmap Mobility, ADEME AMI 2011.

these data enables the development of tools for many stakeholders involved in the supply, processing and/or use of these data: citizens, consumers, households, businesses, networks, communities, local or central governments. These are the players of the “from sensor to service” channel discussed in Chapter 1.

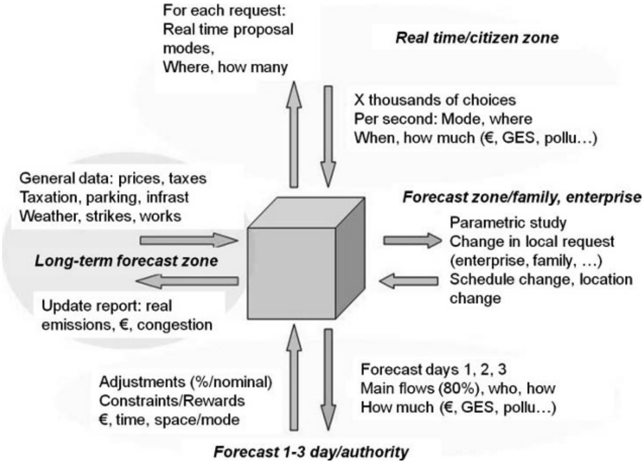

Figure 4.6. *“Open data” structure driven by data providers and producing accompanying mobility data [ADE 11]*

From the creation of a data cloud generating a first cluster of applications, other applications can coagulate, integrating other types of data providers giving additional functionality[29]. Their potential is limitless: it can involve different needs (acquiring information, decision support, put in relation, providing services for the mobility of people, the mobility of goods, etc.) for individuals and professionals in the public or private spheres. The production of data is used to share information and develop a wide range of services: for example, supply and demand of transport, availability and booking of individual or collective vehicles, parking, coordination with public transport means in the park and ride, prioritization of vehicles in favor of fully

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[29] Thus, the Optimod'Lyon (2012–2014) project, coordinated by Greater Lyon, had three strategic areas: (a) an integrated approach to passenger transport and urban freight, (b) the development of services based on ITS systems, (c) the development of innovation policy in partnership between public and private sectors [COL 12].

loaded and properly operated vehicles, use of on-site infrastructures, monitoring distribution or collection of goods operations (Figure 4.7). They are possible in a public area, as in a private space (port, airport, logistics platform, etc.).

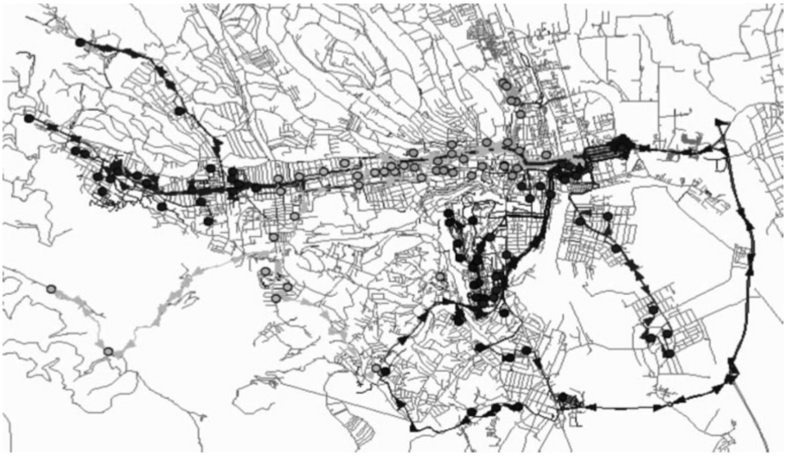

Figure 4.7. *Mission monitoring of a vehicle for collecting household waste: routes and collection points [LUT 08]*

Note that it is essential to define the rules of ethics, ownership and operation of such data. On the one hand, it is obviously necessary to protect the freedom of citizens. On the other hand, some real-time data address a public good, it is necessary to define a right of use, to ensure the control and regulation, and protect their exposure to private stakeholders who could use them for profitable or illegal initiatives. Finally, we must also promote entrepreneurial initiatives to develop services to improve the sustainability of mobility.

4.5. Mobility and urban planning

Access to the city by motor vehicles is generally constrained by *numerous* and unfortunately often heterogeneous[30] *regulations*, which

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[30] In a same urban area, according to municipalities or districts, vehicle access criteria (weight, dimensions, EuroX type emission class, etc.) can be different and sometimes contradictory, which does not facilitate proper management of travel within urban space.

are enacted by local authorities on geographical sectors (street, neighborhood) and the time of day, week, year... Their clarity[31], comprehension and suitability for objectives of good management of the city are widely criticized, especially as these regulations are intended to satisfy conflicting requirements for different types of stakeholders (road users, resident owners of vehicles, residents, businesses, etc.). Better management of these prescriptions is required, whether it is their governance, relevance to the quantified objectives, implementation of control procedures and police intervention. An effective implementation, recognized and accepted by citizens, requires a clear and convincing communication, with long-term and consistent achievement of the desired results. These issues are on the agenda of public policies at different scales of governance (see Chapter 6), using the principles of good management of urban mobility and adapting them to local and regional specificities of urban space (Figure 4.8 shows some principles).

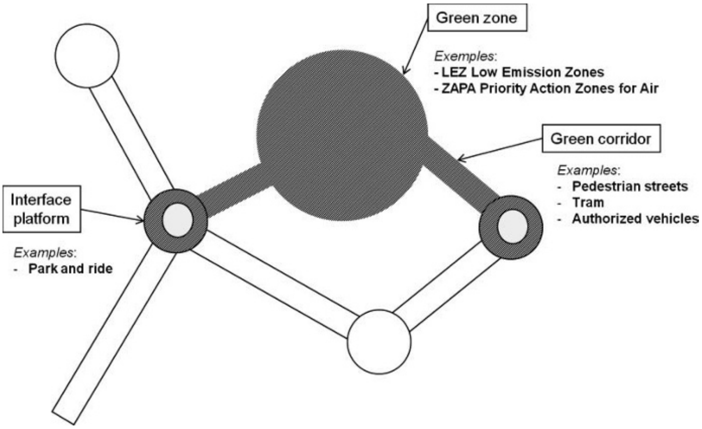

Figure 4.8. *Some principles for establishing urban access regulation*

Beyond the regulatory approach, the establishment of *technical and financial control mechanisms, restriction and optimization of*

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[31] Certain cities offer variable regulations, simultaneously differentiating urban zoning, times, types of uses, types of vehicles, etc., according to coding (for example colors) intended to simplify comprehension of access rules. This type of information requires some learning on the part of citizens.

urban access continues slowly with two main objectives: reducing congestion and improving urban environment quality (gaseous and noise emissions). Singapore, a city state, has been a pioneer in this field and has become a benchmark example that has greatly inspired other initiatives. In Europe[32], London with the London Congestion Charging Scheme (LCCS) set up a congestion charge zone (CZ) [33] in 2003, for which the objectives were to reduce congestion, drastically improve the quality of public transport services, improve the reliability of travel times by car and ensure better distribution of goods. The principle is that the user pays a daily fee[34] – identified by automatic recognition of the vehicle license plate – upon entry or occupation of the zone[35]. In 2008, Milan, based on a similar approach, introduced the Milan Ecopass System (MES) imposing a fee for cars and some freight vehicles[36] in a central area of 8 km^2, *Zone a Traffico Limitato*. The main objective was to reduce the level of air pollution and secondarily to reduce congestion. Its implementation has suffered difficulties in the gradual erosion of device performance. In 2006, Stockholm also launched a 6-month trial after which an evaluation of the results and a public consultation led to sustaining the device. This is to reduce congestion and pollution[37], prioritize public transport and generate resources for financing public transport. We could name other European cities such as Strasbourg, Krakow, Dublin and Verona that, in particular under the CIVITAS[38] program or in consortia[39], offer various cases of application and exchange best practices.

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[32] The website www.lowemissionzones.eu shows some examples.

[33] The affected area is 22 km^2 (extended in 2007 to 42 km^2, and then reduced to its original size since 2011).

[34] Ten pounds per day since 2011, working days from 07:00 to 18:00. Reductions (90% for residents) and exemptions (taxis, public transport vehicles, “green” vehicles, etc.) are applied.

[35] University of Leeds for the EC Curacao Project, U.K., 2009; Transport for London, 2008.

[36] Particularly, differentiated according to their Eurox regulatory emission level.

[37] In this regard, the results are very moderate, they show a reduction in PM0.2 particles between 0.5% and 9%, following introduction of the device.

[38] The CIVITAS program, funded by the European Union since 2002, is open to all transport organizing authorities who want to implement an integrated policy for sustainable urban mobility.

[39] Eurocities and POLIS are examples of European associations of stakeholders, cities or urban areas coordinating their efforts for sustainable mobility.

The failure of the ZAPA[40] initiative in France is an example of a system that raised challenges and difficulties accompanying regulatory policies, requiring reconciliation of technical, financial and social arguments.

These examples show how a growing number of cities, especially in Europe, facing congestion and pollution problems, implement strategies to manage demand for mobility from the concept of access control. They involve the prohibition of access to certain areas (urban centers and other sensitive areas) to traffic of individual vehicles equipped with the less clean and/or less efficient technologies in terms of energy and prioritization of public transport, which is consistent with the massification principle[41]. The access control policies vary, however, depending on the case. They differ according to their purpose (depending on air quality, noise[42], transport efficiency, the financing of infrastructures or public transport), the type of access restriction (persons or goods, type of vehicles and their definition, involvement in space and in time, residents) and the instruments used (regulations prohibiting vehicle access, congestion charges, parking charges, incentives and bonuses, etc.). Their results[43] also vary over time and are assessed in a dynamic context: the "snapshot" effect of the implementation of a measure (from the time it is effective) can be

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40 During the ZAPA-Zone d'Actions Prioritaires pour l'Air - (Priority Actions for Air Zone) feasibility study (2012) in the Paris region, eight scenarios covering different combinations of road access restrictions on vehicles of various categories were designed to estimate their impact on air quality (the main objective being to lower emissions by 10% in this area by 2015 for two pollutants: nitrogen oxides and particulate matter). Public authorities have finally decided not to pursue the ZAPA initiative, particularly for social equity reasons: it led to restricting or prohibiting use of the most polluting and older vehicles, which are usually owned by less fortunate households.

41 This assessment is undermined in the case of policies prohibiting trucks in the city, in favor of smaller and – we have seen – collectively less virtuous commercial vehicles.

42 Holland, with the PIEK program (www.piek-international.com), was the initiator of a proactive approach to improve the sound environment in terms of delivery of goods, now adapted in some countries (in France, the CertiBruit label was created in 2012 by CemaFroid with the CIDB and the LNE).

43 For example, travel times (morning rush hour), pollution levels measured by atmospheric sensors, utilization of public transport or alternative modes, etc.

diluted over time, it must also be assessed in light of changing technical performance of vehicles, fleet renewal, changes of uses, etc. These policies also generate induced effects on zones that are peripheral and external to the concerned areas.

Therefore, according to the initiative, we see a wide range of heterogeneity in terms of the adopted instruments. They can generate additional costs for the community (due to the dispersion of the adopted solutions), and they also carry the risk of discrimination between categories of vehicles or users. The latter generates heated debates[44] and its reality cools political action.

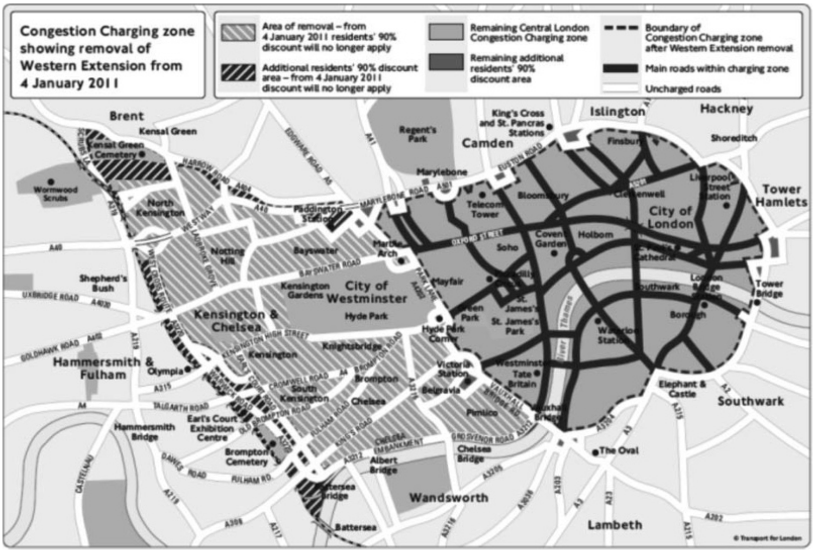

Figure 4.9. *The regulated access zone of London [GRE 11] http://www.tfl.gov.uk/roadusers/lez/*

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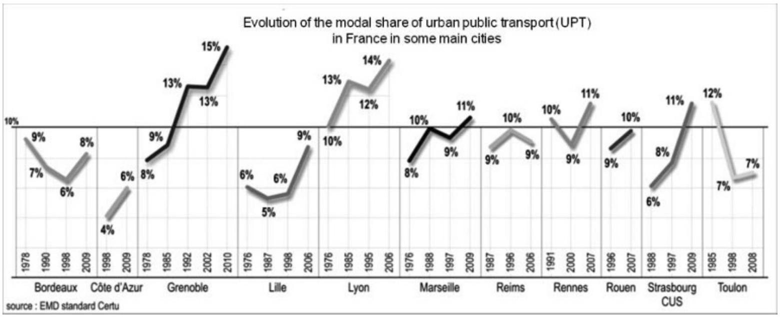
[44] According to Matthieu Glachant, congestion charges affect a population of drivers who have a much higher income than the average town resident, while public transit users are significantly poorer on average than car motorists. A congestion charge would therefore be to take money from motorists and transfer it to the public transport system, either with financial compensation and tariff reductions, or with an improvement of the quality of public transport [GLA 13].

4.6. Urban mobility of people, example of multimodality

Promoting new tools and ways to manage mobility in the outskirts and within cities is accompanied by the development of infrastructure to support the deployment of mobility toward use of the most virtuous modes: public transport systems, cycle paths, improving connections between modes, implementation of car parks and park-and-ride structures, and re-appropriation of urban space. The tendency to use non-car modes (public transport, soft modes) in the city is confirmed (Figure 4.10). It should be further strengthened by the continued implementation of public policies which are both incentive (for example in terms of investment[45]) and coercive with respect to the car (or at least respecting overuse and non-virtuous conventional cars).



source : EMD standard Certu

Figure 4.10. *Evolution of the modal share of urban public transport (UPT) in France in some main cities [CER 12]*

Walking, however, is at the heart of multimodality for the movement of people as such but also ensures linking of different modes of transport necessary for travel (Figure 4.11). Is the "walking" mode a sustainable mode of transportation? Beyond the fact that its essence constitutes of the autonomy of people being capable of exercising, its integration into the range of transport solutions must be

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[45] In France, we note an accelerated investment of urban public transport lines on site: for the "decade of the tram" 2001–2010: 391 km, including 29 km of subway, 246 km of tramway, 116 km of high service level bus BHNS; for the previous decade 1991–2000: 149 km, of which 40 km were subway, 103 km were tramway. The 2011–2020 decade should lead to more moderate heavy investments (but with a BHNS breakthrough) [CER 09b].

better organized. Various studies have addressed not only the issue of accessibility on foot of different resources of the city, but also the exposure to accident risk (cohabitation of "vulnerable users" with other modes, older pedestrians, congestion due to excess street furniture, parked vehicles, etc.) and the need to remove the obstacles of walking in an urban context (physical or cognitive abilities, representation and perception of risk, "walkability" [GEF 95] of urban spaces through better management). Walking is also an indicator of urban quality. Studies on the mobility of seniors [DOM 12] provide elements of common sense from this point of view. Seniors' choice of itinerary does not always correspond to the path with the highest index of "walkability". For those who are starting to feel the effects of aging, it rather corresponds to a logical avoidance of streets with high pedestrian traffic. The presence of benches, trees, wide sidewalks are seen as factors enhancing "walkability" (as we could rest). Congestion or degradation, and busyness, of sidewalks evoke discomfort.

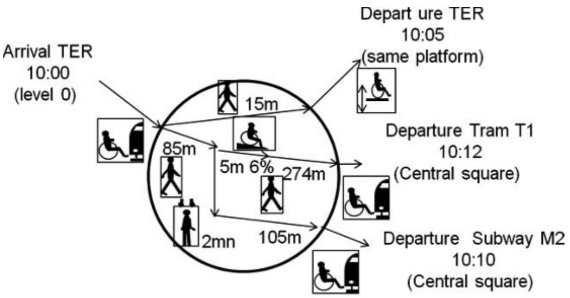

Figure 4.11. *Example of a detailed study of the possibilities of transit in an intermodal station, taking accessibility requirements into account*

Changes in behavior seem pretty fast[46] and strengthen typological differences between categories of users ("generation Y", "trendy", seniors, people of reduced mobility, etc.). "Connected" users have real-time sound and visual information that are individual. This

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[46] Observation of behavior in Ile de France over three decades shows, for the first time, a reversal of the decade 2001–2010: the car is no longer the dominant mode of transportation, walking is leading again [MEY 12].

information may facilitate their access to the contextual environment of their travel[47], but also very significantly increase their risk of exposure to accidents (distraction, lack of vigilance, distorted sound perception). In fact, the city medium is itself multimodal and walking coexists with wheeled modes, motorized or not[48]. If personal assistants are supposed to provide support for contextual mobility, they also offer the alternative possibility to access a world that is "virtualized" and decontextualized from the physical and cognitive snapshot environment, which has been proven to create accident-prone conditions.

The bike and its variants are an alternative and complement walking, classified in the same category as "soft" or "active" modes[49]. Rehabilitated and upgraded in public policies reclaiming urban space, they appear to be complementary, yet in conflict with walking when it comes to occupying the same corridors, when they are not sidewalks. The development of electric assistance devices could contribute to a change in the use of this method beyond cleavage {soft-young mobility activist}, to which it is primarily confined (in most European cities).

We have seen that the use of massified urban transport modes is encouraged by public policies and pricing, and currently it has a significant rate of growth at the expense of the private car. For infrastructure equipment, there is competition between the *subway, tram and bus* (and its high-performance variation, high-service level bus[50])[51]. The choice of location for these modes and their funding are

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[47] Personal assistants are gradually becoming essential travel assistance tools, "multi-purpose" facilitators. "Augmented reality" technology will contribute.

[48] The risks are similar or enhanced for users of two-wheeled vehicles.

[49] "Active mode" is a neologism that underlies the practice of physical activity, as opposed to motorized modes.

[50] At the global level, buses carry 80% of public transport passengers in Europe; they represent 60% of all public transport movements (30 billion passengers in city buses per year in Europe [UIT 13]).

[51] We must also mention cable transport, the last arrival and still anecdotal but relevant in the long term for some urban settings (especially due to their topography), given the interesting and offset features with respect to the use of urban space, land impact, and its energy consumption performance. Various equipment projects are under consideration.

subject to political decisions[52] and rely on rules and procedures formalized and widely practiced by transport authorities[53]. The establishment and development of network schemes should strive to allocate the supply of transport according to analyses of origins and destinations and have a coupling effect on land-related policies. In addition, there is the need to serve the heart of the city but also to rethink the outskirts, their service and their connections with the suburban area, the edge of the area that still belongs to the metropolitan zone. The respective performances of these transport systems are more or less structured to be examined in the long term, as their achievement has an effect on urban policy, especially with regard to heavy modes (rail and/or guided). These are powerful attractors of activities and new urban infrastructure, which in turn generate high pressure in terms of new demands for mobility. Their design is to be compared with long-term needs. It must be accompanied by a policy of public transport "networking" lines using lighter modes with more support and alternative functions than hemming on heavy lines[54]. Figure 4.12, representing Barcelona's structural mesh, illustrates this perfectly.

Diversity and systemic performance of this supply of transport, with the accompanying mobility tools (access to downloaded or personal information) already mentioned, encourages urban mobility that is softened, diversified and adapted to a variety of uses and users. It promotes the use of links using soft and medium more sustainable massified modes of transport instead of cars. The latter, however, remains useful and necessary, and could take its rightful place on roads and public space beside the soft modes and in a manner allowing a progressive part to be involved in collectivization through

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[52] The future Grand Paris Express network should include 155 km of automatic subway. This case highlights the difficulties of the decision process, the recurring tensions between the city, the region and the State, the financial dimensions of controversy, and the impact of choices structuring future mobility in the Paris region.

[53] Such as GART or UITP.

[54] The BusNet concept system (Barcelona) (Figure 4.12), implemented in 2012, goes much further: lines are structured as a regular checkerboard with a mesh of about 1,000–1,300 m, including three "diagonals". Any origin to any destination is associated with the price of a single change (maximum). At the ends of the line, an expansion into many branches serves the suburban area.

use, mutualizing or sharing, subject to meeting comfort, security and customization requirements.

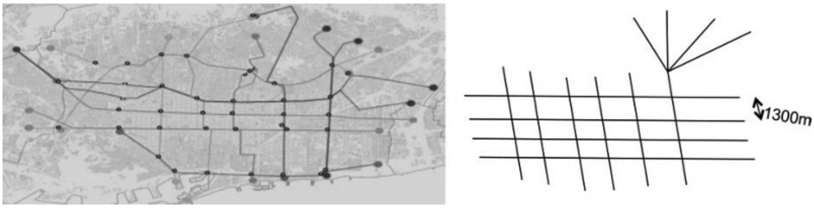

Figure 4.12. *BusNet system concept (Barcelona)*

In suburban areas, or to facilitate mobility between metropolitan and regional areas, the relationship between the car and massified mode (including the timed regional express train, the tram-train, the high service level bus[55]) reinforces: a goal assigned to exchange platforms to better integrate the needs of users by adding mobility services (such as park-and-ride, ticketing, fuel stations, hotels, etc.) neighborhood services (concierge, logistics, consumerism), facilitating daily life and social bonding. There is also a focus on the integration of multimodal platforms in urban space and their transformation into real soft mobility attractors[56].

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[55] This transport tool (which needs reinventing) could be progressively rehabilitated as a supplement or as a credible and responsive alternative to investment into new railways.

[56] In Nice, the Las Planas tram terminus station is a “multimodal integrator of functions and urban spaces. It shows the ambition of an urban connector device between territories and neighborhoods, between modes, and the need to ensure continuity of an itinerary (whether horizontal or vertical, linear or reticular) by working on accessibility and readability. The inclusion of everything in complex terrain (topography, urban buildings and infrastructures) as an extension of urban space, and transparency games between levels and different places generate physical continuities and visual connections that facilitate travel, opening the multimodal city center to the countryside, offering a new vision for the tram. By focusing on architectural, landscape, urban design that exceeds the technical infrastructure project and gives it a social dimension, this project made the multimodal pole an integral part of the city and improved the existing neighborhood by reconnecting it with its environment and giving it a new identity” [IPR10].

4.7. Intercity mobility of people

Generalized to casual intercity travel, primarily involving family travel ("trips") and to a lesser extent professional travel, Zahavi's hypothesis can be expressed in the following terms: "further, faster, more often, in less time". Such a trend is based on economic fundamentals: the perceived cost of mobility has declined dramatically over the past decades. This results from the combination of the price effect (of transport) which has collapsed and the income effect that accompanied economic growth, the result having been a powerful factor in increasing long-distance mobility[57].

The act of being transported while going far can be an end in itself, an objective as such, a powerful object and vector for leisure and consumption for *family travel*, and there is a certain demand, a "contemplative romance" in traveling far: the window separates the traveler from the outside world that we pass through without actually entering it, whether it is sea cruises, travel by rail or coach or by other means. From this angle, slowness is a virtue, more so than speed. It is the framework for interaction between the traveler, the social group that accompanies him and the outdoor space he travels in. It translates into specific elements of specifications for related transport (for example large openings into the countryside to be at one with it, whether it is windows, openings, bridges, etc.). *Rapid transport* by air or high-speed train is seen more as a means, not necessarily very pleasant[58], to arrive quickly, especially aiming at allowing access to a wider range of additional leisure services related to the "exoticism" of unusual situations, infrastructures, equipment and proposed activities

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[57] Yves Crozet (LET-University of Lyon) published a series of works on these issues. They highlight the difficulty – impossibility? – of decoupling between economic growth and mobility, particularly for long-distance transport, as growth creates mobility (and not vice versa) see, for example, [CRO 09] or references to the Koenig formulation (1973).

[58] Users affected by recent developments in terms of control procedures for aviation security and "low cost" flights do not contradict us. High-speed trains have (for now?) a decisive advantage in this regard.

in continuous evolution, capable of meeting the growing demand[59] of consumer travelers.

For business travel, rapid long-distance transport contributes to strengthening the collective productivity of firms (and expert networks) ensuring the development and dissemination of knowledge, design, industrialization and commercial deployment of products and services: because of their complexity[60], these are developed in a now fully globalized context, with distributed organizations, and/or result in a global market with a strong need for adaptation to local requirements (customization of products). Therefore, traveling is integrated into the processes of these companies and networks, as well as long-range communication tools to complement rather than replace it: professionals need to move quickly anywhere to meet face-to-face, relaying international transport hubs on which their activities are grafted.

These airport facilities now adjoin train and road vehicle stations (Figure 4.13), which together constitute powerful leaders in territories and business attractors, with their share of local movements and long-distance services attached. The development of these poles alongside cities poses major problems in terms of local environmental impact (relative to generated pollution, including noise) and control of land policy and use (these are spontaneous activities and mobility attractors)[61].

Under these two aspects – leisure and business travel – long-distance mobility is hand-fed by the global economic development but is also one of its main engines.

We must recognize that the long-term projection on long-distance mobility particularly questions our collective ability to control its “sustainability”. Modulating it, reducing impacts, is particularly

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[59] Increased by the number of consumers, but also by the number of activities in the allotted time-travel budget.

[60] Here, “complexity” means all nested processes and actors intervening in the value chain leading to the spread of the object (product, service) on the market.

[61] The debate in France around the airport project at Notre Dame des Landes (Nantes) has been a prime example.

problematic, for example given the current development of air transport: it seems destined to continue its growth.

Figure 4.13. *We can improve into : Intermodal road/rail/air hub for long-distance travel : airport and TGV station at Lyon-Saint Exupéry, France (Ref. CCI Lyon)*

Infrastructure requirements for the air mode are essentially limited to airports and air traffic control systems. Contrarily, land transport requires infrastructure for all corridors; investment costs and maintenance heavily impact public finances[62], not to mention immobilized surfaces and adverse effects induced during construction and operation: the environmental impact of civil engineering can be major, especially in terms of CO_2 emissions; barrier effects, noise and visual intrusion have very high costs[63]. However, we have seen that the environmental impact of air transport is already heavily penalizing (see Figure 1.4), and the prospects in this area are not favorable in the absence of a real alternative energy.

For short-haul flights, the airport taxiing phase in conventional aircrafts represents approximately 10% of consumed fuel[64]. If take-off and approach are added, the "effective mile" carbon footprint is

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[62] This is obviously the case of high-speed railways.

[63] The economic viability of high-speed rail projects appears to be very low when the expected rates fall, even negative if we count the full balance including expenditure/revenue, time savings and internalization of external costs [SNI 13].

[64] At an airport such as Roissy-Charles de Gaulle, the taxiing of a short-haul aircraft consumes ~ 150 kg of fuel [GAM 12].

detrimental to this type of journey relative to more distant destinations[65]. In contrast, long-haul flights have a more favorable {passenger x km} carbon footprint, but the overall balance of a trip is very bad in absolute value for each passenger[66]: the huge distances must be considered, which account for, for one return trip, thousands or tens of thousands of kilometers for an ordinary passenger.

We are now at the heart of a major contradiction relative to the objectives of sustainable mobility from the citizen-user point of view. To comply, we must choose either not do long-distance travel and continue to travel to our daily dwelling place and workplace or travel meagerly (one trip per year) and stay put in everyday life. Any excess over this rule deeply hampers the “carbon budget” allocated to each individual.

Long-distance travel – transoceanic, transcontinental – has the characteristics of a luxury incompatible with the objectives of sustainable transport, considering the speeds involved. At (much) more moderate speeds, alternatives to the aircraft (cruise ship, long-distance coach, train) become relevant again (but then violate Zahavi’s conjecture).

4.8. Logistics: the mobility vector of merchandise

Freight transport is a link in the supply chain {production-transportation-distribution} for which effectiveness is evaluated on a global scale. Its operation is based on the robustness of transport means but also the proper management of information accompanying goods and quality assurance rules that apply to the “global virtual factory”: zero defects, zero stock, just-in-time. Product flow is managed through a traceability chain including purchase data, transportation, sale, export and import, “packaging” in the form of parcels, lots, pallets, containers with attributes specific to the type of

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[65] For these short flights, consumption is in the order of 6 l/100 km/jet aircraft seat (equipped with turbofans), and about 4 l/100 km/seat for a modern propeller aircraft.

[66] The latest long-haul aircrafts consume, at full load, just under 3 l/100 km fuel per seat. This represents an order of magnitude of 300 one per passenger for a transoceanic flight, or 1 metric ton of CO_2. We conclude that a single return trip on a long-haul flight with a “state of the art” airplane uses the potential annual CO_2 of a future traveler (2 tons of CO_2) [KIE 11].

good transported (cold, fragile material, hazardous material, etc.). Each stage of aggregation and disassembly is followed, referenced from origin to destination. In addition, we can associate data (some in real-time, *V2X*, *cargo2X*) relating to location and vehicle used. These data allow us to ensure the exchange of necessary information between the different stakeholders in the supply chain to optimize a target route. It is built according to international standards (exchange, size and shape protocols, safety procedures, etc.) which allow its circulation[67]. The introduction of parameters specific to sustainable transport, such as CO_2 levels, in addition to economic parameters (direct cost, duration, reliability of itinerary) will be a major change allowing us to compare transport options in terms of carbon footprint and contribute to CO_2 product labeling terms. The data are physically encapsulated in radio-identifiable markers, including electronic chip and antenna, glued or embedded into transported objects and various layers of containers according to RFID technologies[68]. Figure 4.14 describes the layering.

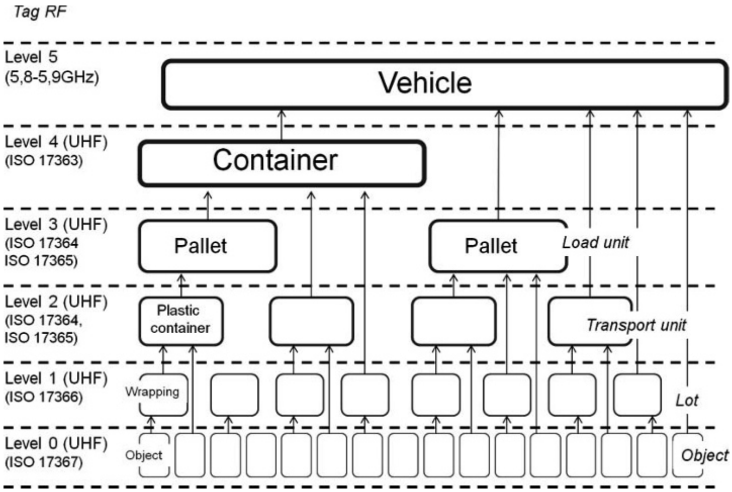

Figure 4.14. *The concept of load level according to ISO 26683 standard: types of freight containers and RFID applications in the supply chain [VAN 10]*

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[67] The ISO 26683 standard for inter-modal and international transportation is a good example of these tools.

[68] RFID or *Radio-Frequency Identification.* "RFID tags" (or "RFID transponder") receive requests transmitted from a radio transceiver, and respond.

The transported entity (the goods) should not be confused with the means of transport (vehicle). The merchandise is stored in a container that meets international standards, in order to allow long-distance routing. To consolidate the entire mobility chain between origin and destination, considerable challenges remain to ensure an overall compatibility of standards for Intermodal Loading Units (ILU: containers, swap bodies) and Intermodal Transport Units (or ITU that, in addition to ILU, include trailers and semitrailers). These containers not only have dimensions that are compatible with the vehicles that transport them[69], but also physical characteristics conforming to their logistics use: resistance to load and efforts, packaging, location and design of parts and plugs for handling.

A container is a box designed for the maritime and river transport of goods, rigid and strong enough for repeated use, usually stackable, and fitted with devices to facilitate gripping and securing. Its dimensions are largely standardized[70], despite them being of a certain diversity. As for the swap body, it is optimally adapted to the dimensions of road vehicles that can be transshipped between modes, usually road and rail. Its dimensions are standardized (European standards CEN EN 284 and 452), but they differ (especially in width) from containers. They cannot be stacked or used in maritime or inland waterway transport[71]. In turn, ITU (containers, swap bodies, semitrailers and trailers) contain various loading units, which are most

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69 Vehicle dimensions are themselves linked to those of infrastructures, which is difficult – if not impossible – to change: street width, platform gaps, tunnel or sluices templates, etc. Only water and air modes are suitable for some adjustments because of the absence of excessive constraints on corridors (only on terminal parts).

70 These are mainly 20-feet-long containers (20′ or ~6 m) or 40 feet (40′ or ~12 m) (defined in ISO 668/1995 American-inspired standards); but other dimensions were also developed for various markets. The 20 foot container unit has become the reference of a transport system (a 20 foot container is 1 TEU (Twenty-foot Equivalent Unit), and a 40 foot container is worth 2). Besides the dimensions, these standards also define strengths and handling equipment.

71 Let us note that work is underway to further define other types of containers with different dimensions that may better satisfy other logistics areas (river transport, urban logistics, etc.). This optimization search for a given application is not in the direction of modularity or interoperability: one must unfortunately choose between standard solutions usable by all (but not optimal for application), and solutions of limited usage with specific situations.

often standardized pallets[72]. Depending on the container, the nominal fill rate of pallets varies[73].

The variety of designs, sizes and specifications complicates intermodality and deprives it of the interoperability that the ILU would allow. Handling is delayed because each case must be identified separately in order to choose the most appropriate technique. The lifting equipment must frequently be tuned or changed. This causes unnecessary costs in the transport chain. It makes investment decisions in the ILU more difficult. The transport system cannot be used at full capacity. There is therefore an important challenge in making a true ILU standard at the European level for loading euro pallets without loss of volume and their transportation by all surface modes (road–rail–waterway and sea – at least for short distances); the characteristics are aimed at concerning both technical and economic performance, and require compatibility with land regulations regarding maximum dimensions of road, railway and waterway transport units. Discussions have failed so far: the swap body, suitable for road and rail, is not suitable for river and differs from the container.

Freight mobility therefore starts at the mobility of its contents. These are casings ("pottings") of different levels of containers, assembled and disassembled in a compatible manner: compatibility on the one hand with the goods to be transported, but on the other hand with vehicles and handling means and transshipment partners as well, who operate on platforms and require specialized equipment and staff. So, the choice of containers is crucial, it has a considerable impact on the packaging specification of the object to be transported. It is

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[72] The "euro pallet" measures 120 cm x 80 cm and is based on the dimensions module 60 cm x 40 cm specified (in mm) in the ISO 3394 standard. It is widespread across Europe (except in the UK where the dimensions of the UK pallet are 120 cm x 100 cm).

[73] ISO shipping containers, with an internal width of 2.33 m, do not allow rational loading of euro pallets with dimensions requiring an internal width greater than 2.40 m. Current crates, of internal width 2.44 m, however, permit rationalization of this loading and increase the number of pallets (the difference in filling is 26%). They are therefore the preferred tool of loaders for combined transport of euro pallets. The semitrailer crate of maximum external dimensions, 13.60 m in length by 2.55 m in width, contains 33 euro pallets – a 40 foot container contains 25.

surrounded by several layers of containers with different types of constraints. In goods grouping operations (from the supplier), through transport by different modes, then successive ungrouping until the ultimate customer (Figure 4.15), the assembly organization and containers associated with each step must satisfy conflicting requirements: to ensure compatibility between vehicles and their loads (for example shipping containers stackable for transoceanic container ships) and to allow the transshipment of cargo from one mode of transport to another while adapting to their ability to contain an optimized set of a stacked goods (for example a set of pallets). The control of this puzzle may require computational tools to help optimize loads for saturation by weight or volume [COU 12] and as an efficiency gauge (in accordance with the massification principle). The approach applies both to ships (for which one seeks to ensure stability during travel, as well as loading and unloading operations) and land vehicles (for example truck loading). It also plays a crucial role in defining the vehicles themselves[74].

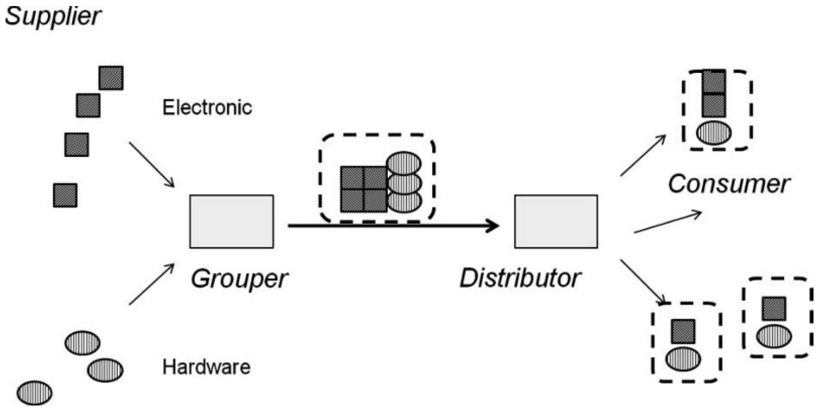

Figure 4.15. *Illustration of the principle of grouping and ungrouping of goods between origin and destination*

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[74] Input data for the design of a truck are the masses and dimensions of loads it is designed to carry, as well as regulatory constraints which it is subjected to (and namely its limits in masses and dimensions that are compatible with the road infrastructure).

4.9. The re-appropriation of urban logistics

Still largely undervalued[75] despite recent efforts to ensure that public policies reclaim the challenge (Chapter 6), yet essential to the city, urban logistics involves a range of activities to ensure the mobility of goods between suppliers and consumers, whether it is industrial, agricultural or commercial business or individuals and households. We generally distinguish logistics sectors by business, stakeholders[76] and {origin/destination} pairs. In addition to these activities' movements, many specific city needs' movements are added (construction, cleanliness, artisans of different trades). Goods require equipment transport, accompanied by operators who provide driving, handling, removal or delivery. Urban goods are almost exclusively done "by road"; this terrestrial infrastructure is omnipresent and essential for approaching the origin and destination (the "last kilometer"). Beyond a certain distance, the question of transport mode is naturally raised.

Work on urban logistics allows us to better understand the characteristics of goods mobility within an urban area. A job represents one pick-up or delivery per week[77]. One inhabitant requires 22 metric tons of general cargo per year (including construction materials and garbage)[78].

The decomposition of these movements into different typologies shows a great variety in their organization. Despite some exceptions (garbage, mail, etc.), it is an activity that depends primarily on the private sector. First, approximately 50% of freight movements are made by individuals from their shopping behavior. The other 50% is divided in half for big trips made by companies on their "own

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[75] Goods can be considered in terms of mobility as "entities of very reduced mobility, who do not vote".

[76] We distinguish pathways of the following branches:
- B2C or B-to-C (Business to Customer): business to the ultimate consumer (individual, household, etc.);
- The B2B or B-to-B: business to business;
- The C2C, or C-to-C (Customer to Customer): from consumer to consumer.

[77] This value is an average that varies depending on the type of job. The value is 0.3 for the tertiary, 0.8 for industry, 3.2 for wholesale, 10 for storage [ROU 10].

[78] City Freight Transport Survey, MEDAD France.

account", while the other half of these movements is made by specialized companies providing this service ("hire" companies)[79]. The majority (approximately 75%) of these is done on rounds, others are by direct route. The need to travel in an urban area will obviously depend on the density of houses, shops or businesses in the area. Available tools[80] provide a good order of magnitude. In Greater Lyon, the number of vehicles doing rounds on behalf of others, to power business, is approximately 10–20 per hectare per week in the outskirts and up to 130 in central districts[81]. This activity is hampered in its exercise by numerous and heterogeneous access regulations and also generates pollution and conflicts (use of urban space, parking, inefficient vehicles), all causing economic asphyxiation of centers and generating counter-productive effects in terms of logistics efficiency and the environment.

Among the many requirement aspects of sustainable urban logistics, some features pave the way for much improvement.

First, the role and implementation of "terminal" logistics spaces from which final or initial movements burst (Chapter 3) should be reviewed. A particular but very revealing and illustrative example is shopping malls, supermarkets and hypermarkets[82], which are very specific logistics areas. ADEME has long drawn attention in this regard to the negative role of extensive urbanism and hypermarkets in urban periphery, which generate very strong automotive pressure. The environmental cost is significant in relation to more favorable local supermarkets (located in neighborhoods in the city), supplied by rigid trucks and within walking distance for the customer.

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[79] In their "own account", transportation is provided by suppliers or customers themselves.

[80] FRETURB software, LET (Laboratoire d'Economie des Transports, Université de Lyon).

[81] LET Laboratory, Grand Lyon and Interface Transport company.

[82] The commercial center at the Alps entrance (Lyon) is supplied daily by 70 semi-trailered trucks. It has 7,000 individual car park spaces. Each parking space sees a daily turnover of about three cars. Seventy trucks loaded with 10 tons provide the same function, "influx", as 21,000 cars loaded with about 30 kg (which provide the "efflux") [FAV 11b].

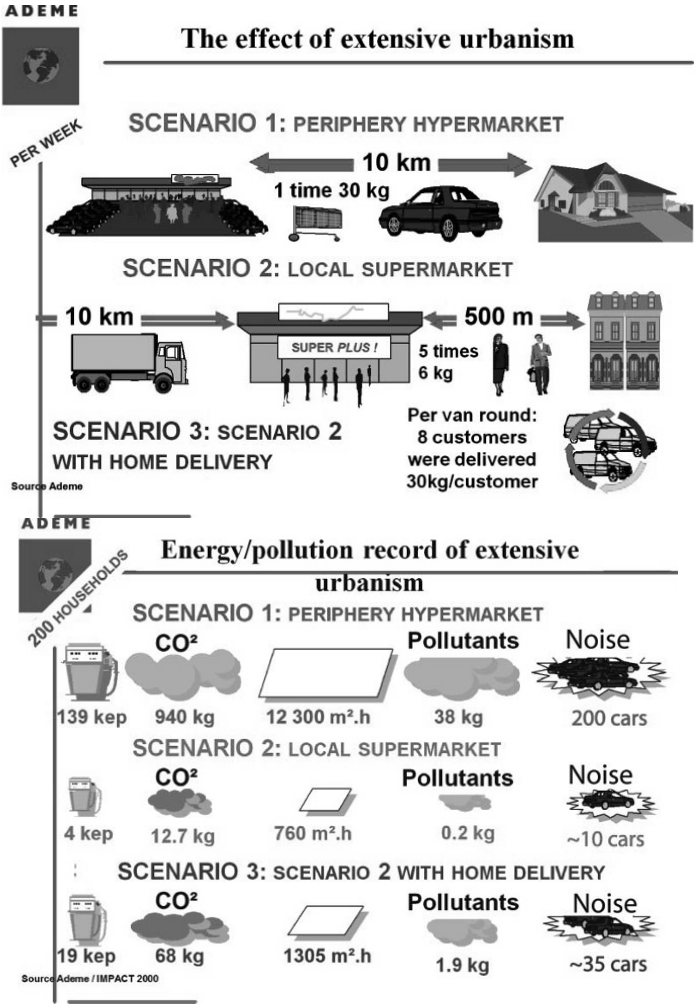

Figure 4.16. *Effect of implementation of large commercial surfaces on the environmental performance of induced activities [ADE 00]*

Another largely emerging issue is “e-commerce”, which saw an annual growth rate of in France, in continuity with the previous years. This explosion in demand generates a new logistic, which is gradually organized. To shorten time, manage the inventory, reduce costs, including those of transportation, online sale (and will increasingly) relies on robust logistics: suitable storage, detailed preparation, specific packaging, B2C transport and delivery and management of return flux[83,84].

This is why the concepts of *urban logistics space* (ULS) [85] are on the agenda. The characteristics of a ULS may vary depending on the situation (location, size, access conditions, etc.)[86]. The aim is to allow a new organization of urban logistics combining both:

– a centralized design (supplying the city with a network of suburban logistics platforms under pooled management);

– a decentralized local system involving various types of "last kilometer" vehicles with carrying capacity and a variety of features, motorized or not, self-service or not.

This architecture is designed to meet the needs of a stringent demand in terms of delay and just-in-time, as well as requirements to reduce socioeconomic and environmental impacts[87].

Figure 4.17 shows the typology of vehicle movements underpinned by a generalization of this organization, which can be adapted to most types of urban goods[88] :

– Vehicles use urban corridors allowing massified flow (Figure 4.17(a)); they provide movement between suburban and urban logistics platforms (ULS) with optimized fill rates. We will see in

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[83] Let us add that direct consumer-to-consumer transactions could take off. The future potential importance of this C2C type of transportation induces the need for distribution networks and very durable relay points.

[84] For fresh produce, the extra cost of CO_2 in this type of transport can be partially offset by lower CO_2 storage footprints [RIZ 08].

[85] An urban logistics space is "a device designed to optimize the delivery of goods in the city, functionally and environmentally, through the implementation of transshipments" [BAU 06].

[86] We distinguish urban distribution centers, local distribution spaces, collection or relay points, logistics agencies, etc. A delivery area equipped with storage capacity can be a specific variation.

[87] The MODUM ANR project (2011–2014) aims to study this type of logistics.

[88] Transport of cold products, urgent products (pharmaceuticals), etc., may require adjustments in relation to short messaging in e-commerce. It is the same for delivery to industrial workshops, supermarkets or restaurants, compared to delivery to individuals, etc.

Chapter 5 that such {vehicle-corridor} combinations are possible depending on patterns resembling public mass transport systems (here, goods replace people).

– Local movements (deliveries/removals) are provided by rounds (Figure 4.17(b)) or by pendulum (Figure 4.17(c)) with other specific {vehicle-infrastructure} combinations.

Adaptation to the field may change according to urban settings and types of neighborhood and goods, but the principles remain: it is to best massify on every scale, addressing three components in a coordinated manner:

– infrastructure ensuring flows (trans-urban corridors, local roads innervating the neighborhood);

– trading platforms and storage;

– vehicles.

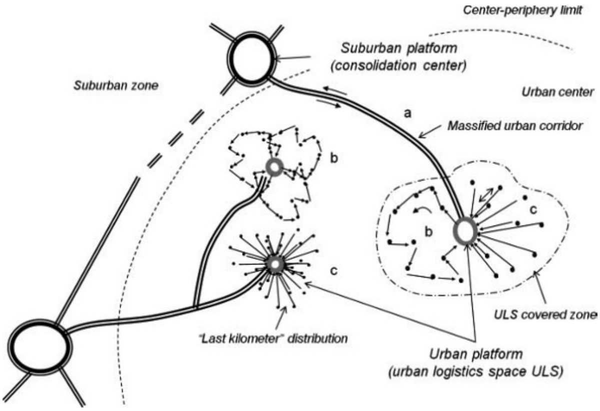

Figure 4.17. *An organization principle for sustainable urban logistics [FAV 13]*

Each scale (see Chapter 3) also requires the adapted combination[89]. The success of this adaptation is naturally conditioned by the implementation of a fourth component: the *coordination of*

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[89] "Last kilometer" vehicles are (generally) smaller than vehicles higher up in the ladder.

stakeholders, starting with the same coordination among public authorities[90].

We must provide the framework for economic stakeholders: obtaining funding grants, regulations and access to urban space, prohibitions and privileges, encouraging good practices and promoting adapted vehicles. This coordination is very difficult to initiate, but is essential for deploying a project. We must also ensure the economic viability of these organizational solutions, which requires us to revisit the model: distribution between internal costs charged for transport and hidden external costs[91] and rules of fair competition. Such arbitration will be based on consultation.

We must also note the difficulties linked to the absence of a natural "carrier"[92] of the initiative, contrary to public transport of people, freight transport is (generally) in the private sphere. It does not fall under the seal of an organizing authority: it is therefore necessary to invent it[93]. Because of rising awareness, a number of cities (at least in Europe) will progressively demonstrate how to manage the difficulty regarding implementation, governance and economics of more sustainable urban logistics systems.

4.10. Intercity logistics: squaring the circle?

Current developments in world trade show continued growth of freight transport between stakeholders and globalized markets.

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[90] In addition to political support at the metropolitan level (the town) and at local level (district, street), public authorities have a role in governance and cooperation between economic players (chamber of commerce, trade unions, traders, logisticians, carriers) and citizens and their representatives (consumers, users, neighbors, etc.). They are also responsible for the operation of infrastructures.

[91] Especially as it is currently difficult for companies to make a profit that carry out freight transport in the city.

[92] Logisticians and loaders have implemented some outstanding initiatives (with the Distripolis Geodis Group, LaPoste-Chronopost Group in Paris, CityLogistics in Lyon, 2012–2013).

[93] Operational organizations cited as examples such as La Rochelle in France, or Monaco, Padua, Italy, etc. have had to implement specific systems.

Projections suggest a continuation of this growth[94]. This means that transport of long-distance freight, operated primarily by transoceanic maritime traffic, will continue to grow and require the provision of a drainage infrastructure for these fluxes – by road, rail or waterway – between ports and urban areas[95].

The European White Paper on Transport (2011) has the goal of transferring 30% of road freight over 300 km to a mode other than road by 2030 and over 50% by 2050. The possibility of a modal shift of freight from road to a more "virtuous" mode (waterway or rail) obviously depends on the type of the transport. Depending on the market, infrastructures and type of goods, it is a more or less realistic goal: available European data demonstrate that 60%[96] of metric tons.km involve distances of less than 300 km. These distances are associated with the implementation of logistics platforms that link the territories together.

The effectiveness of logistics platforms is ideally determined by their location in the balance between essentially intercity supply and mainly urban distributions, with a special emphasis on transport economy and CO_2 emissions reduction[97]. Unfortunately, there is a spontaneous tendency to spread and push these platforms further from urban centers because of forces related to the cost of land [DAB 11], which produces dispersed platforms with questionable, even counterproductive, effectiveness (Figure 4.18). In the context of urban

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[94] In France, in a 20-year perspective, growth of domestic demand for freight, of all modes, would be of the order of 1.5% per year with a more pronounced development of international trade flows and transit (2% per year), which would increase the concentration of traffic on the two north-south corridors and access to major ports (Antwerpen, Le Havre, Marseille, etc.).

[95] In 2006, of the 362 billion tons x km (t·km) carried out on French territory (excluding oil), more than half were short (intra-regional) or medium (inter-regional) distances. International traffic (151 billion t·km, including transit for a little less than half) was roughly equal to the national inter-regional traffic (152 billion t·km) [PIP 09].

[96] Eurostat is a Directorate General of the European Commission responsible for statistical information at the community level (www.ec.europa.eu/eurostat).

[97] According to the Casino Group, its new logistics system in Gonesse and Wissous (France) for fresh fruits and vegetables saves transport of more than 2 million kilometers per year, and an annual reduction of 2,200 tons of CO_2 emissions with respect to the former (2013).

policies, public authorities have a duty to guide the allocation of land areas for structuring activities and anchoring approaches to sustainable mobility, such as the allocation of space to facilitate and optimize the virtuous movement of goods. They can generally, however, only channel, influence or hinder progress of the economic agents involved. In the absence of regulatory tools, the rate of return of a logistics space is insufficient, currently disproportionate to that of a commercial space or a pay parking (for example in terms of turnover per m^2).

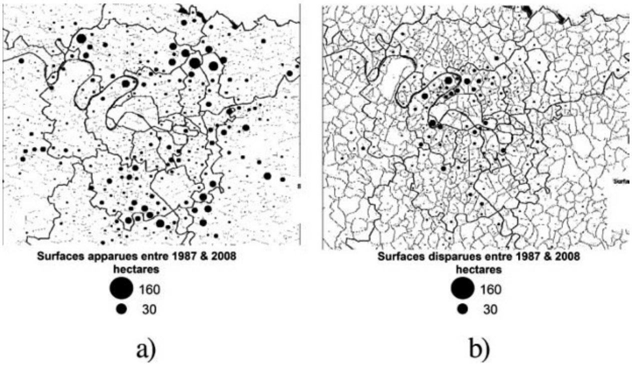

Figure 4.18. *Logistical footprints evolution (Paris) between 1987 and 2008 (hectares). a) Surfaces that appeared and b) surfaces that disappeared [DRI 12]*

Not surprisingly, major logistics areas are located either near ports and their hinterland, near cities, or on major transport routes (road–rail–waterway). In France[98], for which the four main markets are the Ile de France, the Lyon[99], Marseille and northern regions, 2.6 million m^2 of warehouses were sold in 2011 and the growth continues. It is a dynamic in full mutation. Tensions are being exerted on the land because of the gap between availability identified in multimodal sites and estimated needs for the next 20 years, for which growth could be confirmed over time. However, the offer appears limited in the existing dedicated logistics sites, especially for major logistics facilities, which consequently risk dispersion of activities. The

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[98] Warehouse supply is focused on the Seine axis and the Rhône-Saône axis.

[99] There are 4 million m^2 of warehouses in Lyon region (2011).

allocation of new more “productive” spaces is to be compared with the issues of aging and renewal of logistics areas. It leads to spectacular achievements[100].

Figure 4.19. *Example of a logistics area [RUL 10]*

How are these areas (points of arrival and departure of urban fluxes) linked in order to exchange goods between each other, drive, disseminate and distribute the incoming flux from ports (whether it involves quick evacuation) or industrial land areas? Routing is done according to transport infrastructure corridors combining road, rail, waterway and air modes. The choice of logistics responds to economic decisions (cost, efficiency, punctuality) in a context constrained by many strong regulations affecting vehicles, infrastructure and transport professionals. Short distances are generally done by road. Beyond a distance dependent on many factors [NIE 92], subject to the presence of available and efficient rail infrastructure, transfer to rail is

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[100] The terrestrial platform made by GSE for the Jysk company in Radomsko, Poland hosts two high bays of a height of 40 m with a storage capacity of 175,000 euro pallets, for a ground occupancy of 27,000 m². The fully automated storage system, is able to store a large volume of goods. Restricted soil occupation and minimized access time were privileged.

preferred. Over medium distances (beyond 300 km) and long distances, the distribution of flux between road and rail could therefore change significantly in the long term depending not only on public policies but also on the evolution of economic and environmental performances of different modes of transport, beginning with the presence of infrastructures. Meanwhile, on long-distance transportation at the European level, a cohabitation of powerful traffic flows and weaker rail flows can be noticed, limited by inadequate infrastructure, organization and interoperability deficits and prioritization to passenger traffic[101], despite projected political will.

The future involves cooperation between the modes ("co-modality"[102]), made possible by the juxtaposition of these infrastructures, the organization of transshipment hubs, the exchange and use of information associated with goods and their containers. We will not succeed without promoting and enhancing the relevance of each mode and the necessary juxtaposition.

The maritime mode and its land extension, *the waterway*, are essential for massified flow transport over long distances. Gigantism[103] has allowed a drastic reduction in costs for intercontinental transport and has brought transoceanic geographical areas closer together despite distances. In a more "regional" manner, motorways of the sea, encouraged by European policies, allow an

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[101] In France, the flow of long distance goods is concentrated on two North-South axes: Catalonia-Italy/ Rhone-Saone valley/Benelux on the one hand, and Aquitaine/Paris-Seine/North on the other hand, with a significant share of rail freight, and a majority of transit traffic and international trade.

[102] As opposed to "inter-modality" that puts modes into competition, co-modality affirms their complementary logistics chains. We also speak of "sync-modality" to express the possibility of using routing circuits that are variable according to real-time availability configurations between different modes from an origin to a destination (this is one of the variations of the "internet of things").

[103] The container ship *Emma Mærsk*, 397 m long and 53 m wide, capable of carrying more than 11,000 TEU, is a prime example that was put into operation in 2006. Vessels even greater called "Triple-E" with a capacity up to 18,000 TEU are progressively being put into operation. The new lane of the Panama Canal is designed for vessels up to 14,000 TEU.

alternative to road or rail[104]. These flows, which are loaded or unloaded in ports, generate significant improvements[105]. Rehabilitation of river ports that allow goods to approach areas of activity and ensure a link with urban logistics is also running, but it runs into conflicting interests.

Rail mode appears to be inevitable in the context of sustainable transport. As the status of the rail is changing, we can continue to expect a gradual improvement of its effectiveness in Europe to ensure long-distance transport. These necessary evolutions concern introduction of competition, organization of work, the division of responsibilities[106] between the infrastructure manager and the traffic manager, improving technical specifications for interoperability such as the template, signage, the spacing of platforms and voltage[107]. If the performance of the railway convoy carriage is commendable[108], those of a railway line in operation are more limited and do not allow consideration of a massive shift of freight from road to rail. A reasonable short-term goal is to contain the increase in transportation needs by increasing the non-road portion through rail. Figure 4.20

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[104] Spain developed a deliberate policy of opening more regular relationships from its ports on both the Atlantic and Mediterranean coasts. The Gijón-Nantes sea motorway, with three return trips per week since 2010 (as of 2013) had an annual target of 13,000 trucks in the first year, for a journey time of 15 h.

[105] The extension of the *Maasvlakte 2* of Rotterdam port, the number one port in Europe and fourth in the world, began in 2008 and is expected to end in ... 2033. Due to the additional flow needing to pass in the *hinterland*, a 160 km railway dedicated to transit goods has been created. The port authority is aiming for a change in the distribution of transfer modes, going from 60% of trucks in 2013 to just 30–35% in 2030, in favor of river transport (which would reach 45%, against 33% today) and rail (which would jump from 6% to 20%). The port, equipped with means for transfer and vehicle tracking (Container Transfer Point (automatic cranes), AGV (Automated Guided Vehicles), computerized controls via Cargo Cards), aims to triple the number of TEU managed (11 million TEU were managed in 2012).

[106] In France, Fret SNCF continues to be the major player, and nine other rail companies operate on the rail network since its opening to competition in 2006. The activity of new entrants, who were very limited in 2006 (less than 1% market share), reached in 2007 a market share of 4.7% transported metric ton-kilometers, exceeded in 2008 by a market share of 10%, and reached 20% in late 2010 [MED 12c].

[107] In France, 50% of rail lines are not electrified.

[108] A (full) train per day carries several hundred tons, representing approximately 200,000 pallets per year minimum for regular service. 750–1,000 m long trains are in circulation.

shows the flows of the European network, which has some major corridors[109].

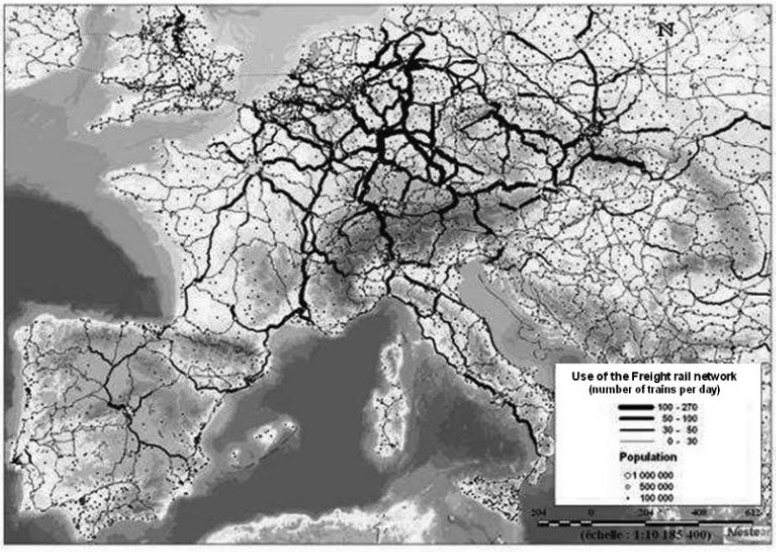

Figure 4.20. *European freight rail network and flows (Source: Nestear 2005, cited in the R-shift-R PREDIT 2012 report)*

Combined transport is defined as a service:

– using two modes in which container changes does not occur within the same transport channel;

– of which the major part is done by rail or waterway, so that upstream and downstream journeys by road are as short as possible.

Goods are loaded from warehouses or factories in containers or swap bodies, transported by road to a transfer site then transported by train to the terminal destination (where they leave by road).

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[109] The Rotterdam-Genoa freight corridor, for example, sees some 130,000 trains pass per year, the equivalent of nearly 4 million trucks.

A variant of combined transport is the *piggyback transport*. It is a shuttle train carrying trucks, not containers. The train is composed of flat lowered carriages interconnected by passages allowing a "truck roll" from one end to another, or (alternatively) equipped with a rotating platform for boarding on the side[110]. To ensure loading that complies best with railway gauge height, some wagons have compact bogies with "small wheels". Intermediate varieties allow semitrailers to be boarded, which cannot be handled vertically through gripping[111].

Integrated into global chain, combined road–rail transport therefore includes a set of services with technical, commercial and organizational characteristics, with areas of competition and areas of complementarity. Performance varies according to the type of material transported, transshipment platform equipment, market segments involved and frequency of rail service [SET 11]. Road–rail traffic is on average carried out at a greater speed than that of conventional rail freight, combined transport trains and piggyback transport being used with priority over other freight trains[112,113]. Transshipment hubs (Figure 4.21) require organization and innovative technical means[114].

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[110] The Modalohr system, related to other initiatives such as the Flexiwaggon or the Shwople train consists of a low carriages with a central structural turntable that serves as an access ramp for road vehicles. Unlike classic combined transport, neither crane nor gantry is required, since trucks are present. But the station must be specialized and dedicated; its operation is more expensive.

[111] The Cargo Speed concept, roll on-roll off (Ro-Ro), is based on a rotating lifting system (the "pop-up" mechanism) incorporated in the line between the rails. The terminal can be used to load 30 semi-trailers in parallel without additional handling equipment.

[112] Thus, most of the traffic between the north and south (and vice versa) of France is performed in "night drop", i.e. departure of the train in the late afternoon (~19:00 h), arrival in the early morning (~06:00 h).

[113] Four rail motorway links are operating in France (2013): the TransManche connection with Britain, the Aiton-Orbassano transalpine link with Italy by Frejus rail tunnel (called the Alpine rail highway AFA), the rail highways plain links of the Perpignan–Luxembourg (extended to Sweden), and the Atlantic (Basque Country-North of France) for transit with Spain (Lorry Rail/Geodis VIIA).

[114] For example, the Dourges platform near Lille (France) has allowed, since 2003, the combination of rail, road and waterway. With a holding of 300 hectares, it includes a combined transport site and logistics area providing good attraction of the site. Its operating structure, in which several operators are involved, is itself innovative. An extension of 120 ha is underway, to implant 300,000 m² of new warehouses in 2015.

a) b)

Figure 4.21. *Combined transport systems. a) A piggyback train [MOD];b) a transsshipment swap body http://www.modalhor.com/*

The challenge is to strengthen the credibility of rail as a structural element in the efficiency of the supply chain from origin to final destination. Economic performance, varying across countries and organizations, however, is not currently provided[115]. Performance in terms of flows is also limited[116]. High speed rail freight transport (such as the European CAREX[117] network or TGV Lyon-Turin) should not change the situation on the economic front and the demonstration of their environmental interest poses many questions.

Under these conditions, *the road mode* is omnipresent but it should move toward greater efficiency associated with a reduction of its environmental footprint.

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[115] The – relative – success of these initiatives in France is shown by the Court of Accounts (France) 2011 report. It points to an operation deficit of the alpine highway, which survives on grants from the two states of France and Italy (€5 million in 2011), despite a 50% gain in traffic in the last five years. It only carried 26,000 trucks in 2011, compared to 100,000 expected at launch. The 1,000 km railway highway between the Grand Duchy of Luxembourg and French Catalonia are also subsidized, at 40%.

[116] Forty vehicles per train, 20 trains per day would give 800 veh/day (in 2011, there were 11,000 veh/day on the Atlantic road axis between Spain and northern France).

[117] The EURO CAREX project aims to create a rail service for the modal shift of trucks and short and medium-haul cargo to high-speed trains for freight transport and air pallets, starting with a network of rail lines linking some major European airports (www.eurocarex.com).

In terms of footprint, to replace diesel derived from fossil fuel, we have engaged the partial introduction of biofuels (usually in the form of a blend) from different sectors in different regions. Natural gas in its liquefied form (which allows a satisfactory range, typically 800 km) could power big road trucks by introducing the necessary infrastructure. In the long term, it suggests "electrified highways" (Chapter 5).

In terms of efficiency, these energy changes will be accompanied by a high intelligence capacity to "produce" transport according to "green corridors" from the point of view of optimized traffic safety, environmental footprint and flow. In terms of vehicle architecture, it could evolve in the direction of massification and modularity to do "more with less" and better cover the different needs of different transport businesses and their standardized containers.

Fill rates are high but still perfectible; they usually saturate more volume than mass (for general cargo[118]). Figure 4.22 shows the fill rate observed in a European transport company in 143 trips. The units are the number of pallets, m^3 (v), kg (mass). In this configuration, it is primarily the number of pallets that characterizes loading performance, then volume, then the mass of the transported goods.

Specific to the European context of regulating weight and dimensions of vehicles, the current debate on the *EMS (European Modular System)* is indicative of prospects for road freight improvement and the accompanying tensions given the risks expressed by some[119]. The EMS is a rolling assembly of greater length than conventional road trains. They consist of standardized combined loading units (tractor or rigid, semitrailer, trailer, dolly), the total of

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[118] For specialized transportation, the nature of the filling is not bidirectional: this is the case for transports shuttling between a collection point and one (some) point(s) of deposit (garbage, supermarket deliveries, building materials, etc.). Note that this is also the case for an individual or household who goes to the mall for weekly shopping.

[119] EMS is also referred to in the media and by pressure groups as the "super truck", "eco-combi", "monster truck", "mega-truck" or "giga-liner". Critics especially accuse it of strengthening road competitiveness at the expense of other modes (rail and water). Supporters highlight the economic and environmental benefits compared to conventional road vehicles.

which is longer and heavier than a conventional {tractor + trailer} set. A multitude of combinations exist[120]. To give an example, two EMS convoys provide the same transport capacity as three conventional vehicles. The consolidated benefit in terms of energy efficiency is approximately 25% (Figure 4.23).

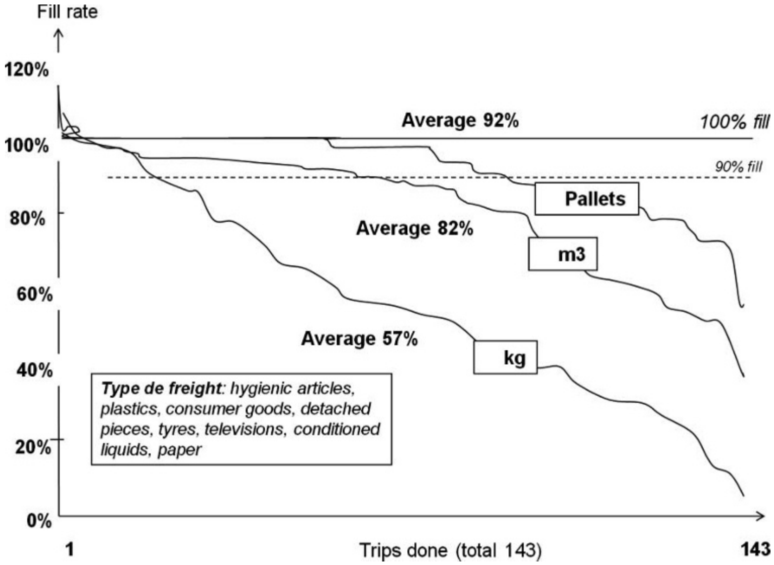

Figure 4.22. *The loading rate (number of pallets, in volume or mass) of semitrailers for shipments of general merchandise. Statistical distribution of the measured values of 143 transports for a European transport company for 3 months in 2001 [AB]*

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[120] The peculiarity of such a team, approved by the European Directive 96/53/EC, is its size: unlike classic heavyweight features limited by national rules (in France ,18.75 m length and a weight of 44 tons for a {tractor + semi-trailer} set), a rolling assembly of great length can be up to 25.25 m and have more than one joint. The whole set may exceed 40 tons provided it is to increase the number of axles: 48 tons for 7 axles, 58 tons 8 axles (with at least two driver axles). These EMS transport 52 pallets at European standard or ISO standard containers instead of the normal 33.

The European Directive, which limits the length of border road trains in circulation to 18.75 m and that of road assemblies to 16.50 m, allows Member States to authorize longer vehicles, or vehicles that are longer and heavier than those authorized in international traffic, in domestic traffic in their territory including "for transactions using a modular approach". Sweden and Finland have allowed EMS since 1997, the Netherlands joined more recently (under framed conditions).

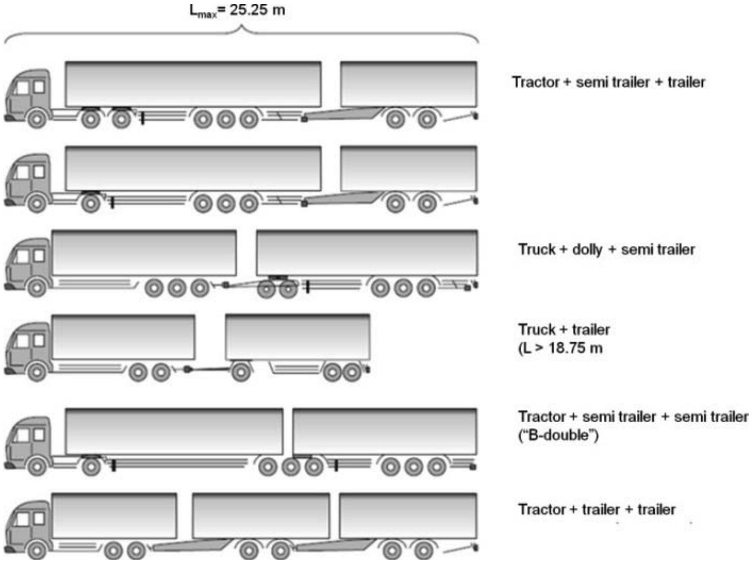

Figure 4.23. *EMS silhouettes from recombination of existing elements (www.ems-france.org)*

From the perspective of sustainable transport, intercity logistics therefore present all the characteristics of squaring the circle: an insoluble problem, an impossible thing: the organization of globalized trade pushes the flow of goods in maritime corridors through ports, depending on the available ground infrastructure. The distribution of these flows is based on territorial logistics structure (their platforms, production and consumption areas). It uses the most relevant modes of transport from the point of view of efficiency. The question is not to transfer freight from road to rail (or waterway), but to ensure greater complementarity and seek the best overall effectiveness of this link in terms of sustainable mobility.

4.11. Paradoxes and mirrors of sustainable mobility

Overall, we need to modify our appreciation of the organization of mobility as a potential lever for sustainable transport.

For urban mobility, organizing the transport of people results in light and scattered urban periphery modes complemented by more massified modes, as the heart of town is approached. The heaviest modes circulate in the vicinity and inside urban centers[121]. In contrast, for the transport of goods through an organized transport approach, massification is done the outskirts, on as public power restricts their diffusion to the center, resulting in large regional vehicles in the urban periphery relayed by small vehicles in the town center. A suburban park-and-ride scheme for the mobility of people, connected to the city by a public transport massification "bar", is directly analogous to that of an urban logistics space powered by a collective transport "bar" of goods, but with one fundamental difference:

– for the mobility of people, the park and ride is usually on the outskirts of town, as massified transport "tucks" users into the city (Figure 4.24);

– conversely, as we saw in Figure 4.17, the urban logistics space is in the center of town: here, massified transportation "tucks" goods from a logistics consolidation center on the outskirts;

– the superposition of the two schemes with respect to the urban area shows that in one case (for people), the massified corridors are predominant and intersect in the heart of town to diffuse widely in the periphery. As for goods, the reverse is true (Figure 4.25). There exists a kind of bilateralization of the structuring of urban transport systems that act as attractors of mobility of people through infrastructure and politically encouraged organizations, and "repulsors" of goods that seek to enter the economic engine.

The two modes of organization and structuring (corridors, platforms, governance) should become more coherent and effective by the widespread intelligence that will pervade all expectations and operating urban mobility systems.

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[121] By "urban center", we mean the space with a relatively high density of population and activities in comparison to the whole urban area. It is not only the very center (usually the historic heart of the city) but also its concentric extensions.

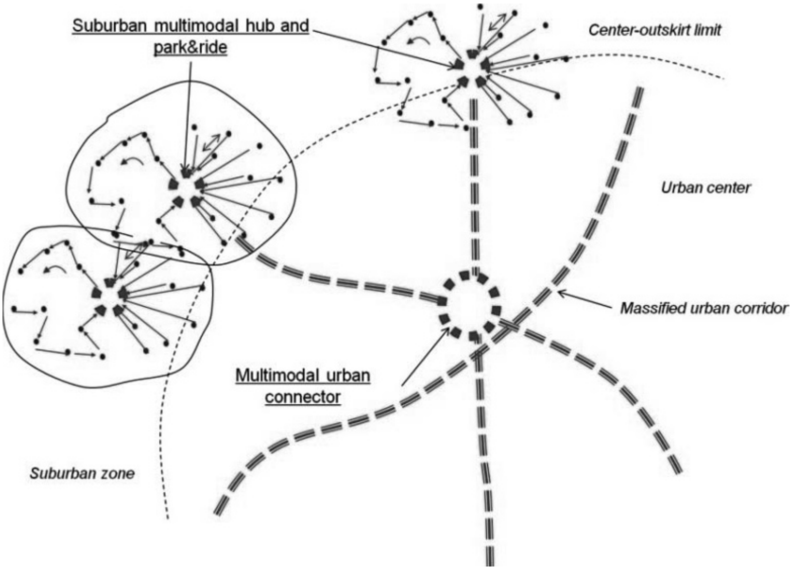

Figure 4.24. *Illustration of the linking of transport systems for urban mobility of people [FAV 13]*

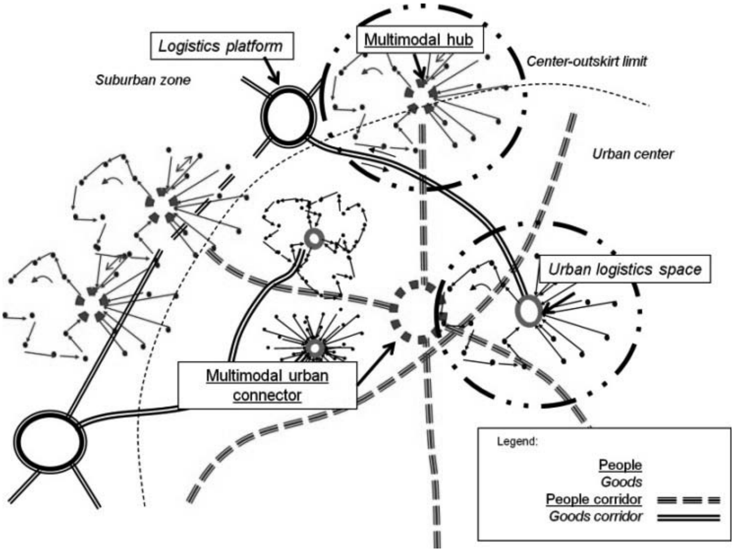

Figure 4.25. *Bilateralism of urban transport systems structuring for people and goods [FAV 13]*

For long-distance mobility, goods hasten slowly when people are hurried. The slow never-ending traffic of container carriers or massified bulk carriers flows powerfully through shipping lanes where energy expenditure is marginal per transported metric ton (pending a better performance, even with the return of sailing ships). In comparison, the rapid flow of air-transported passengers consumes an unreasonable amount of liquid fossil fuels today (and in the future). The two streams meet and oppose on railways and roads, sharing the same "cake" (train paths, highway lanes, (air-)port infrastructure) at a highly contrasted energy cost: *a person consumes 30 times more energy, for the same traveled distance, compared to a commodity of equivalent weight.*

All these flows have one ultimate goal: to satisfy essential mobility needs, necessary or unnecessary, of the consumer-worker-fellow-taxpayer that we each are alternately. Each of us is a stakeholder of our own mobility and what this implies regarding the satisfaction of our needs and wishes.

Chapter 5

Innovation Projects for Sustainable Transport Systems

In this systemic context, introducing innovation is not easy. While technology provides spectacular inventions in the areas that we have developed (energy, materials, intelligence), their implementation and deployment into the sustainable transport market requires more than just good intentions. We need to collectively organize the steps to gradually achieve a convergence of the conditions for a successful transition from invention to innovation, from the laboratory to the market.

5.1. Dealing with the transport system through the multistakeholder approach

Consultation is on the agenda, as sustainable mobility solutions will come from a coordinated set of actions on vehicles, infrastructure, operating conditions and their uses. The time of spontaneous and individual initiatives bringing significant progress seems behind us; we must now ensure governance of innovation in transport.

Contemporary media based on the Internet, images and social media networks have facilitated the emergence of consultation structures, which are in full swing. Whether these are associations, clubs or clusters of R&D, innovation or business nature, whether with a technological, socioeconomic or political connotation and of local initiative or global ambition, these structures bring together networks involving the world of research and the world of industry and public organizations. They use think tanks, seminars and workshops, webinars, etc., where experts share, brainstorm, imagine solution ideas, decide on projects and undertake developments leading to innovative proposals. The field of transport and mobility is full of such initiatives.

The projects that lead to sustainable transport solutions demonstrate the interest – and the need – for a multistakeholder approach. It should cover not only the technological field but also economic, social, legislative and regulatory aspects.

Innovation indeed implies “the meeting of an invention and a market”. Here, the invention relates to an integrated set of products and services. As for the market, it is dependent on achieving performing results in terms of effective and demonstrated mobility, the application of normative, incentive and regulatory instruments as well as a competitive new solution compared to current solutions in terms of internal and external costs[1]. It is mostly the result of an awareness, appropriation and dissemination of new applications. Technological innovations should indeed be appropriated by stakeholders. If users do not change their behavior, they are not fully appreciated.

The deployment of an approach involving human, economic and social sciences, along with technical sciences, is a guarantee for good treatment of this essential part of innovation in the field of sustainable transport. It involves imagining and the acceptability and ownership of solutions, together with their sustainability over the long term, and also resilience[2] to accidental or intentional risks. The integrated approach, whether cross-sectorial and multisectorial, is therefore essential for addressing the development of relevant innovation. In

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[1] We must, in particular, evaluate environmental impact costs.

[2] Here, resilience is the ability to anticipate risks in a system, to provide the means to build a protection policy together. If a risk becomes a reality, it allows us to manage the crisis better

addition to stakeholders in charge of the transport system itself, public authorities, economic stakeholders, other transport and infrastructure users are also involved.

5.1.1. *LUTB Transport & Mobility Systems*[3] *think tanks (see the appendix about LUTB)*

For example, the LUTB Transport & Mobility Systems think tanks have debated, since 2006, the evolution of transport systems of people and goods necessary for urban areas: they discussed how to improve and coordinate all entities (vehicles, infrastructure, organization and mode of operation) to provide a transport service adapted to its use. Transport solutions for cities should satisfy the different needs of mobility of persons (individual, collective, interactive) or goods (distribution, cold chain, roads, hazardous materials, etc.).

This requires a multistakeholder approach covering the chain of action for smooth deployment. The large-scale testing of solutions before they are placed on the market is fraught with difficulties because we must submit a solution integrated with the constraints of a multidimensional environment and evaluate it under different angles: performance (notably environmental) and reliability, its economic relevance, resilience, governance and acceptability of different types of stakeholders. To be able to configure a transport solution in a dedicated urban environment that can restore all or some of the constraints of a real situation, a few testing platforms have been deployed in the world with the capacity to test advanced multistakeholder technologies[4].

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[3] LUTB Transport & Mobility Systems is a cluster that aims to deploy innovative products from R&D initiatives from industry, research and educational organizations and national government agencies. Involved in developing urban transport solutions based on mass-scale transportation, it originally focused on applications for trucks and city buses. It has gradually developed an interest in all transport and urban mobility systems (www.lutb.fr).

[4] These platforms can deploy from laboratory conditions (such as the TRANSPOLIS platform project, whose goal is to develop mass-scale public transportation systems [TRA 11]), up to full scale of (nearly) real urban environments (such as the city of Masdar, in Abu Dhabi (United Arab Emirates) [MAS 13]).

The emergence of *living labs* sites is another example of this evolution. These are typical of a public–private partnership putting users themselves in the position of experimenter under real conditions in order to test innovations in mobility. They can observe performance and identify the systemic relevance of innovative transportation solutions based on a reduced sample placed in a contextual situation[5].

Let us take, for example, urban logistics. To develop sustainable transport solutions, it is necessary to deploy a multistakeholder approach. Figure 5.1 shows their diversity and connections.

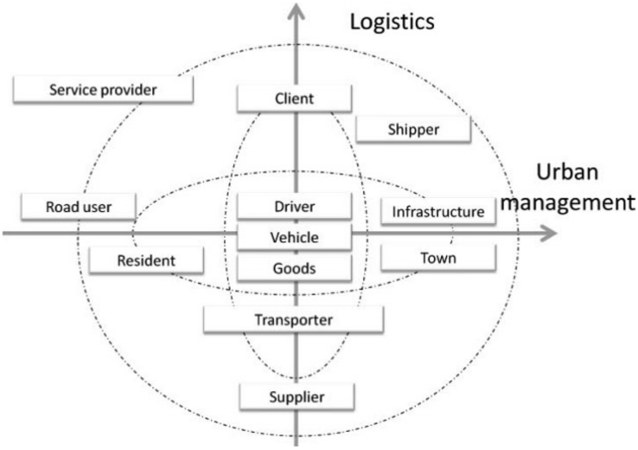

Figure 5.1. *Stakeholders of a transport system – example of urban logistics [FAV 11c]*

It shows the interest and the need to coordinate these stakeholders in order to identify the most relevant solutions for rehabilitated urban logistics. It includes the following:

– Stakeholders in the supply chain. These are essentially private. Their purpose is to ensure proper distribution of the goods, in cost and time. Let us note that this causes another channel to appear in our range, the “from supplier to consumer” channel, which passes through the shipper and the transporter.

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[5] Among the many examples currently in Europe, the Augmented Mobility in Brittany (BMA) project involves 18 demonstrators and 45 solutions to evaluate and “operationalize”.

– Urban management stakeholders, mainly public, including city authorities, users and infrastructure managers, and local residents themselves. Their purpose is not only to minimize the environmental impact of urban operations, but also to ensure the proper functioning of a city.

– At their "intersection" is the driver, his/her vehicle and his/her cargo, body and goods.

– Within their boundaries are service providers for optimized urban logistics.

5.2. Transport systems and energy

We have seen (Chapter 2) that new energy solutions for transport vehicles are being deployed or planned, as shown in Figure 5.2. To ensure their efficiency and economic and societal relevance, they must be evaluated in a system context. It is here that the need to position them among all their interactions with the real world comes into play: how to fuel these vehicles with electricity, hydrogen or other environmentally friendly fuels, which can be alternatives to fossil fuels? What are the actual performances, instant and in time? Can they be generalized (to an entire fleet) or transposed (to other applications)? Are they applicable (by retrofit)[6] to vehicles that are already in circulation? Can we deploy them on a European or global level and according to what standards? What are the real impacts on the economic and environmental plan? What is (are) the business model(s)? All these questions and many others can only be resolved through increased cooperation between stakeholders, on the basis of scenarios under real conditions with tests and trials, evaluations and conclusions for enlightening economic stakeholders and public authorities. In addition, these activities are accompanied by the establishment of normative, standard and regulatory tools.

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[6] The term "retrofit" means the acts of equipping vehicles that are already in use, therefore are being used, with additional equipment leading to improved performance (here, environmental performance).

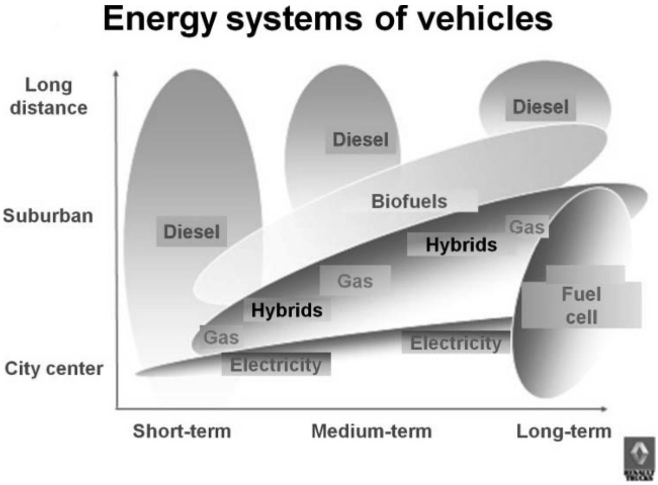

Figure 5.2. *A vision of the evolution of energy systems for freight transport road vehicles [FAV 09]*

The start-up and take-off of *the electric car sector* (and hybrids) provoke all the encouragement and desires of public powers. The deployment of recharging infrastructure supports the establishment on the market of a set of vehicles produced either by established manufacturers (who have a range of new types of vehicles offered on the market with adapted economical models) or by new entrants convinced of the short-term potential of this market[7]. The launch of this however, in 2013 remains very fragile and limited to a few hundred vehicles monthly, in significant markets (France), with a breakthrough in light commercial vehicles. Correspondingly, the installation of recharging stations available to owners of electric vehicles continues to increase on roads and in public car parks[8].

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[7] At the end of 2011, for 32,880 electric vehicles in Europe, and 613,226 electric two-wheeled vehicles, there were 10,869 charging stations and 166 rapid charging stations [AVE 12].

[8] We counted in France, in February 2013, 1,473 public charging terminals available to electric cars, with 5,698 plugs installed, and a target of 8,000 terminals installed by late 2013. In one year, the charging infrastructure has been multiplied by 4.4 (334 charging stations in February 2012). The European Commission recommendation would be to set up 97,000 charging points in France by 2020. These measures could increase to nearly 795,000 charging stations available to the public in Europe in 2020

The electric vehicle was developed to be deployed in urban areas, for which there is already a credible response, allowing unrestricted access to all protected areas, day or night. But it has real flaws regarding other types of use because of its limited autonomy. Some also blame it for being a vector of social disparities, because although it complements the already prolific offer of urban transport means, whether public or organized, it does not yet provide a definitive answer to commuting from urban peripheries and on an intra- and interregional context. The individual hybrid vehicle obviously expands this potential. The evaluation and implementation of hybridization, which is now widely acclaimed for pure applications of individual vehicles, continues for more specific applications, whether they are goods[9] transporters or city buses[10].

5.2.1. *Electric charging stations*

Designed to be able to connect to household equipment with a standard plug, electric vehicles will get better charging performance at specialized charging stations. The current generation of electric charging stations (which operate via a cable between the station and vehicle) includes a management and payment system. It involves energy supply and data exchange (for example the state of the battery or time of charging onset). It is designed to ensure safe use. Connected to the distribution network, itself connected to a server, it adapts to

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(compared to about 15,000 in 2011). France has an even more ambitious goal of 400,000 charging stations by 2020, corresponding to a fleet of 2 million EV or HEV, with an intermediate step of between 30,000 and 60,000 charging stations in 2015 (for a fleet of 150,000–300,000 vehicles) [AVE 13, HIR 13].

[9] Tested in early 2009 as part of an experiment under real operating conditions, a Renault Premium Distribution HybrysTech truck, used by Greater Lyon and SITA (Suez Environment) for nearly a year, carried out 5,000 km of testing as refuse collection, in 500 operating hours and collecting 550 metric tons of waste. Measurements confirmed the reduction in consumption by 20–25 %, ease of use, low noise level of the vehicle, especially during the collection in all-electric mode. Other tests were performed for other transport professions: construction approach (with Colas), delivery of beverages (with Coca-Cola) [FOR 12].

[10] The urban community of Bordeaux and Grand Dijon acquired, respectively, 30 and 102 hybrid buses (2013). That same year, Quebec equipped itself with more than 400 hybrid buses.

any environment[11]. The battery is charged using a charger that converts alternating current from the network to direct current, only possible when charging a battery. The charger is either embedded in the vehicle (usually 3.5 kVA power, or even 7 kVA) or positioned in the charging infrastructure; in this case, the constraints of weight and size being small, power can be much higher (up to 50 kVA or more). The technical characteristics of the electrical plug, the cable connecting to the vehicle[12] and the vehicle side connector are still the object of different options: first, to meet the different needs of charging speed or different types of vehicles (electric or hybrid cars, quadricycle, scooters, etc.) and second, due to the absence of a definitive and widespread standardization[13]. The charging time of the battery is directly related to the power of the charger[14] (Figure 5.3).

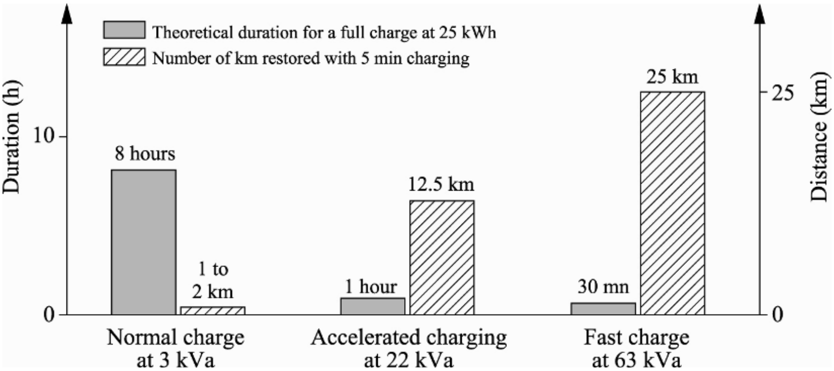

Figure 5.3. *Theoretical duration of complete charging for an electric car with a capacity of 25 kWh [HIR 13]*

We observe that the deployment in great numbers of rechargeable electric or hybrid vehicles requires charging infrastructure to be

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[11] The SOBEM-SCAME Evolution range includes a GPRS connection to perform updates remotely in order to incorporate new identification or payment features.

[12] This cable can be fixed (attached to the station) or embedded (attached to the vehicle).

[13] In 2013, several proposals coexisted, including the “type 2” by Mennekes and the “type 3” by Schneider Electric.

[14] For a car, it is 6–8 h for a normal charge (3.5 kVA), half an hour for fast charge (43 kVA).

available in public spaces[15], in addition to facilities being available at home, work or in private spaces in general (vehicle depots, for example). Conversely, the design and distribution of public infrastructure depend on development prospects for the vehicle market. This training relationship, where cause accompanies effect, exemplifies the need for concerted policy between different stakeholders so that they can move "conservatively", which is a major prerequisite for successful implementation of sustainable transport solutions (Figure 5.4).

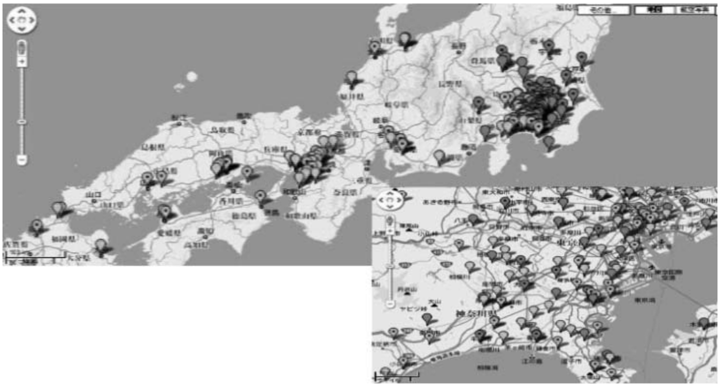

Figure 5.4. *Geographical location of fast charging points, Japan (2010)*

In France, for example, public recommendations are to invest in equipment for a charging station in public space whenever a (local or regional) fleet acquires five additional vehicles (electric vehicles (EVs), hybrid electric vehicles (HEVs))[16]. This requires considerable

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[15] For a user with a garage or a single parking space in France, 90% of recharging is done in the private sphere (home, work place if equipped), 1% public parking, 4% on the road, 2–3% on private land open to the public and 2–3% by fast charge, usually at a service station [HIR 13].

[16] According to these recommendations, an urban area of 200,000 inhabitants in France, which would include a fleet of 1,000 EV-HEV in 2015, should have 200 stations for normal or fast charging (without focusing on fast charging) in public spaces. Investment costs are estimated at between €3,000 and €8,000 per station for the materials, engineering, civil engineering and network connection. The annual maintenance cost would be 10% of that amount. Fast charging would be more limited, depending on the service station model, with much higher costs (between €30,000 and

anticipation in the allocation of budgets and public decisions, in the context of uncertainty about market visibility. Some car manufacturers are also taking initiatives to establish consortia and encourage charging infrastructure equipment[17]. In addition, they develop services allowing vehicle users to maximize their ease of use and research charging facilities more efficiently, developing tools based on global positioning systems (GPS), smart phones and other mobile and connected means[18]. Economic models associated with these investments (pricing, billing, maintenance) do not seem stable[19].

We note that it is necessary to average the supply of electricity over time to satisfy all EV-HEV fleets in all these charging facilities. The instantaneous electrical power required and the acceptable limits of production and installed electrical distribution networks raise supply difficulties that must be addressed in a flexible manner that is also synchronous with the charging requirements of vehicle fleets dependent on usage. The challenge is to better distribute electricity consumption at the right time, depending on the distribution capabilities, avoiding peak phenomena (typically in the evening after work). The question of resource management involving production and consumption of electricity, known as a "smart grid"[20], is not detailed here. But it must be kept in mind because it is obviously a key component of electromobility. Many evaluation projects on EV charging are also carried out in order to test for the most effective

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€55,000). For comparison, a home charging system costs between €500 and €1,000 [HIR 13].

[17] Nissan has partnered with Circutor, DBT, Efacec, Endesa and Siemens in order to accelerate the development of cheaper and more compact fast chargers in Europe.

[18] BMW-i is an example of this approach.

[19] Because of the diversity of parking spaces, including their management, three large management cases are to be processed: public parking spaces managed by a dealer under a public service delegation (PSD) contract; those managed directly by the community as part of a control authority (in this situation, there is no intermediate operator, the community must establish an *ad hoc* contract and call a specific operator) and finally, private spaces open to the public (with different situations, depending on the existence – or not – of a sub-dealer). There is also a plan to establish a link with car-sharing deployment services [HIR 13].

[20] The smart grid refers to the entire chain from the point of production to the point of consumption of electricity.

strategies in terms of technology (connection, identification), control, pricing or performance[21,22].

5.2.2. *Other fast charging*

A charging terminal for electric vehicles located on public roads occupies a significant space and represents a potential target for vandalism. In these developments, "wireless" charging should play an increasingly important role. Currently behind compared with wired solutions for standardization reasons, it could occupy a significant part of the market in 2020 [PIK 13]. This solution has already been tested or implemented in niche situations, for example supplying a fleet of vehicles dedicated to repeatable tasks (buses, mining fields, etc.). The transfer of electricity from grid to vehicle can be made in different ways in the absence of cable: it may or may not involve contact.

For technologies with electrical contact but without a connector cable (conduction solutions), and beyond well-known trolleybus applications that are widely distributed in some European cities, we have seen the emergence of solutions for road vehicles called "opportunity charging": city buses charge their batteries or super-capacitors when they stop at their station or depot through a catenary[23] mounted on the roof and connecting to a gateway positioned at the

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[21] We can mention the SAVE projects in France, Eco Grid/EDISON in Denmark, EKZ in Zurich, "Green e-motion" in Europe (information provided through AVERE France, see www.france-mobilite-electrique.org/).

[22] The SAVE project (Seine Aval Electric Vehicles) (2011–2012) mobilized eight public (CG Yvelines and the Ile-de-France region) and private partners (Renault-Nissan Alliance, EDF, Schneider Electric and Total), and 65 electric vehicles; 130 charging points have been installed in public and private spaces, involving 40 communities and businesses. Throughout the project, recharging was carried out 6,200 times, representing 70.5 MWh. The costs and installation problems of charging stations were evaluated: interoperability between networks, terminals and vehicles, need for power management devices, specification for tools and supervision and operation services of charging station networks (http://www.renault-ze.com/en-gb/z.e.-news/save-project-61017.html).

[23] A number of experiments are demonstrating systems based on tram or trolleybus technologies and operating through pantographs that charge the batteries in a few minutes when the bus arrives at its terminus. The process is fully automated and the driver does not have to leave his seat to activate it.

endpoint during the time of parking. Energy transfer takes place during the contact and it stops when the vehicle is restarted. The design of the system aims to provide the vehicle with just the right amount of electricity needed to continue its mission until the next recharge. This principle can be generalized to any vehicle linked to a mission, a regular and predictable route, it optimizes the design of a global transportation system in terms of fixed charge capacity relative to the energy capacity on board the vehicle: the number and distance between points of charge, and the charging time at these points are related to the design of batteries on board the vehicle for energy and electric power and, subsequently, the associated weight and cost.

An alternative to a plug on top is *ground contact* connecting to an infrastructure buried in the road. Charging can be achieved by a conduction bar above which the vehicle is positioned. The vehicle is then equipped with an underbody collection system. These devices are especially used for captive applications (service of an industrial plant, for example). We must obviously control the risks in terms of handling and safety.

In *contactless charging systems* that use different variants of available technologies (near-field or far-field, inductive coupling, resonance induction, microwaves[24], etc.), particular emphasis is placed on *charging by induction*. These emerging applications of a proven technology for transferring electrical energy from one coil integrated in the infrastructure to another coil embedded in the vehicle, with a respectable yield (80–90%). The constraints of vehicle positioning relative to more or less demanding installations in terms of distance and alignment may require robot-guided assistance. The design of the system naturally depends on the performance (slow or fast charge, vehicle type[25]). The potential risks of these devices on health have not

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[24] The possibility of transferring powers of 10 kW over a distance of 4 m using microwaves of 2.45 GHz and a yield of 84% was demonstrated by Nihon Dengyo Kosaku (Dengyo) Co Ltd and Volvo Technology Japan in 2012 (http://www.greencarcongress.com/2012/.html)

[25] The 12 m electric bus from the company e-moss (NL) is thus powered by an inductive charging system of 60–120 kW from the Conductix Wampfler company. Charging by injection feeding during trips in addition to the deep night charging

been fully evaluated. Note that these devices can be implanted laterally (for example at the license plate of the vehicle).

Replacing the battery when it is empty is an alternative to fast charging as discussed above. This principle has long been practiced in a traditional manner (for example in municipal vehicles), but now has its modern counterpart in the form of a specialized electric car service station: the automatic replacement of electric batteries is done using a robot positioned under the car to access the old battery and extract and replace it with one that is charged. The cycle time is approximately 3 min. For the Better Place company, the owner of this concept and the origin of its implementation, it is more than just a solution in itself; this is a tool included in the sale of electric mobility, which hits the bull's eye and includes rental of an electric car, its batteries, access to charging infrastructure and electricity costs[26]. Removal of the old battery and its almost instantaneous replacement are possible in specialized stations and participates in the provision of an integrated mobility solution that transforms the economic model and changes the relationship of the user relative to the vehicle, from the status of owner (of the vehicle and its battery) to the user of an electric mobility service that is charged for use and not for possession. Note that this business model, for which the similarity to well-proven mobile phone models is regularly stressed, is not the prerogative of a single company. Various operators or consortia involving vehicle, batteries and charging station manufacturers, service providers and electricity suppliers (preferably "clean") now offer an integrated solution to equip public areas and spaces with a charging infrastructure network and market the electromobility service using contracts that are usually subsidized by public funds. The launch is fragile but the movement seems irreversible.

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allows it to be operational for 18 h, traveling 288 km per day, without having to resort to lengthy stops to achieve a full charge.

[26] Better Place has chosen Israel and Denmark as two pilot markets to equip and deploy its offer, in partnership with Renault-Nissan as the supplier of electric vehicles. In Israel, 21 rapid exchange stations ("battery switch station" or "Quickdrop" according to Renault) were operational in 2012 as well as 2,000 charging points.

5.2.3. *Toward electric motorways?*

By installing induction terminals under the road infrastructure, we can profoundly alter the status of this infrastructure: any electric vehicle equipped with a system adapted to the capture and management of energy transmitted by induction can be recharged automatically at passage over this type of terminal, starting with car parks[27], then traffic lights and then along common road sections. This reasoning also holds for conduction devices, whether the electricity is provided by contact with the ground infrastructure through rubbing, from the top with catenaries[28,29] or laterally. It is thus easy to dream up road infrastructures continuously equipped with charging devices for dynamically providing the electricity required to move the vehicle, which would charge its batteries through current capture, depending on its progress and then move on to non-equipped sections using the electrical energy on board. Some even believe that eventually, roads would be convertible into photovoltaic panels, which transform, store and then deliver solar energy to vehicles because of these charging devices.

Several recent projects in Europe, the United States and South East Asia[30] allow us to assess electrical charging during movement. Different induction[31] or conduction technologies have been tested, for which efficiency performance, power level, safety, cost, Quality-of-Service, etc., are subject to developments. In these applications, batteries embedded in the vehicle are smaller than those required for

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[27] A future solution to rehabilitate delivery areas: equip them with contactless charging and management devices (booking, communication, services) that are adapted to electric trucks [LUT 11a].

[28] The Siemens company has widely communicated its experiments on hybrid trucks that charges through a catenary on a dedicated motorway lane (2012).

[29] These devices exist already for the urban trolleybus equipped with perches that provide electricity capture from above.

[30] These R&D projects are generally financed through public aid. They show the relevance of a coordinated approach. Initiative carriers are generally transport or vehicle industries and they cooperate with industries in the electricity, infrastructure and services sector.

[31] The project conducted by the Energy Dynamics Lab (EDL), a subsidiary of Utah State University, has demonstrated 5–10 kW transfer by induction, under laboratory conditions, with a yield of 97%, the terminal being at a depth of 200–300 mm below the ground.

static charge. Demonstrations are systemic; they address different aspects – economic, legal and organizational – conditioning real implementation of these systems.

Beyond the theoretical vision of an elegant long-term solution where roads could function like electrified rail infrastructure, with flexibility and autonomy in addition (especially the ends of “lines” and the first/last kilometers, which could be done autonomously through on-board electricity), the obstacles appear to be very high:[32]

– they underlie the establishment of vehicle equipment first, with the ability to dynamically acquire electrical energy, under good energy efficiency and safety conditions;

– infrastructure (as well its power supply by properly-designed energy stations and networks) is yet to be installed and maintained despite traffic circulations that risk gradually damaging the electrical equipment[33];

– operating conditions and integration of traffic must be mastered, inevitably initially dominated by more “conventional” vehicles;

– the precise positioning of vehicles relative to electricity supply infrastructure is also a prerequisite. The need for ITS technologies to achieve this is a “must”; they are also required to control energy exchanges. They can intervene in a dual manner (also using the energy transmission channels as communication channels);

– risks must be addressed to prevent accidents or to intervene in case of an accident. Maintenance interventions must be set out.

Among many other questions, it is necessary here to have an appropriate business model that considers investment and operation. Until these conditions are met[34], the issue of equipment of dedicated

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[32] [AVE 13].

[33] Henri van Damme (IFSTTAR 2013).

[34] Opinions are controversial about the costs, implementation methods, and deadlines for the concepts of electric highways providing dynamic energy. Costs of approximately €0.5–€2 million per kilometer are suggested. The completion prospect is 3 years for a vehicle equipped with mature technology, 5–10 years for circulating clusters of hundreds of demonstrator vehicles, decades (50 years?) for real generalized applications [AVE 13].

infrastructure portions, either in continuity or locally, is raised. Different architectures are possible to “pave” the transition from the equipment of in-station fixed charging points, which are on the agenda of the 2010s, to continuous dynamic charging points, whose outcome could be considered the “long term”: pending perhaps gradual trivialization, once the interoperability of a standard charging system is provided for travel for the greater number of vehicles, adaptations of the general concept are quickly imaginable for individual cases; examples include equipment of new reserved/dedicated road infrastructure for truck traffic along specific corridors, or that of urban lanes also reserved/dedicated to urban vehicle traffic lanes, analogously to sites today that are dedicated to public transport.

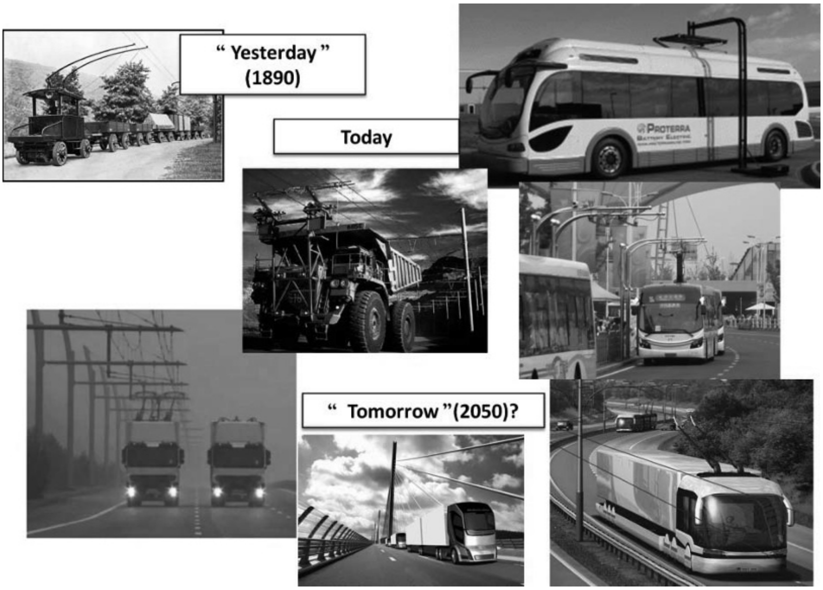

Figure 5.5. *Illustration of a modernized old idea: the electric road. Trolleytrucks and trolleybus, charging infrastructure by conduction or induction (see Low Tech Magazine*[35]*, Proterra*[36]*, Siemens (2012) and Volvo (2011)*

Without waiting for these foreseeable niche developments (as illustrated in Figure 5.5), possibly too futuristic in their deployment,

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[35] www.lowtechmagazine.com.

[36] www.proterra.com.

some corridors are now reserved only for electric vehicles carrying their own electricity on board: these vehicles do not recharge while continuously draining their energy infrastructure during movement, but only at static itinerary ends[37]. The term "electric highway" then covers an obviously much more limited outline.

5.2.4. *Other energy solutions*

In parallel to electric charging infrastructure, for which the principle is now widely acclaimed, other types of energy alternatives are widely mentioned, evaluated and even encouraged by multistakeholder initiatives backed by public funding: they involve, depending on region of the world, compressed natural gas (CNG), liquefied natural gas (LNG) and hydrogen, all potentially from a renewable primary energy.

Let us underline first that the maturity of these sectors is generally low. The problem is not only the station providing the energy: the production and transport of energy to the station are other factors (as well as the availability of vehicles with corresponding technologies). Let us also emphasize the need for standardization (at least European) of these stations. Technical specifications and common security are also needed regarding refueling points, whether hydrogen or natural gas, whether in gaseous form at high pressure or in cryogenic liquid form (pending hypothetical solid storage). In general, the lack of consensus on a European standard is considered by some experts as one of the most important barriers to more widespread use of alternative energy vehicles in Europe. Finally, the equipment of stations and infrastructure for hydrogen and natural gas runs into competition with the electricity sector, which alone attracts near-exclusive investment, whether public or private (we saw that it was one of the conditions for the field to take off). There is clearly a plethora of channels in potential competition in relation to financial possibilities. These are insufficient to establish coherent systems

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[37] In the Netherlands, an "electric highway" (Freeway electric) reserved for electric two-wheelers (bikes and scooters) connects, since 2013, the cities of Almere and Amsterdam.

beyond the scope of a local initiative, and their economic and environmental relevance for the long term is not sufficiently demonstrated.

Local initiatives, however, tend to encourage the emergence of solutions based on local stakeholders or potentials, with captive fleets:

– turning agricultural or hypermarket waste into biogas to power buses or trucks;

– turning household waste into hydrogen to power garbage trucks;

– using a local power generation installation to store it in the form of hydrogen;

– not to mention all the possible combinations (joint use of gas and electricity, or electricity and hydrogen, and other possible combinations for applications in transport and housing).

They can certainly lead to relevant local ecosystems in principle, but are still not very effective from an economic and industrial point of view, and especially not easily generalizable to transport (which is the most difficult to implement because it requires on-board energy).

For hydrogen, cooperative initiatives have been around for a long time, but they are not accomplished and are scattered. We, nevertheless, feel they could gradually bear their fruit:

– in particular, because hydrogen has the capacity to store the surplus energy, whereas electricity has a net deficiency;

– but also because the hydrogen sector may require, in relation to its electricity equivalent, less investment in material quantity (copper, lithium, etc.) and network equipment.

We note, for example, a very significant activity in Germany for the entire hydrogen sector and in France for storage and applications[38].

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[38] The GRHYD project, launched in 2013 and led by GDF Suez with a dozen partners, aims to test the use of hydrogen (produced from electricity supplied by wind turbines) in transport and housing at a neighborhood scale. On the transport side, the goal is to learn how to store and use it, mixed with natural gas in internal combustion engines of buses.

European funds are allocated to the development of hydrogen electric mobility[39]. The objectives of a hydrogen service station every 300 km along all main European corridors (those of TEN-T)[40] for the year 2020 are shown by the European Commission.

Some experts argue the considerable potential of the hydrogen sector, which provides the technology to transform, store and reuse a very distributed primary energy generation (wind, solar, nuclear and others) according to needs. For the future, the chapter on "hydrogen mobility" remains to be written.

As for *natural gas*, it is torn between very mixed application domains.

On the one hand, it is positioned as a biomass resource capable of providing a renewable fuel gas for gas vehicles, using it in its compressed form. It then regards local or regional vehicles' fleets, fueling from a single supply point (compressor station), which is preferably located in the heart of the geographical region served by these vehicles.

On the other hand, in its liquid form (cryogenic), it also appears as a credible alternative to diesel for long road haulage. In this case, its renewable characteristic is neither sought nor displayed, but rather the virtues of methane in terms of global and local emissions. Note that the equipment of major transnational and international road corridors with storage stations and LNG distribution is engaged in North America and Europe[41,42].

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[39] Financed within this framework, the first public station in the Netherlands (2013) will provide hydrogen to power fuel cell vehicles. Operating with two pressure circuits of 350 and 700 bars, it has a distribution capacity of 50 fills per day, each offering a range of 500–600 km per vehicle. Similar high-capacity equipment (200 kg/day) will be installed in 2014 in Bremen, Brussels and Birmingham to supply small electric city cars in the SWARM project (http://swarm-project.eu/technology/air-liquide.html).

[40] See Chapter 6.

[41] Some corridors are thus equipped in North America (USA, Canada), which allow large-travel road trucks to circulate on natural gas over long transcontinental

5.3. Transportation systems and architecture

The evolution of transport systems portends unbridled innovation potential regarding physical vehicle architecture and infrastructure, in order to meet a set of evolutionary requirements in performance and physical characteristics. This requires the removal of current blockers in regulations that contain the capacity to innovate toward more effective solutions (regulations on weights and dimensions, those relating to operating rules, etc.).

Satisfying basic transportation requirements imposes physical characteristics intimately relating connections between vehicles and their infrastructure and has a direct impact on their architecture.

We must push vehicles onto a support which ensures their *lift* (soil, water, air, etc.). Traditional technologies naturally use gravity, which sticks the vehicle to its support. Either the lift is provided by solid contact forces transmitted by rolling (floor, ballast), or it results from the balance between the forces of gravity and buoyancy (water, air), combined with hydrodynamic lift or aerodynamic lift. An additional requirement is to maintain stability in total safety (when stationary as well as dynamically).

Innovative concepts regularly emerge with alternative solutions: magnetic levitation or the air cushion that reduces and neutralizes contact forces and friction associated with land transport (but it takes energy to produce these phenomena). Machines and solutions using these technologies are already on the market. Similarly, hydrofoils or airships taper in a diversified way, aiming to reduce energy requirements to move a vehicle within its carrier fluid (water or air). We also mention cables or pneumatic pipes[43].

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distances. Europe is carrying out works in this direction (Blue Corridor project). The Commission recommendations for 2020 would be a station every 400 km.

[42] Let us recall here that the application of LNG as an alternative to heavy fuel oil for marine applications is under way.

[43] This is the case for the concept of the Tesla and SpaceX Hyperloop, put forward by Elon Musk. The Hyperloop would appear in the form of a long tube inside of which capsules, able to hold up to 20 passengers, would travel at a speed close to the speed

To establish and maintain *a trajectory* that is consistent with the corridor topography, guidance is either imposed by the infrastructure or provided through {vehicle-infrastructure} interaction control. In the first case, we can mention rails that allow a very robust transverse guide of railway vehicles, but are limited in longitudinal adherence capacity for braking or ramps. In the second case, we can mention the adhesion of wheels to the ground for road vehicles: it provides longitudinal and lateral support, which is dependent on the {pneumatic-ground} torque characteristics; in the same category, the combined rudder effect ensures maintenance of aircraft trajectory, and for ships, the rudder provides guidance in water, etc. Combinations of innovative guidance systems involving both vehicle and infrastructure are being tested (for example optical or magnetic guidance of buses, rail guidance of certain road vehicles, cable guidance).

Transport of boarded mass (*loads*) must be ensured under the most efficient conditions. This first implies the highest possible ratios between transported and unladen mass, and therefore the lightest possible architectures[44]. This also requires determination and limitation of static and dynamic forces in vehicles and their infrastructure, and may impose diversification and distribution of these efforts over more axles or targeted reinforcement of infrastructures[45].

We can also combine, join and separate various different vehicle modules within a transport system depending on the mission: this function involves the assembly and disassembly of transport modules, operating in packs, platoons or convoys with real or virtual links. Each module must be equipped with either an autonomous movement

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of sound. The capsules never come into contact with the walls of the tube thanks to an air pressure system.

[44] Thus, the empty weight of a car is approximately 1,100 kg. It can carry five passengers, or 400 kg. The ratio is 0.37. The empty weight of a maxi-code truck is 12 metric tons (distributed between the tractor, 7 metric tons, and trailer, 5 metric tons). It can carry between 28 and 32 metric tons of useful cargo. The ratio here is 2.4.

[45] The fight against “wheel tracking” caused by on-site heavy road vehicles (for example a bus) is one example.

capability or an association/dissociation capacity with respect to a motor module[46].

Figure 5.6 shows some aspects of the abundance of concepts and innovative architecture achievements for the transport of persons on roads, combining vehicle(s) and infrastructure, across different functions: lift, trajectory retention, stability, modularity, etc. Several trends are expressed to cover the diversity of uses, configurations and types of transport.

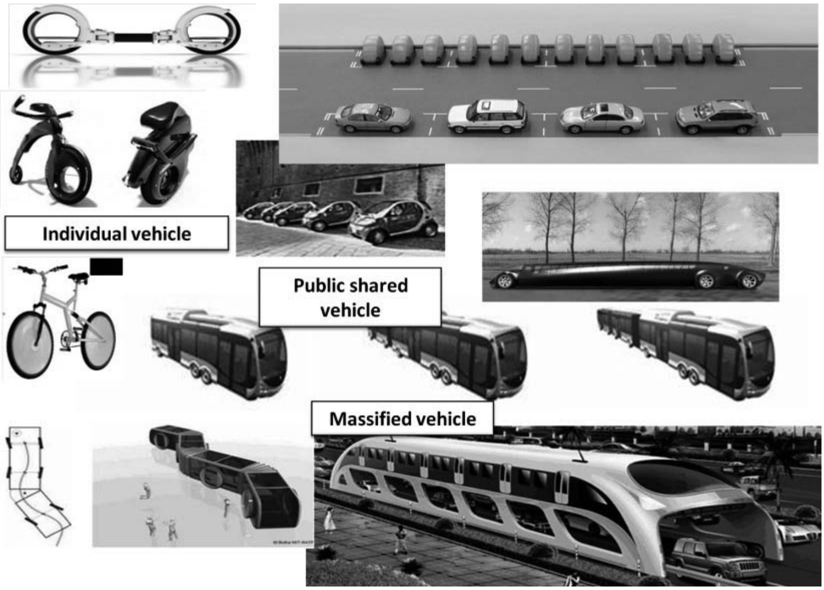

Figure 5.6. *Illustration of the diversity of architectures of land transport systems [BRO 11, YIK 12, DAY 12, IRI 11, DEL 12, [ADE 13] (http://www.chinahush.com/2010/07/31/straddling-bus-a-cheaper-greener-and-faster-alternative-to-commute/)*

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[46] This is the case for road and rail freight transport, which have a wide variety of module combinations governed by the infrastructure and operations rules and constraints (see Chapter 4). Experiments aimed at diversifying silhouettes and combinations of vehicles (by splitting or assembling) between intercity mode and urban mode are also underway.

To cover the variety of needs, developments lead to offer a range of *individual vehicles* (from the walker's assistant for those on foot, to the intercity autonomous vehicle, through a spectacular swarm of variations in urban or suburban vehicles on two, three or four wheels, encased or not, possibly tiltable[47]) for the most part equipped with electric propulsion.

These individual vehicles can be managed as a *collectively organized system* with car parks, location, shared mode, subscription, etc.

Finally, *massified public transport vehicles* also evolve to increase efficiency from their architecture and structures: they become modular, integrated (or not) in a specific site, with specific lanes (possibly shared), at least in some sections, and using at least partial electric traction. These vehicles require developments leading them to obtain exemptions from normal traffic rules (cockpit position, gauge, length of trains and silhouette, insertion into traffic, etc.).

In a similar manner, Figure 5.7 illustrates the freight system architecture. Again, scalability and suitability of use are expressed to cover all the features of logistics: easy handling because of access and height of vehicle floor (lowered), adaptation to transport business (cold, e-trade, etc.), assembly and disassembly of crates and modules, integration into corridors and on logistical platforms. To satisfy the rules of massification, combinations of modules can be encouraged to massify according to a "virtuous" operating mode on sections of heavy high-speed corridors, to then burst loads at the ends by the most suitable massification modules to cover the "last kilometer", using smaller vehicles[48].

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[47] Renault's Twizi and Toyota's i-ROAD are vehicles for which the architecture was designed around electric mobility, possibly "self-shared".

[48] For example, the Cargohopper concept of Hoek Transport company: a small electric tractor pulls three trailers to distribute to a historic center (Utrecht, 2009). In another variation, the Renault Trucks' Urban Lab demonstrator, in cooperation with Gemco E-Trucks BV, is equipped with electric drive and has a suspension system that lowers the entire truck to ground level during handling (2012).

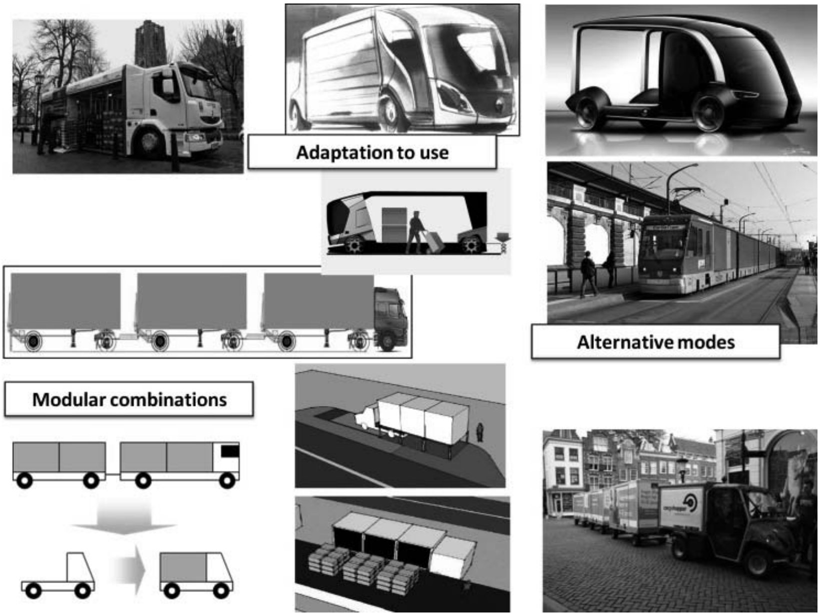

Figure 5.7. *Illustration of the diversity of urban freight transport system architectures (from Cargohopper Utrecht, CarGo Tram Dresden, Urban Lab Renault Trucks, DELIVER EU project (www.deliver-project.org) and CityLog EU project (www.city-log.eu))*

Let us include a search for mixed solutions: the ability to transport people and goods at the same time or successively with the same system. The examples cited readily concern the tram[49], but other combinations are explored.

5.4. Intelligent transport systems (*ITS*)

As discussed in Chapter 4, while for the individual person, use of a connected mobile phone has become an integral part of daily life, its

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[49] The revival of freight trams is usually associated with CarGo Tram system, linking the city of Dresden (Germany) with the DVB transport company and Volkswagen, whose factory in the city-center is served every 40 min by a freight tram 60 m long with a load capacity of 60 metric tons (a carriage carries the equivalent of three trucks). Other operators are interested, such as the RATP (Paris) that tested the Freight Tram (2012).

application to mobility stakeholders is a major trend. As shown in Figure 5.8, a long-term flexible, economic and assured connectivity is authorized by new networks and communication technologies such as LTE[50]. It provides in return an amount of data from all these connected mobile devices, being route trackers as such and providing multiple criteria for optimal management of necessary infrastructure and vehicles resources. It operates by forming data "clouds" (open data) allowing the emergence of new services for the use of different transport stakeholders, for example in the field of real-time traffic management[51]. This change confirms the importance of defining and making interoperable and intermodal common digital platforms work. It involves exchanging these data between the stakeholders, for the benefit of their respective uses, with well-defined rules for use, property and security. The goal is the implementation of transport solutions optimized regarding the challenges mentioned in the introduction: the question of the massive deployment of these technologies is open, as we must look at it in terms of its legal and regulatory implications and in terms of social, economic and environmental acceptance.

Again, *a systemic view is required* with the interweaving of multiple stakeholders that underlie it. It leads us to consider all transport system entities as connected and interfaced between themselves, equipped with self-intelligence enriched – or hindered – by their interactions. Each entity can potentially benefit from this coupling, and develop a behavior satisfying its own objectives, while contributing to an improvement of the collective goal. This group, which has a specific level of intelligence, appears as a new and separate entity with an attribute for a higher complexity level, for which the control requires changing the initial paradigm, with the involvement of a new type of "meta-stakeholder".

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[50] Long-term evolution (LTE) is the most recent development (2012) in mobile telephony standards.

[51] The Optimod'Lyon project and its European extension the Opticities project are major examples [COL 12].

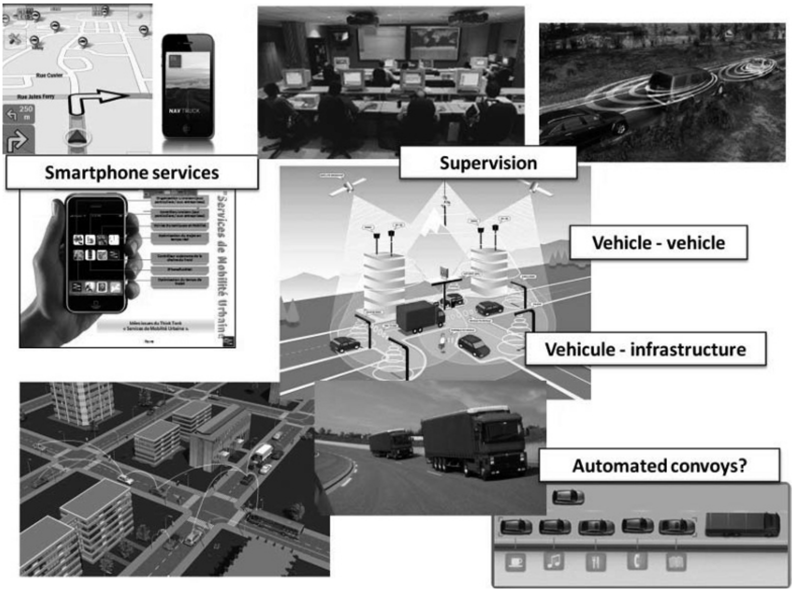

Figure 5.8. *Various levels of intelligent transport systems, from smart phones services to an integrated urban supervisor. Applications to road transport (see Renault Trucks smartphone services "NAVTRUCK" (2011), Grand Lyon traffic control center "CRITER" (2011), Chauffeur2 EU project (1998), [CVI 10], [SAR 12] and [SAF 10])*

Users, whether passengers or drivers (or pilots), are simultaneously both the stakeholders and the final goal of sustainable mobility. They naturally involve their own intelligence into the systemic chain through their continual actions and provision and acquisition of information. These pass through the human–machine system interface: cockpit, displays, information panels, actuators, etc. But the nomadic assistants which they are provided with complete this intelligence, not only by their additional ability to access and treat information to help make a decision (choice of route, for example), but also by their ability to supply information such as the location of their “owner”. The GPS coordinates of (almost) each user are now available, which obviously is a very powerful tool for managing and optimizing transportation systems. It allows system managers to access real-time transportation requests.

This also applies to *goods*, for which the development of technologies for the identification and traceability such as the RFID can provide reliable identification, location and individual control over the logistics cycle[52].

On the *vehicle's level*, which are the mobile key elements of transportation systems, the same problem takes on another dimension: vehicles transmit and receive information in real time and can treat them with appropriate processor speeds for this operation[53]. They use the obtained information to perform different actions:

– verify and monitor (a driving or piloting environment, working state, failure prognosis);

– measurement (distances, risks);

– decide and act (brake, steer, accelerate, avoid);

– optimize (to ensure safe travel and the best possible productivity), interacting with pilots, drivers and operators.

The information is here indeed managed by processors that act instead of people (with the essential question of human–machine interfaces and split of roles). On the vehicle, all functions (driveline, ground connection systems, longitudinal/lateral/vertical vehicle dynamics, etc.) are provided with sensors, processors and actuators for circulating and using real-time information necessary for the operation of the vehicle. This architecture is interfaced to the external environment via communication systems and exchange protocols ensuring interaction with the environment: operations base, infrastructure, supply chain, etc.

As for infrastructure, they are also equipped with means to capture (traffic or environment settings), inform the operator and the user, control and intervene through action on its control devices or through its operators (Figure 5.9).

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[52] This development is one of the applications of the "Internet of Things".

[53] Some applications require a response time in the order of a millisecond.

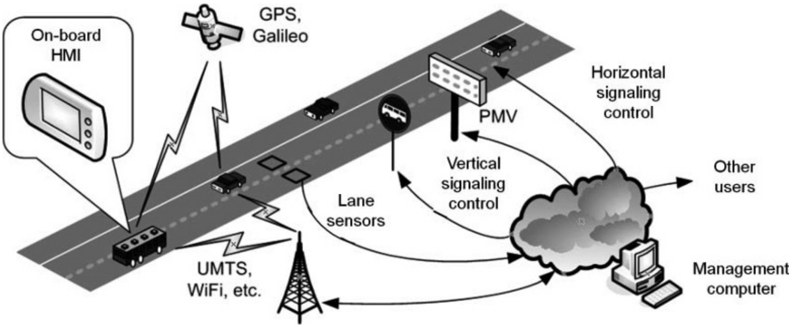

Figure 5.9. *Principles of exchange and interconnection between elements of a road transport system [ADV 11]*

Vehicles that are today already connected to management centers[54] will in future be even more so by interconnecting between themselves and their infrastructure. Transport systems are immersed in unbridled "intelligence", but it should be structured and controlled. In addition to the technological dimension, ethical and legal dimensions are essential[55]. How do we move from experimental stages that are more and more numerous in the world, but remain limited to confined sites (at least for the most "impactful" of them – such as automated vehicles moving without human intervention) to actual implementation, gradually introducing new technologies onto the market?

In the most obvious cases, innovation is introduced to a new independent dedicated system (on-site)[56]. If it involves integrating some vehicles into an existing system, and existing modes of transport, the introduction can only be progressive and even more cautious. We must test, adjust and gradually generalize innovation

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[54] Fleets of trucks and buses, and planes are tracked in real time from management centers. They have all contain geolocation, operation and planning information.

[55] If a vehicle equipped with these technologies is involved in an accident, how to define and allocate responsibility between the "driver", the manufacturer, the other stakeholders in the context, etc.?

Among other examples, the issues of "retrofit" systems (which is included in vehicles that are already on the market) and after-market procedures (rehabilitation of features of a used vehicle by delivering new standards) are also raised.

[56] The D line of Lyon underground, fully automated and driverless since 1992 (first in the world), is an example (SYTRAL).

from the first equipped vehicles[57]. The difficulties of implementation are easy to imagine when these applications touch on security, within systems where new equipped vehicles coexist with old non-equipped vehicles. International cooperation and a multistakeholder approach is crucial here to achieve global standards and harmonization and interoperability of solutions.

5.4.1. *Several European projects on intelligent transport*

All stakeholders in a transport system are therefore interconnected by communication systems. We must standardize the exchange protocols of such information. Adaptation to different needs and uses are the objectives of cooperative work to develop the applications, usually encouraged by public funding. *From the perspective of road applications*, the ITS community – along with its meeting venues and international association organizations[58] – conducts collaborative projects to assess and develop the capabilities of intelligent transport systems, to develop standards and to contribute to their dissemination. They have multiple purposes[59].

Since the PROMETHEUS program (1987–1995), which was the forerunner in Europe, a number of projects during the last two decades have made it possible to build the foundation on which the current developments depend for the future of intelligent road transport, as well as for sustainable transport.

The list of projects that allow us to mark this evolution is now well supplied, and it is renewed at higher speeds gradually crossing through the stages necessary for completion. The projects, classically of 3–4 years, are succeeded at a rate of evolution of technology on the one hand and capabilities of system integration, evaluation,

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[57] The average age of vehicles in a fleet is approximately 10 years.

[58] For Europe, this is ERTICO, an association of all national ITS communities in the European community. The three “regions” of the world (Europe, America and Asia) alternately host the ITS annual conference.

[59] From a government point of view, current actions involve eight areas: driving aids, multimodal information, public transport management, electronic payment, emergency management, regulatory control, freight transport and traffic management [JAN 13].

dissemination and deployment on the other. Conducted on a European or national level, they result in generally significant gains on the major posts that are addressed: reducing greenhouse gas emissions and other emissions, improving safety and improving transport efficiency.

They are complemented by *system tests under real conditions* (field operational tests (FOT)), which are programs for demonstration and experimental evaluation on a large scale or in a real environment to test the efficiency, reliability, robustness and acceptability of solutions introducing ITS technologies. They anticipate the implementation and operation conditions on a widespread scale.

Among the tested benefits, we may first mention navigation, traffic information and all driver assistants, which play a role in improving safety, energy efficiency and productivity of transport. But more importantly, the introduction of automation and other features from real-time exchange capabilities between mobile devices and with infrastructure gradually strengthen the need for these tests. The challenge here is to manage the increasing interactions between instantaneous transport components in the context of their dehumanization, with the expected benefit of optimization, but the major risk of exclusion of man in the decision loop and in its governance.

In Europe, these demonstration and evaluation processes have been widely encouraged by community funding (using the R&D-FP[60]). A number of FOT sites associating public and private partners are implemented for a specific purpose, on a territorial scale and for a limited time. They are associated with numerical and physical simulations hardware-in-the-loop (HIL) and with testing on dedicated resources.

The following projects are a few samples of these developments.

The CVIS project (2008–2011) is a European project funded under the FP6 Framework Programme, with a budget of €41 million. The

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[60] FP (initiated in 1984) is the EU Framework Programme for Research and Development, which has supported a number of European R&D activities, here in the intelligent transport domain (see Chapter 6).

aim was to develop vehicle-infrastructure cooperation to improve road safety, optimize traffic and reduce the environmental impacts of transport. It provides features on traveler cooperative assistance, strengthening the driver's attention and integration of on-board automation. From the goods transport perspective, CVIS' applications are also numerous: mission management (vehicles, fleet, transported goods), supply chain, traceability (hazardous materials, cold chain), access control, advance booking of loading–unloading areas. Cooperative management of road and urban networks, the allocation of access priorities, priority of vehicles (such as buses) is also discussed. We emphasize those that make transport sustainable: more intelligence to increase efficiency and therefore reduce the energy and environmental costs.

The SAFESPOT project (2006–2010), a European FP6 project, included 51 partners. With a budget of €38 million, the objective of SAFESPOT was to understand how intelligent vehicles and intelligent roads can cooperate to improve road safety. The aim was to prevent road accidents by developing a safety margin assistant (SMA) that detects potentially dangerous situations in advance and extends the capacity for the driver to know his/her environment in space and time by integrating vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communications.

The objective of FREILOT (2009–2012) and eCoMove (2010–2013) was to develop integrated sustainable transport solutions, focusing on energy efficiency for road operators and freight transporters: optimizing trips by limiting unnecessary distances; conserving fuel by practicing eco-driving; producing tools to manage traffic more efficiently. The combined use of several complementary technologies coordinated and co-managed by several stakeholders (Figure 5.10) allows us to quickly obtain significant results. FREILOT showed CO_2 reductions of 25% because of the linking of four (almost) available technologies: prior reservation of delivery areas before committing to a round, governing vehicle acceleration and speed in urban areas, assisting the driver for real-time eco-driving, prioritizing traffic lights for vehicles involved, which are given privilege because of their virtuous attributes.

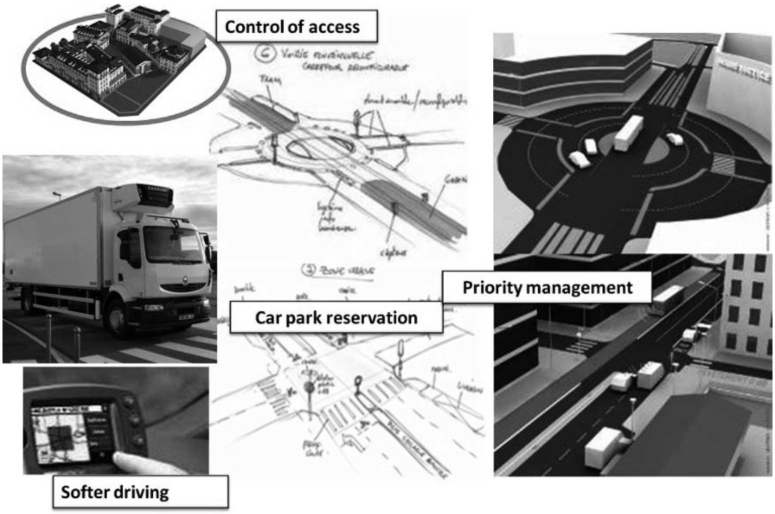

Figure 5.10. *Different functions tested in the FREILOT project www.freilot.eu*

The Have It project (Highly Automated Vehicles for Intelligent Transport), for which the objective was to explore different degrees of automation of the vehicle, or *the SARTRE project* (Safe Road Trains for the Environment, completed in 2012), which studied the possibility of forming convoys of vehicles on highways, are the continuation of first tests during the 1990s (American platooning projects, European CHAUFFEUR2 project). Here, the implementation is now tested in real traffic. Thus, SARTRE involves autonomous cars rolling in convoy, a sort of “train” of vehicles attached by virtual links, which maintain the intervehicle distance through an autopilot. Only the first vehicle is controlled by a driver, a qualified road professional. With wireless links, the subsequent vehicles accelerate, turn and brake in phase with the first vehicle. The project tests the influence of various factors (such as interdistances of 5–15 m, or speeds of approximately 85 km/h) in terms of a relevant operation: insertion in the interstitial spaces, linking or exit of the platoon, or even overtaking or lane-changing conditions with vehicles that are not equipped. The ultimate goal is to improve the operation of the infrastructure by maintaining road safety, reduce congestion, lower average consumption of vehicle and free the driver from tedious tasks.

In *the DRIVE C2X project* (2012–2014), various stakeholders of C2X technologies tested, at seven actual sites, a common communication system on a variety of different brands of road vehicles equipped with the same human–machine interface to identify the elements of a pan-European cooperative mobility system.

As for *the CityMobil2 project* (2012–2016), it implements a pilot platform for automatic urban road transport systems, associating driverless vehicles organized in a collective fashion. It targets applications of service of areas at the end of public transport, where it is to be connected to individual vehicles. Five sites were selected for 6 months of testing, involving sets of 6 vehicles. Issues of social and legal acceptability are particularly studied.

We could continue this consuming description. It leads us to this: these cooperative projects, European or national (or international for some), are born, live and die in a cycle of 3–4 years. They are supported by new collaborative initiatives, from which market and competitive economy conditions emerge, to gradually build the architecture and the means for transport solutions innervated by distributed, shared and connected intelligence. The result is a potentially safer more efficient transport, with contained environmental impact.

5.4.2. *Linking of systemic layers of intelligence*

The introduction of successive layers of intelligence centered on the vehicle gives it a seemingly irreversible trend of capacity of autonomy. Gradually, it is equipped with features for acting instead of the driver, by processing information of more complex nature (from a temporal, spatial, contextual point of view).

The introduction of these services in cars is undertaken or planned, starting with those that run at a slow speed or in a simplified environment (automatic aid for maneuvering or insertion into traffic, parking groom service). Meanwhile, highway driving will become more autonomous, and the autopilot may arrange travel at higher and higher speeds[61]. At the final stage, the individual vehicle will have all the necessary digital data to define both the mapping environment (using databases related to its geolocalized position, with a sufficient level of resolution) and its environment context (presence and identification of obstacles and mobile items). It is surrounded by its electronic sensory "bubble", adaptive and interactive, which provides its protection space. This bubble has the ability to detect not only risky situations but also opportunities. It adapts to the situation. In particular, it can exchange information with the bubble of vehicles or other moving items around it, so that the vehicle can make agreements with them. It helps maintain safe spaces with vehicles (by interacting with the engine and "shorting" human intervention). It allows guidance according to the desired trajectory in the infrastructure (for interaction with steering system). It allows alignment capability with the previous vehicle(s), and "behavioral cloning". The driver monitors the scene.

Under these principles, *the pack flow of vehicles* (in pelotons, platooning), all served by the leader vehicle, has a significant, even major, potential in terms of sustainable transport:

– it reduces the energy losses due to aerodynamic drag: maintaining successive individual vehicles at reduced interdistance in their wake is more effective the shorter the distance between vehicles[62];

– it limits driver behavioral dispersions, which are vectors of jerks. These, in turn, generate sequences of acceleration and deceleration

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[61] Google, in its Self Driving Car project, released in 2011 an experimental car that is driven without driver due to multiple sensors and cameras. The vehicle obtained permission to circulate freely in some US states (provided that a human remained on board to take control if necessary) and covered hundreds of thousand kilometers without an accident [URM 13]. This vehicle continued recently to raise passionate debates on the capacity, speed and limits to increase the concept up to an operational level. At the top of the debate, we recognize the issue of the respective roles of machine and man [GUI 13].

[62] The benefit of a small distance between trucks traveling in convoys can be approximately a 10–15% reduction in consumption compared to a single vehicle, by a direct effect on their {S. Cx } (where S is the frontal surface, Cx is the drag coefficient in its form generalized to the convoy).

that increase energy consumption[63], emissions and noise, wear of vehicle rolling base systems (brakes, tires), safety risks;

– it reduces the risk of congestion and the associated accordion effect, saving the time spent;

– it reduces surface footprint and increases the efficiency of infrastructure.

This mode of collaborative management of vehicles in convoys potentially increases both the performance of the infrastructure and unit efficiency per passenger or per transported metric ton.

If we now look at the connection with the infrastructure, the individual intelligent vehicle forms, with an intelligent infrastructure, another systemic dimension to optimize their combined operation, according to a management system inspired by railway management (management "by cantons", for example).

From the infrastructure perspective, real-time traffic management using instantaneous information to act by optimizing short- and medium-term traffic here also shows good potential for efficiency and environmental impact reduction. Eventually, the necessary information could be provided by the mobile vehicles, more than from the infrastructure itself. The vehicles, equipped with varied and potentially different characteristics, will act (and already do) as sensors. Traffic optimization directives (set speed or distance, for example) that are suggested or imposed by the infrastructure may be transmitted to the on-board actuators that will react autonomously without human intervention. The vehicle then becomes a custodian of an on-board traffic management function, containing both sensors and actuators (in-car centric traffic management).

Several questions are raised by the likely evolution:

– how do we split the roles between centralized traffic management back office and mobiles?

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[63] Avoiding interrupting the flow of a vehicle significantly reduces its consumption and emissions (CO_2, nitrogen oxides and particulate matter, noise). For a heavily loaded combustion engine truck, one can gain up to 1 L of fuel by an avoided stop.

– how do we gradually introduce vehicles with these changes?

– what will be their penetration influence?

– what strategy will be followed in an emergency?

In addition, this concept, for which we must evaluate the significant contribution in terms of sustainable transport, becomes the seat of potential conflict between the satisfaction of societal interests (to reduce the negative effects of traffic), and the satisfaction of private interests (to satisfy the user, for example by reducing the travel time).

At the higher level of complexity, *the simultaneous management of successive packs of vehicles and intelligent infrastructure* can be achieved by strengthening their coordination through an oversight involving infrastructure and its management and operation stakeholders. High levels of equipment allow us to consider highly optimized traffic and operating contexts, in order to take full advantage of the integration of ITS in vehicle–vehicle and vehicle–infrastructure interfaces. We can imagine driverless vehicles, intersections without lights where mobile vehicles follow and modulate their dynamic behavior to cross without slowing down or stopping. Imagination has no limits, and the boundaries for the "technologically possible" are gradually shifted further away. It remains to translate them into operational and socially acceptable solutions.

For example, the emergence of autonomous road vehicles to transport people (or goods) is arriving[64]. These vehicles can move automatically and without a driver, according to the information from contextual sensors and guidance. Designed with specific architecture, they are equipped with electric motors and carry out their own recharging. Their implementation is currently anecdotal and largely limited to private spaces (recreational areas, airports), or on very low-speed public sites (pedestrian paths). It could be developed, subject to

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[64] The Navia vehicle by the company Induct, that presents itself as "a robotic shuttle service for urban mobility", is a reference in the field ([LUT 13], www.induct-technology.com).

concomitant changes in regulations that allow the practice[65]. On these issues, it is imperative to address the rise in power of technological possibilities in terms of the removal of legal and societal locks[66].

5.4.3. *Toward an interoperable continuous chain*

The concepts of green corridors, green areas and access management in space and/or time have significant potential impacts in terms of operating modes; they may involve all channels {driver/vehicle/infrastructure/other users}. Considerable progress is underway, in terms of safety, reducing environmental impacts and Quality-of-Service. The progressive deployment of these potentials could, in the long term, lead to operating modes of stemming from convoys operated by largely automated interaction capacities (maintaining speed and distance, virtual link, emergency braking, collision avoidance, (semi-) automatic convoy management, etc.). In the corridors, dynamic lane management allows us to adapt, at each point and in real time, flow operating constraints to maximize the overall performance while allowing individual prioritization. At the ends of corridors, transport operations are linked with transshipment operations, toward platforms or modal exchange areas (road, rail, water, air). ITS technologies have the potential to optimize these transfers during the mobility and logistics planning stages (such as linking trips, advance booking of a charging station or delivery area), transshipment, or in terms of feedback (for example to improve

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[65] The BASt (German Federal Highway Research Institute) outlined its vision of the evolution of automation in road traffic vehicles, and the regulatory issues that are raised depending on the degree of automation on the one hand, and cooperation on other hand. It distinguishes between the following five modes/degrees: solo driver, driver assistance, partial automation, high automation and total automation. The other dimensions of the issue are addressed: vehicle speed relative to its context (between low-speed maneuvers and highway cruising), duration in the mode, etc. [GAS 12].

[66] As for standards and certification, several international bodies are active. These include the Automation Working Group in iMobility (TNO & Volvo), the VRA Road Vehicle Automation Project (ERTICO) funded by DG-Connect, the ISO 26262, the US DoT Policy on Automated Vehicle Development. A European Directive is in preparation for 2017. It involves specifying the functional safety requirements (for electronic control systems), degraded modes, redundancies, etc., certification requirements, cyber security (ability to withstand cyber attacks) [PAR 13].

organization). They allow better planning of the connection between the modes (access infrastructure management and use of platforms).

All these features are entities of a more integrated scheme involving other stakeholders: vehicle, fleet, freight channel operators and managers, those of infrastructure (roads, traffic and operation, communication, energy) and those of territorial entities (regulatory, access, etc.). Some of the information provided by the {vehicle system} are transmitted or accessible to these stakeholders (positioning, operating or loading conditions, autonomy, etc.). They also produce information that is transmitted or accessible to the {vehicle system}, such as infrastructure conditions (state of service, regulatory conditions), traffic conditions, various forecasts, operating rules, availability, etc.

The various stakeholders are gradually linked to the connected vehicle. Permanent or event exchange loops can be imagined between the different system components, to optimize the operation of each component or the system as a whole. The optimization function can address the minimization of a “cost”: for example, reduce the level of congestion, risk of accidents, CO_2 emissions[67], etc. The virtues of sustainable transport can thus be preferred.

5.4.4. *Man–master on board?*

Where is man in all this? In this context, he holds a controversial position. If he remains at the heart of mobility, his position within the transportation is gradually marginalized. He becomes a spectator of his management by the (transport) system, an observer of the relinquishing of his prerogatives and tasks. From his position as a stakeholder (driver, chauffeur, pilot or operator), he could become a passive spectator (as a passenger) or active spectator (controller or supervisor): somehow, technology indeed brings ingredients to improve transport performance (in the sense of “sustainability”), provided that man is gradually dissociated.

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[67] We evoke California’s “near zero emission corridors”.

However, the development of transport systems toward automation leads to big discussions. Is it not dehumanized? The impact of this integration with respect to psychological, social and human needs and expectations remains to be measured. The technology is not the only aspect to cover; communities must be involved in the economic, legal, and regulatory[68] domains, in the analysis of impacts and decision-making. Current projects illustrate the importance and the need for a multistakeholder approach, starting with users and managers of the uses. This trend also confirms the importance of clearly defining the ingredients and the rules of ownership, operation and monitoring of intermodal, interoperable common digital platforms and related algorithms. If they are used to exchange data between stakeholders, for the benefit of their respective use, they must achieve the goal of optimized transport solutions in terms of individual, group and systemic angles when faced with the challenges mentioned in our introduction.

It is to be feared that human needs will not be taken into account at the societal challenge level, which is raised by this technological revolution that could provide both the best and worst:

– the best, through the huge potential it offers in terms of improving overall efficiency, and reducing negative impacts on the physical environment, which goes in the direction of sustainable transport;

– the worst, if it is done in spite of the forces that control the mind and the human spirit. If it takes its place on the level of navigation, piloting and governance of operators who oversee transportation systems, substituting it by robotic automation with which all human relationship is excluded.

Referring to Zahavi’s conjecture, it is also to be feared that these efficiency gains are not put into service to reduce the demand for

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68 The Vienna Convention on Road Traffic, signed on 8 November, 1968, is the current reference. It stipulates (article 8) that “Every moving vehicle or combination of vehicles in motion must have a driver” and that “Every driver must always be in control of his vehicle ...”. But efforts are underway to make it evolve, and on the other hand other regulations for guided transport exist.

unsustainable mobility, which throws us into a frenzied consumption of transport. Instead, they will cause a proportional increase in demand: increased efficiency, especially in speed and security, would induce an additional request for the "void" thus created.

5.5. The integration of transport systems, services and transport solutions

Given the smooth functioning of human society, the transport system is but one functional system among many others (housing, health, etc.). As such, it has many interactions with other systems that surround it, bringing their own contribution to sustainable development issues that cohabit, interfere, nourish and feed it. The development of a sustainable transport system is to be positioned in its interaction with other systems that are necessary to it, or to which it must adjust (Figure 5.11).

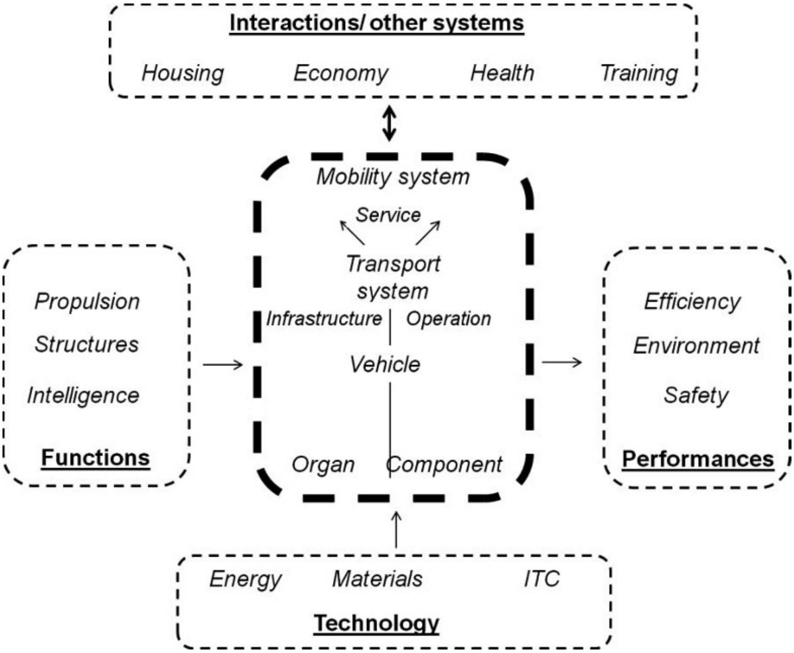

Figure 5.11. *Positioning of transport systems in the systemic chain between technology and transport solutions*

Here, we report these major interactions[69].

First, by nature, as we have developed it, the transport system includes both the vehicle system and the infrastructure system. Operating modes and operating procedures must be added, which constitute the control layer. These ingredients determine the overall performance of the transport system: its capacity in terms of output and speed, energy consumption per transported unit (passager.km, metric ton.km, etc.), environmental impact (amount of unit emissions), security (risk prevention, resilience, etc.) and Quality-of-Service.

On the other hand, the transport system interacts with energy, materials and structures, and intelligence sectors, which constitute the envelope. There must be a systemic linkage with these different dimensions.

Finally, it is integrated into general activity (housing, economic activities, city life, health, culture, education, etc.), and has some interactions that we must stress because of their impact on the development of sustainable transport. Figure 5.12 shows an illustration.

5.5.1. ***Development of equipment***

In support of the transport system, important evolutions of equipment have a strong impact on the potential development of sustainable transport. It is impossible to draw up a comprehensive state here. The few examples below provide a perspective.

Transport infrastructure continues to evolve. Work on the "fifth-generation" [70] road is an emblematic element. Equivalent work relates to rail infrastructure[71]. We seek to strengthen the capacity of the

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[69] The in-depth treatment of these interactions is beyond the scope of this book.

[70] After the path (1), the Roman road (2), the tarmac road (3), the motorway (4), the "fifth-generation" road is next on the agenda of road concept development plans. It will be "intelligent, resilient, adaptive, accepting…" [IFS 12].

[71] The creation of the RAILENIUM Technological Research Institute (North Region, France) in 2012 aims to develop R&D, innovation and engineering training in rail infrastructure matters.

infrastructure to allow flow of more productive vehicles, reduce costs (investment, maintenance, sustainability), while meeting the characteristics specified above in terms of integration on energy plans, materials and structures, and intelligence.

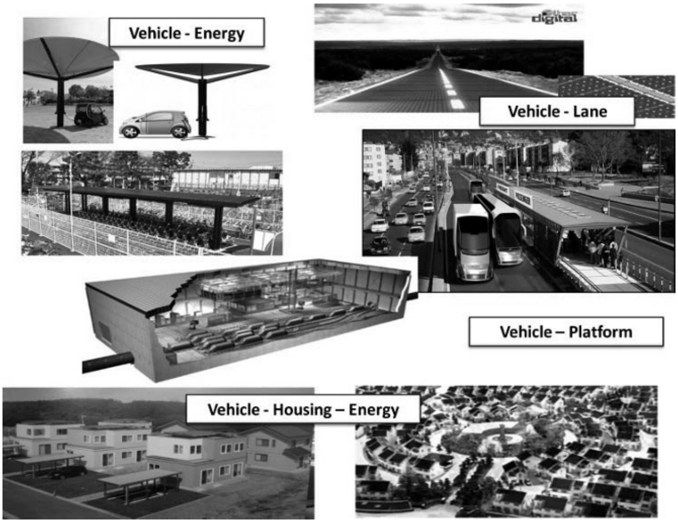

Figure 5.12. *Illustration of the diversity of systemic integration situations between the transport system and other interfaced systems [SUN 12, UTA 12, HON 10, PAN 11, VOL 13]*

The production of electricity by *photovoltaic cells* scattered over various surfaces linked to a transport system is widely recognized as likely to add, or even integrate, the energy required for individual or collective electrified transport: either by direct transfer of electricity (using the aforementioned smart grid networks), or in the form of hydrogen to facilitate storage. Indeed, it appears that numerous pieces of equipment that have surfaces exposed to the sun are potentially suitable to be transformed (starting with the transport infrastructure or their borders, buildings, shelters, homes, etc.). Because cell technologies, with their support and energy management systems, evolve quickly, we can thus imagine equipping these facilities with it. This idea, however, must be validated by demonstrating its economic and societal relevance.

We can mention many examples of this trend: shelters equipped with these cells provide energy for electric vehicles when parked: whether it be bikes, cars, or that car parks are public or private[72]. As for houses, they could gradually be equipped with home charging stations, independent or interconnected, for recharging, using their own energy production, the individual vehicle attached to the home[73].

Urged concepts offer a real systemic management on the level of home, of a group of houses or an entire neighborhood. They demonstrate how to provide and distribute photovoltaic energy production, its processing, storage and management of its use between different consumers in the family unit[74]. These include household appliances, heating and air conditioning, as well as vehicle(s) attached to the home. Management protocols also provide energy to recover electrical energy stored in the vehicle for re-injection into the network (based on the "vehicle-to-home" principle)[75].

From the *intermodal platforms* perspective, integration of the same elements allows the development of features that facilitate and improve the efficient use of transport. Parking areas are equipped with energy and intelligence to ensure the best use: detection and identification of availability of parked vehicles, vehicle charging, shared management, diagnostics and maintenance. They gradually become platform spaces to continuously ensure the mobility chain, facilitating the reception and service of vehicles, and the relay with neighboring available transport modes, whether individual, group or massified. The bus stops are equipped and designed to associate mobility services and local services for the benefit of all categories of

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[72] SunTree ® marketed by Solarquest has equipped, since 2010, at the Hôtel de Police in Avignon (France), a 1,100 m² car park area for an estimated production of 225,000 kWh per year. Tesla has begun the deployment of a fleet of fast charging photovoltaic stations from its California base.

[73] Honda has designed a mobile charging station that uses home photovoltaic energy to make, by electrolysis, hydrogen without CO_2 emission [FRA 12].

[74] The family unit is here the basic element of a generalized approach to each level of this systemic organization.

[75] Several initiatives are underway in Japan (smart community projects), in particular involving the car makers Toyota and Mitsubishi (and its M-Tech Lab). The environmental city project in Fujisawa is planning to be operational in 2018.

users[76]. Delivery areas are not left out, which ultimately should be rehabilitated in the public space by developing their capabilities (intelligence and energy connection)[77], to ensure parking of vehicles and safe freight handling.

5.5.2. *Development of services*

The linking of vehicles, platforms and modes of organization leads to a *new service-based offer* “packaged” into new systems, combining products and services to ensure the linking of mobility. After the bike, the urban car is thus integrated into an offer that gradually emerges as an individual mode managed collectively in terms of use and economic model. *Car sharing*, systemic changes of the rental car, is built from bricks combining the elements that we have mentioned, and is based on a highly modified business model: a pioneer among others, Autolib’[78] proposed a “self-service” short-term rental of 100% electric cars without forced return to the starting point, geolocalized and with a dedicated network of charging stations. This system illustrates the ingredients that we have presented: the integration of solutions coupling energy (here, electricity), mechanics and structure (here, a new vehicle), intelligence (geolocation, booking, billing, etc.), resulting in an innovative {product-service} offer combining vehicle, infrastructure and organization.

Carpooling, which applies to the case of occasional long-distance travel as much as to commuting, is also the subject of important initiatives. The idea of better value through sharing and the availability of a particular car on a set route is evidence that communication tools make it feasible[79]. The principle can be broken

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[76] The EBSF European project has allowed the RATP (2012) to test an intelligent bus station accessible to people with reduced mobility or with disabilities (visual, auditory), with innovations on the thermal, lighting, acoustics and sound, and visual aspects, a small shopping area, a self-service library and digital services [VIG 12].

[77] The ALF Project (future area of delivery) suggests changes in this direction [DAV 13].

[78] Autolib’, equipped with BlueCar cars of the Bolloré Group, appears as the first self-service electric car public service developed across a large European metropolis.

[79] Many Websites offer deals to look for suppliers and applicants. See, for example, www.covoiturage.fr.

down in different ways in the collective field, especially at the enterprise level. The basics: search and find overcapacity, and organize it onto a participatory platform. The ingredients: make the service visible and legible, provide a legal framework, and integrate it into a framework for interoperability with other modes of transport and their interfaces (for example including park and ride, carpooling areas and reserved parking spaces near supermarkets).

Car sharing and carpooling are available in various ways, generating new applications, such as the rental of one's own car[80]. Considered as services providing temporary access to a car, quickly and easily, they are changing the way users are positioned in relation to the ownership of a vehicle[81]. They integrate themselves, on the other hand, willingly into public policies for sustainable mobility. The positioning of different stakeholders – owners, users and subscribers, manufacturers, suppliers and service managers, insurance companies, public transport operators, local authorities, etc. – is done in many ways according to collaborative and non-stabilized business models[82]. From a niche market, they gradually evolve, differently in different countries, toward a mass market [PRE 13]. Figure 5.13 shows an overview of the French market in 2012, which seems to grow rapidly, and gradually structure itself.

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[80] "The car is shareable" (www.buzzcar.com).

[81] ADEME (2013) published the following results for the practice of car sharing:

– lower cost than a personal car (reducing expenses related to fixed costs (depreciation and insurance) and parking);

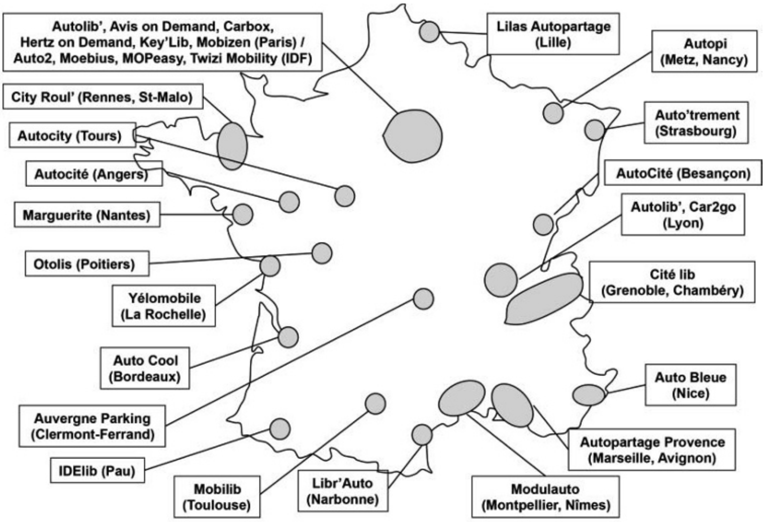
– less use of the car (41% fewer kilometers after switching to car sharing);

– smaller footprint (each car sharing car replaces nine personal cars and releases eight parking spaces);

– increased use of alternative modes (walking, cycling, public transport, train, carpool);

– user adoption of eco-mobility policies such as urban tolls, access restrictions, measures to restrict parking.

[82] We counted in France in 2012, 35 car-sharing services, which would target 120,000 subscribers in 2015 (five times more than in 2010). The conditions for success are: proximity (of vehicles), and flexibility (of use: booking, cancellations, availability) for a price that is reasonable. The return on investment for the operator in the short or medium term remains highly uncertain [XER 12].



Le service Mu by Peugeot est disponible dans une douzaine de villes – Source XERFI d'après opérateurs

Figure 5.13. *Car sharing map – France 2012 [XER 12]*

5.5.3. *Transport solutions*

The previous examples addressed the car. It was part of the "individualized" object-property status, equipped with an engine using fossil fuels, with an architecture that gradually gets heavier with each new generation[83], (relatively) devoid of autonomous intelligence. It entered the new century with a debauchery of not only technological but also conceptual initiatives, combining physical product and services. It is now positioned as a use solution, encapsulated in the mobility chain: equipped with a connected motor (to the grid), thin and redesigned to safely carry passengers, interactive and accompanied with services that should improve its adaptation capacity to a greatly enhanced stress field: in particular, in terms of regulations on CO_2 emissions, control of access to sensitive urban areas and parking.

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[83] To meet specifications combining enhanced secondary safety and comfort, each new model in the 1980s and 1990s has weighed more than the previous one of the same market category.

This trend is also running on the side of heavy urban transport. Here, developments aim to satisfy a more productive and regular use, with excellent punctuality, regularity close to that of a heavier transport system (metro), high commercial speeds, emissions quota, for a contained cost per transported passenger. Thus, the evolution of buses[84] integrated into *bus rapid transit* (BRT) systems for which different variations are interpretations of the same conceptual assembly. Widely deployed in some "regions" of the world (including South America) [85], the BRT are urban road systems that combine:

– vehicles with a specific architecture that can use alternative energy;

– adapted and prioritized infrastructure: it is (partly) exclusive, optionally equipped with a contactless guiding system, optical[86] or magnetic[87];

– intelligence on information to users and operators, control of automation, operation to offer a mobility service providing a substantial benefit in terms of efficiency, reliability, emissions and insertion [CER 11b].

Their variant for suburban and intercity applications is now underway, particularly in France[88], with the concept of rapid transit

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[84] The European Bus System of the Future (EBSF) project (2009–2012) was associated with five bus manufacturers under the aegis of the UITP: Irisbus, MAN, Evobus, Volvo and Scania. It has led to proposals for innovations in urban buses that support the overall approach into a broad context of use (users, operators, organizing authorities, public authorities etc.).

[85] The bus rapid transit (BRT) can be positioned as a more flexible alternative to the tram. Their deployment is engaged in many countries. More than 150 cities around the world are equipped with BRT systems, some with highly integrated systems (Bogota, Curitiba, Seoul, etc.) [SUZ 13].

For example, the Metrobüs system in Istanbul, which for a line of 40 km, in 2010 carried approximately 800,000 passengers per day, more than the public transport rail network of 150 km (excluding commuter trains). In France, on the basis of evidentiary experiences (for example TEOR in Rouen), deployment now seems assured, mainly because they are more economical than public rail systems [CER 11b]. In the version named e-BRT, vehicles are dynamically electrically charged by the infrastructure.

[86] Example of the TEOR system in Rouen.

[87] Example of the Phileas system in Douai.

[88] The @CAR project supported by the FNTV aims to develop an innovative bus system for regional applications.

coaches integrated into a multimodal mobility chain, including park and ride and other platforms, and which are connected to other modes of organized transport.

Obviously, the *tram system* and its variants are also suitable for significant evolutions, whether for power (energy efficiency, contactless transfer, etc.), architectural scalability or intelligence for users or operation.

In addition, various “intermediary” concepts between the bus and tram are under development, offering various alternatives to municipalities willing to invest in surface public transport. It involves:

– energy (usually electrical with various capture solutions – but this is not exclusive, biofuels and natural gas are also acclaimed);

– architecture (connected and modular convoys able to disconnect to outskirts networks; a ground connection, a rail or road guide);

– intelligence (widely disseminated information between operators, vehicles, users – automatic driving).

The main industries work with their system partners on integration leading to a variety of solutions. Let us note that these systems all require a surface with on-site features, which is a precious and rare commodity in terms of land. The layout of intersections and corridor lane assignment are key elements that determine their operational performance. These do not agree with downgraded privileges, and any compromise leads to their decline. However, these management choices cause a barrier effect that thwarts other uses of the corridors: they significantly reduce the flow performance of the thus dedicated surface, which can only be shared with other modes in addition to its nominal operating conditions.

This fragmentation effect is just what the *urban transport by aerial cable*, cable car or gondola, wants to solve. This new entry was recently introduced, because of its lower energy impact, and its ability to integrate with less difficulty in urban areas[89], apart from the delicate issue of private property surveying that can create integration or landscape impact problems. Due to their ability to open up areas that are inaccessible or underserved for particular geographical reasons[90], the cable car can prove to be the transport systems of outstanding performance, compatible with environmental and economic needs to meet the urban medium. They may involve rungs relevant to an optimized multimodal transport scheme. However, the lack of references in relation to heavy operating and maintenance conditions severely limits it to (so far?) specific initiatives.

In terms of evolution toward transport solutions, and supporting walking, which continues to perform a vital role in mobility (especially now that it is equipped with "intelligence"), *bicycles and other cycles* are not left behind[91]. Already encouraged in most cities, and gradually accompanied by infrastructure specific for welcoming them, parking spaces, powering and protection, they can become a mobility core integrating electric support, recognition of the user, GPS positioning with support for routes (using specialized mapping) and wireless connection to the grid. From the vehicle architecture perspective, innovations continue to appear in matters of transmission, silhouette, alleviation, and highly innovative[92] "vehicle" concepts are regularly offered. Surveys [IND 10] show the interest in the electric bicycle as a factor for triggering change in user behavior[93].

The review of developments in transport means to integrated systems obviously does not stop there. We could talk more about

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[89] With the achievements of Medellin, Rio de Janeiro, the example of Taipeï urban cable car should also be referred to. Its flow rate is 2,400 people/h in each direction.

[90] Crossing a river or a stream, servicing a hill or relay between high points are configurations in favor of this system. The displayed cost per kilometer varies depending on the source (€15 M for 500 m and 1,200 passengers/h in Brest [BRE 12], the order of €10 million/km according to other sources). The speed is 7.5 m/s, 12 m/s is aimed for. The CO_2 cost is approximately 10 g CO_2/passenger/km.

[91] The "Bike City" congress now annually reports on these developments. In 2013, it was held in Vienna (Austria).

[92] Certain concepts may also refer to the sport of skiing.

[93] The European GoPedelec program promotes and evaluates electric bikes.

maritime[94], rail or air transport. Here, we especially try to show that, with proper connection of stakeholders, evolution is in progress; it involves incorporating these ingredients (energy-structure-intelligence) in a differentiated manner, adapting to the context of the mode of transport but in order to meet sustainable constraints based on the same fundamentals: economically viable and environmentally appropriate solutions for them to appear on the sustainable transport market (leaving business models to evolve), combining products and "packaged" services to fit into the mobility chain, consistent with physical and digital interfaces to satisfy it, and governed by established rules to respect the balance between the various stakeholders and the requirements they underpin.

5.5.4. *Innovations in operation and supervision*

We discussed *low emission zones* (LEZs)[95] in Chapter 4. The temporal and spatial access management, supervised by the local authorities, permits the promotion of sustainable transport solutions by constraints or by virtuous operation privileges, combining the intrinsic performance of vehicles and their good operation (especially their passenger or goods fill level, and their level of gas or noise emission). This requires a centralized management of control operations, based on continuous observation of the parameters characterizing the operation quality of transport system(s). Control centers become real operations *supervisors*, receiving real-time information and redistributing it to the various public or private operators, in order to meet the targets set in the context of cooperation between public and private partner policies: compliance to access rules, assignment of privileges, triggering alerts and response in case of security or environmental conflict. They also provide the role of guiding the different stakeholders involved in the decision-making, by creating

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[94] Work on the evolution of maritime or sea cruise transport leads to the same conclusion: the energy (wind, liquefied natural gas, photovoltaic, etc.), architecture (design, shape, structure of the hull and ballast, relief, etc.) and intelligence (during navigation, when approaching stops, when maneuvering, docking, etc.) are driving the development of transport solutions.

[95] The information regarding LEZs (countries, cities, vehicles involved) can be obtained from www.lowemissionzones.eu.

the link between the different bodies[96] involved: on the one hand, those involved in the crisis headquarters (decision stakeholders), and on the other hand, those in the crisis theater (operational stakeholders).

In road corridors, restrictive rules of operation can thus address the heavy axes on which governments impose servitudes to facilitate productivity in transport capacity and reduce their environmental impact. These provisions, which generally first restrict heavy freight vehicles[97,98], can introduce priority conflicts between the transport of people and freight. The evolution of transport systems should benefit from innovative ways to prioritize the use of urban expressways and facilitate the development of shared transport. This is especially true in urban outskirt travel, which is largely dominated by the car: carpool car parks and ride facilities, road and motorway stations, lanes for vehicles with high occupancy rates, control tolls for other users wishing to use these lanes. This is also to focus on virtuous collective modes (or organized individual modes), giving benefits to transport with high "added value" in terms of sustainable mobility: these are, for example, carpooling, buses and coaches, and their connections with urban rail modes, particularly due to the increase in their capacity for transported passengers[99] or metric tons: they allow the reduction of congestion by reducing the number of vehicles (through massification) and improving average speed (by "intelligent" regulation).

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[96] In France, these include various organizations associating the Home Office, Ministry of Defense, Ministry of Ecology, local authorities, infrastructure managers.

[97] Thus, Tyrol (Austria) developed the Nachtfahrverbot (night ban) since 2007. This ban on night driving was imposed on trucks for noise control reasons. It concerns vehicles that are not equipped with the latest generation of antipollution devices (www.bmvit.gv.at/index.html).

[98] We note that these provisions contradict the principle of massification.

[99] We speak of "traffic intensity" to describe the number of people passing through a given point, measured wayside. Tests to optimize the efficiency of specific sites on urban expressways have been implemented and could be generalized. In Madrid, the lane on the A6 motorway, accessible to vehicles with more than two people on board, provides a mileage intensity of 100,000 passengers per day; in the United States, the system of reserved lanes, high occupancy vehicle (HOV), provides a smooth flow for buses and carpoolers. In some cases, drivers in a hurry may also use these routes, with tolls.

Cooperative access management may reach seaports or airports, to encourage virtuous modes, giving privileges to compensate for the extra cost in investment and operation: access to these areas, for which the economic impact is strategic and for which environmental impact is considerable, are primarily reserved for vehicles with low emissions, and/or good fill, and/or massification[100], resulting in a measurable advantage per passenger seat or per metric ton of goods.

5.5.5. *The linking of systems in a mobility solution*

In the following example, which concerns urban logistics, we would like to "close the loop" by illustrating the interactive and integrative nature of solutions implemented in the various projects presented above.

We saw that the city, which is subject to the conflicting balance between logistics forces and urban requirements shown in Figure 5.1, seeks an alternative to the traditional model of goods distribution. Collaborative projects that we have described in this chapter provide new technologies or processes to this context (systemic technological bricks).

It then involves deploying them to implement the achievement of new real-scale urban logistics systemic practices. They must be able to handle the variety of situations (type of urban area, type of infrastructure, type of goods to be transported, etc.)[101]. In an inter- and multidisciplinary approach involving applying physical sciences to economics, human and social sciences, we must support the development of associated economic models (on the vehicle and infrastructure level, on the system level), and through evaluation of public policy tools and necessary partnership.

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[100] Thus, the authorization to make night deliveries would be limited to vehicles with low noise solutions, equipped with certified technologies (for example the CertiBruit label in France).

[101] This is the meaning of the "CityFret" program carried out by LUTB over the years 2009–2012 [CAU 10].

The integration of these bricks in a mobility solution facilitates (but also implies) the emergence of associated mobility services, such as:

– advance booking and secure delivery areas;

– access control particularly granting access privileges of green corridors and green areas to “clean” and virtuous vehicles, well loaded and well organized;

– assistance for optimizing routes and direct tracks or rounds;

– assessment and monitoring of the environmental footprint of vehicles and logistics operations;

– tracking and secure management of urban transport of sensitive goods (urgent products, hazardous materials, etc.).

We also note the possibility to link operations between “massified” vehicles on heavy corridors (trucks, buses, trams) and smaller vehicles, heavy vans or light electromobile “last kilometer” vehicles to ensure the fine coverage in living and trade zones. This link is more or less favorable for different types of urban structures and activities, from the urban hypercenter to the much less dense suburban areas, from coverage of a central shopping center to home delivery of fragile and urgent products. We can consider transposing the organization modes gradually applied to the mobility of persons onto goods, such as car sharing or carpooling, aiming to share and pool rounds, and by careful management of corresponding data channels: supplier logistical data to the end customer, urban traceability and supervision data. It is then necessary to ensure the parallel management of associated trading platforms.

Also, let us not forget the issue of urban logistics spaces which, as such, because of their geographical location in the heart of urban areas, have systemic characteristics: they relate to land management, vehicle access and their impact on residents, the transfer of goods, traffic, data, energy and management, monitoring of environmental impact. These characteristics here require multistakeholder cooperation and the development of related services.

Consideration of the “system approach” between vehicles, drivers, cargo, infrastructure, environmental factors, organization of the city and economic stakeholders involved thus leads to the emergence of redefined urban freight mobility. It involves a modernized work of stakeholders, at the center of an urban transport system architecture redesigned for each city scale. These factors may lead to a re-appropriation by the city of its flow of goods. The implementation of adapted governance, equipped with a capacity of shared and collaborative supervision, leads us to consider these flows in terms of public transportation of goods.

5.6. Application prospects

New technologies are carriers of a capacity to drastically reduce gaseous (including CO_2) and noise emissions, and a dramatic improvement in the mobility of people and goods, security and safety, operating costs and Quality of Service. But they are certainly not enough to achieve sustainable transport solutions. They should be placed in a policy project to promote them from an economic, environmental and social perspective in order to meet the objectives of sustainable mobility.

Some spectacular concepts have been proposed by companies, research groups, some futurists, who design “staggered” transportation systems combining technology and market. The following are the few examples:

– For maritime applications, the EOSEAS project by STX, implementing a proven large-scale technology, imagines a vacation cruise system based on a ship powered primarily by wind energy (which is a return to the fundamentals of this mode of transport) (Figure 5.14).

– For guided terrestrial systems, high-speed magnetic trains[102] (MAGLEV, Transrapid, Swissmetro, etc.) have already produced

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[102] Not to mention older concepts such as lifting air-cushion (for example the Bertin sky train developed over the decade from 1965 to 1975, which reached a speed of 422 km/h).

spectacular achievements, but struggle to reach a market. The Hyperloop subsonic pneumatic train moving in air-compressed pipes would reach Los Angeles from San Francisco (550 km) in 35 min[103].

– For urban systems, the city of Babcock Ranch is developing a mobility concept based on automatic vehicles[104].

– For aircrafts, pioneers offer prototypes without internal combustion engines and powered only by solar energy[105].

Figure 5.14. *EOSEAS liner concept [STX 11]*

These examples show what the near future can bring us, but it is difficult to separate what is achievable from that which is utopic, as some areas are moving fast. In a time when technology advances in numerous areas, the potential success of some technologically attractive solutions will be highly dependent on the ability to mobilize and adhere the stakeholders involved – the number of stakeholders

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[103] Elon Musk, the inventor of the concept, evaluates the cost of the project at approximately 6 billion dollars.

[104] The Babcock Ranch project in Florida is to become the first global city fully designed around solar energy. Electric automatic individual vehicles, managed in fleets, provide transportation for people and freight on dedicated infrastructures.

[105] The Swiss Solar Impulse project (Bertrand Piccard and André Borschbergen), developed at EPFL, is a prime example.

involved to adhere and to be mobilized increases with increasing depth of the solution across the different scales (geographic, temporal, thematic) of the system – which induces multiple interactions. Solutions that need a significant economic and societal investment in the long term will be more difficult to deploy because they require a meaningful and lasting political will.

However, the contemporary period shows a very rapid shift capacity toward alternative solutions, orchestrated by a combination of political motivations and economic fundamentals: prices and energy security, competition, ecological sensitivity, investment capacity, territoriality, social networks and local policies. Everything can go very fast in the era of information processing, of access to "knowledge" and of the proximity between solutions and uses.

Thus, brought back to the scale of the history of transportation, the speed of emergence of the contemporary electric road vehicle is atypical. In a few years, we have gone from stage of conceptual work on components and vehicles to that of integrated transport solutions and their associated services. The scientific and technical community, at the beginning limited to the circle of "technologists" and laboratories, has gradually expanded to now include social groups and urban communities[106]. Regular announcements broadcast amazing information on the rapid progress (though often not consolidated) of supporting technologies. And also, new business models for the development of innovations in transportation emphasize the fundamental role of services provided by the information technologies and their effectiveness in the appropriation of new forms of mobility[107].

So heading toward more sustainable transport remains paved with questions expressed by the scientific results of systemic multistakeholder innovation projects discussed in this chapter, as well as public policies in different regions of the world. Here are a few:

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106 The "first congress of electro-mobile communities" in France was held in December 2012.

107 Note the analysis of this trend in the blog hosted by Gabriel Plassat, ADEME (www.transportsdufutur.fr).

– when will hydrogen (for which production and storage infrastructure is yet to be invented) or natural gas (which is easy to operate), in their compressed or liquefied forms, bring about significant shifts in observed electromobility trends?

– can we consider a global convergence of solutions, or will each region deploy its own underlying trend?

– will structuring choices of integrated transport solutions be sensitive to socioeconomic risks, or contrarily, will they be sufficiently resilient (especially with respect to investment policies in structuring facilities)?

– are we orienting toward cohabitation and multiplicity of transport solutions, on the scale of a city, a region, a market?

– how far can the service evolve, how will it impact the behavior and needs of mobility [108]?

– what is the role of human behavior when faced with the automation that technology offers?

– how do we divide the responsibilities in case of a regulation malfunction of automatic vehicles resulting in, through systemic effects, a major accident involving some (or many) vehicles and/or an "unmanned" infrastructure?

These are questions that the multistakeholder innovative transport system projects seek to shed light upon.

Further, or alternative, development to systemic integration of these new technologies should be highlighted: this evolution is that of the implementation of progressive organizational innovation, which may include various aspects. We list some examples:

– The abandonment of the requirement of vehicle ownership for its use, resulting in "less car ownership, more car sharing", has clear advantages in terms of sustainable transport, be it only the impact on immobilized surfaces.

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[108] This question obviously has a reciprocal: how far can behavioral change and mobility needs go, how will it impact the service?

– Development of linkage capacities and linking of different “just necessary” modes to meet the transport demand is possible: using information technology, and the widespread sharing of data and their applications, according to approaches inspired by the “Internet of things”. This focus leads to much better use of infrastructure and available vehicles, without significantly increasing funding requirements.

– The creation of sustainable mobility organizing institutions will (would) allow provision of multimodal solutions to travelers, combining means of public transport and individually organized transport. The same approach can address urban logistics: the lack of a logistics regulatory authority today penalizes its economic and environmental performance, and its acceptability by citizens.

– The potential of a revised parking of private vehicles policy will allow better use. This privileged location is an optimal node for associating mobility services with local services. It can contribute to better management of interfaces between modes of different status[109], a guarantee that the complexity has been well mastered.

We note that these actions are all individual and collective. We can imagine initiatives at each scale of application, temporal and spatial, and by allowing interactions (i.e. how they are systemic).

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[109] Parking here is the privileged place where an individual mode and a collective mode link, in an organized context, the interface place between private and public ownership status.

Chapter 6

Public Policies, Economics and Sustainable Transport

As we saw in Chapter 5, the implementation of sustainable transport solutions is dependent on public authorities' willingness; however, they cannot act alone. It involves implementing public policy tools that are likely to incorporate the greatest number of stakeholders. They must be compatible in terms of command levels (underpinned by various territorial and administrative levels), as well as for the diversity of stakeholders involved in the definition and implementation of these policies, whether they are in the public or private sphere and of economic, social or environmental persuasion.

6.1. From global to local

The space for public policy in matters of sustainable transport is structured according to a double linkage, in the dimension of time as in that of space.

On the one hand, it ensures policy convergence between multiple societal demands often generating contradictory constraints: competitiveness, environment, mobility, regulation, financing of equipment and infrastructure, etc. Promoting one objective can be detrimental to another; the role of public policies is to develop the best course of action to satisfy these conflicts of interest. We note here that the "time" variable is at the heart of all positions. The electoral deadlines are usually "short-term", while reasoned objectives emphasize the importance and the major impact of visionary policy over the long term (in terms of population health, climate change, prevention of technological risk of low but non-zero probability, etc.). Here, as elsewhere, public policies must develop the fairest compromise between a tactical position based on instant indicators associated with societal response that is highly sensitive to everyday concerns, and an anticipatory strategic position and long-term investment for "future generations", with uncertainties to be explained. Moreover, knowledge is needed. They are not easy to approach, and science must be used to inform public authorities.

On the other hand, we must also create the link and consensus between different scales of territories and their organizations, from local to global level. Here again, the perspective is different for different types of impact. Promoting economic competitiveness is usually national or even local, while preventing greenhouse gas (GHG) emissions concerns everyone on the planet. The first political action requires a communal vision that is accepted, recognized and shared, then the development through "cascades" of action plans declining each administrative and territorial level, which requires the involvement of public decision devices for each territorial level. It is therefore the "space" variable that accounts for the local decline to both local and global expectations.

It is useful here to recall the evolution of actions that led to imposing recognition of the impact of human activities on climate change. At the forefront of these activities is transportation. The implementation of targets on GHG emissions, with consequences for transport, is at the heart of political action on sustainable transport.

6.1.1. *Impact on climate*

The objectives of GHG emission quotas are discussed at global conferences on climate change, driven by the United Nations since the founding conference in Geneva in 1979[1]. They are based on the Intergovernmental Panel on Climate Change (IPCC), which is responsible for scientific monitoring of the process of global warming[2] since 1988. The international treaty known as the "Kyoto Protocol" (1997), aiming to reduce GHG emissions, was established under the United Nations Convention on climate change for which the participating countries meet once a year since 1995[3]. Its entry into force is evidenced by commitments to reduce emissions with legally binding targets, as well as the declined implementation of actions to national level[4]. However, a general consensus on the practical arrangements and the actual extent of their implementation was far from being reached between the various parties (developed/emerging/developing countries, United States/Europe, etc.), and is regularly subjected to tough negotiations in successive United Nations conferences on climate change. To renew beyond the 2012 Kyoto commitments, successive attempts have been made, including conferences in Copenhagen (2009) and Cancun (2010), but they have resulted in minimal agreements. The 17th conference, in Durban (November 2011), ended with an agreement to extend the Kyoto commitments beyond 2012 and to establish a road map leading to the development of a global pact in 2015 to reduce GHG emissions,

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[1] These conferences receive a wide international media audience. The second conference was held in the Hague from 1989 to 1990. It concluded with a commitment by 12 states of the European Economic Community (EEC) to stabilize CO_2 emissions at 1990 levels by 2000. In the third conference, known as the Earth Summit in Rio in 1992, the United Nations established a Framework Convention on Climate Change, and the so-called Conference of the Parties (COP) is now annual, since Berlin 1995 COP 1.

[2] The IPCC piloted the writing of the 1990 report (1st report), 1995 (2nd), 2001 (3rd), 2007 (4th), 2013–2014 (5th), which takes stock of scientific knowledge on climate change and its potential impact on the environment, economy and society. This knowledge confirms the influence of human activities in terms of impact on climate, global warming and rising sea levels.

[3] Signed on December 11, 1997 at the 3rd annual conference of the Convention (COP 3) in Kyoto, it was ratified by the European Union in 2002 and entered into force on February 16, 2005. This protocol was designed to reduce emission levels of six greenhouse gases: carbon dioxide, methane, nitrogen and three substitutes for chlorofluorocarbons by 5.2% by 2012 compared to 1990 levels.

[4] The European Union and its 15 member states ratified the Kyoto Protocol on May 31, 2002.

for which the entry into force would be scheduled for 2020. The text includes, for the first time, all countries in the fight against global warming including the biggest polluters: China, India and the United States. However, it neither provides legal constraint, nor does it increase the level of measures to reduce GHG emissions in order to limit warming to less than 2°C. Non-governmental organizations unanimously criticize the lack of new concrete commitments.

Europe officially welcomed the Durban agreement it was calling for, because it allowed for the continuation and extention of the Kyoto commitment and it involves measures accompanying initiatives led by developing countries. It should, however, be noted that in these global negotiations, not all countries show the same vision or the same goals. Europe is in fact in a leading position on clean development and climate, especially relative to the Asia-Pacific Partnership countries block, which includes the United States, Australia and four Asian countries: China, Japan, India and South Korea. These countries account for nearly half the GHG emissions in the world. Their position is that the fight against global warming should not impede economic growth and that the biggest part of this struggle must return to the private sector. Other elements of the debate focus on the actions and financial compensations to support the struggle of countries most exposed to the consequences of global warming.

A *Green Paper* opened in 2013 helped prepare the European position on the international agreement that should be finalized in late 2015 and implemented from 2020 to 2030, according to the decisions of Durban. The Green Paper raises a series of questions on the type, nature and level of climate and energy targets for 2030, and on the competitiveness and fairness of these measures. Actions must remain consistent with European policy in the field of energy. Dated 2011, a road map to build a "competitive low-carbon Europe for 2050" [EUR 11a] traces the suggested pathways to achieve the goal of an 80–95% reduction in GHG emissions compared to 1990 levels.

Based on a {cost–efficiency} approach, it provides guidance for sectorial policies[5].

6.2. European transport policy

European transport policy is naturally associated with its energy policy and other aspects concerning the societal, environmental and economic topics. It lies on several levels: support for research, support for investment (in infrastructure), development of road maps and action plans, and development of regulatory Directives and their implementation.

The history of European policy on sustainable transport dates back to the 1990s, through the amendment of the founding treaties taking into account not only the rise of the environmental dimension, but also the international pressure led by example through conferences such as that in Kyoto. In 1995, we instituted a community transport policy overtaking structuring by mode of transport, advocating an integrated approach and displaying a greater target than the sum of performances of different modes of transport. Among the reference texts, we can cite the *White Paper on Transport Policy (2001–2010)*, followed 10 years later by the *White Paper on Transport Policy (2012–2021)*. According to the procedures of the Union, the White Papers set policy recommendations, which, after consulting the European Parliament and the Member States, can lead to Green Papers or Communications that list the options for achieving these objectives. These in turn generate Action Plans, which confirm the selected options and announce concrete measures. After consultation, the European Commission plans legislative proposals that are discussed with the Council of Ministers and the European Parliament[6] then are adopted in the form of European Directives.

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[5] For transport, in this road map we note: technological innovation, incentive measures (taxation, infrastructure financing, improving public transport, urban planning, promotion of low-carbon modes), sustainable biofuels (especially for aviation and long-distance road transport), etc.

[6] The Commission also issues *packages* involving, for example, Communications, Directives and Action Plans, like the one on alternative fuels called the *Clean Power for Transport Package* (March 2013).

Recent years have thus generated a set of policy actions to prepare and implement major shifts in transport policy matters.

The *White Papers on Transport Policy* lay out structuring principles on transport policy. The first edition (2001) showed the intention to decouple growth in travel demand from economic growth. It was estimated that the rate of traffic growth was leading to unsustainable and incompatible environmental impacts with objectives in terms of CO_2 and energy independence, and a way to contain this without affecting economic growth needed to be found. This target was corrected at the mid-term review in 2006, which endorsed the need to migrate toward the principle of co-modality, as an "efficient use of different modes of transport on their own or in combination" in order to obtain "optimal and sustainable utilization of resources".

The second edition, a decade later, re-raised the question of a modal shift from road toward more "virtuous" modes. The final text reflects the balance of views between the different stakeholders, mainly the Commission on the one hand and the Parliament on the other. The principle of co-modality is emphasized once again. While recognizing the essential importance of the road, and because of negative effects generated (congestion, pollution, energy dependence, etc.), it shows the importance of an integrated approach where technology is only one element from a set of practices of which the implementation is essential to meet policy objectives, including the internalization of external costs.

In the expectations of the 2011 White Paper, we note the need for a reduction of GHG emissions of at least 60% for the transport sector in 2050 compared to 1990, yet these continue to increase. An intermediate goal is to achieve a 20% reduction compared to 2008 levels by 2030 (which still places it 8% above the 1990 level). There is also the issue of exhaust and noise emissions of a local nature, which remain a concern despite progresses. Other expectations recognize the importance of technology, the competitiveness of the European transport industry, the quality of infrastructure and operations, including the removal of community barriers to facilitate virtuous and effective methods, guaranteeing transport productivity involving increased mobility and reduction of induced environmental impacts.

The second White Paper accordingly outlines European policy vectors for the transport of people and goods for short and long distances. Ten structural objectives are shown for developing and deploying systems for sustainable fuels and propulsion, optimizing the performance of multimodal logistics chains, increasing the efficiency of transport and use of infrastructure through effective information systems and financial accompaniments, taxation in particular. The proposed strategy involves:

– first, implementation of the single European transport area, matching the framework to promote professionalism of staff, safety, security and Quality-of-Service operations;

– second, innovation and technology of products and services, nourishing a systemic and multistakeholder vision and including urban mobility action plans;

– equally, qualification of a modern infrastructure with a network of structuring corridors and the means for communication and appropriate information, combined with pricing policies internalizing external costs;

– finally, the need to ensure compatibility of European policy with the surrounding world, in order to avoid competitive distortions and to ensure the effectiveness of these measures.

A list of 130 measures followed as initiatives to be animated, relating to various aspects of this policy, and on the different modes of transport. In this list of great interest that foreshadows the different aspects of European policy on sustainable transport, we can find most of the political actions that Europe plans to undertake in the decade 2011–2020, for which the impact in terms of sustainable transport will take place over subsequent decades[7]. It includes guidance in terms of technological research, the principle of co-modality and internalization of external costs. The potential for reducing emissions from passenger cars in urban areas is emphasized. From the perspective of freight, the use of trucks appears specialized to regional

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[7] On average, a research program initiated in 2015 will lead to innovation maturity between 2025 and 2030. Dissemination and the effect of this innovation, taking into account the lifetime of products (which may be 20 years), will continue until 2050.

services and is limited over long distances; their architecture can be optimized to increase their effectiveness. We are aiming for carbon-free urban logistics. The multimodality of freight is favored by adequate financial instruments (mostly based on environmental efficiency standards) and the implementation of green corridors. User education, behavior change and speed limits are also mentioned.

In wake of the *White Paper on Transport Policy*, several key instruments for transport have been published. We can note, for example, in recent releases:

– An action plan on urban mobility (2009), which proposes 20 measures to help local, regional and national authorities achieve their objectives in terms of sustainable urban mobility[8]. This action plan proposes, for example to support cities in their efforts to acquire their own vehicles for public transport, or implementation of "green zones" to ensure environmental protection without introducing a discriminatory barrier to the movement of citizens. It urges action to better integrate multimodal transport systems and promote single pricing.

– An action plan on the implementation of intelligent transport systems (2008) and a Directive to accelerate its deployment [ITS 10]. This particularly concerns specifications for compatibility, interoperability and continuity of ITS solutions applied to traffic information and travelers[9], emergency call systems and parking of trucks. Figure 6.1 shows the agenda for implementation.

– A Green Paper on investment policy in European transport infrastructure (Trans-European Transport Network (TEN-T)) and a review of their director scheme (2011).

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[8] However, this text emphasizes the principle of subsidiarity, recognizing that the full responsibility rests with local authorities.

[9] The Commission is aiming for the adoption of multimodal route planning systems by 2015 that take into account all modes of transport and all possibilities offered by public transport. They give users all the information they need to prepare their journey from door to door in just a few "clicks", and allow them to travel in a manner best suited to their needs: the fastest option, the cheapest option or the option with the lowest impact on the environment.

– An Action Program on road safety (2011–2020), which aims to halve the number of road deaths throughout the decade, advocating a seven-goal plan with an integrated approach.

– A review of the 2007 Action Program for freight transport and logistics.

– A Package for transport and clean energy (2013), which specifies the requirements in terms of infrastructure and standards to provide transport (especially road and river) with electricity, hydrogen, liquefied natural gas and compressed natural gas.

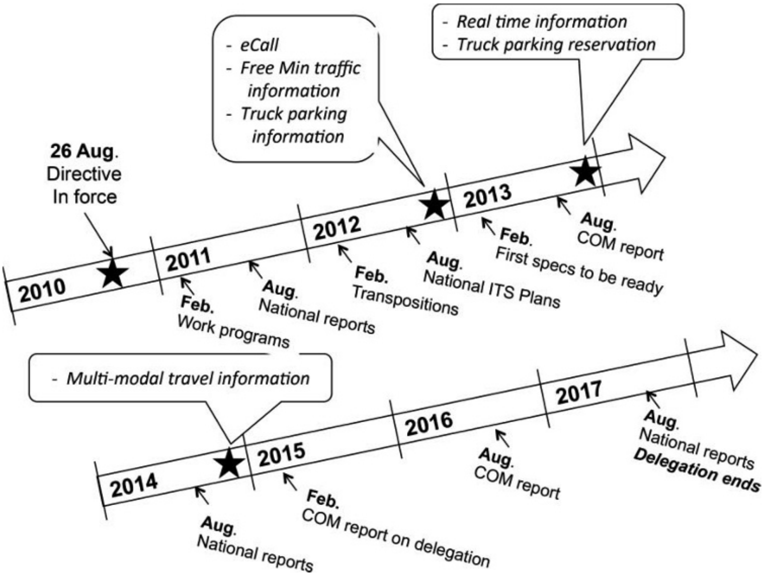

Figure 6.1. *Agenda for implementation of the European Directive on Intelligent Transportation (ITS Directive) [EUR 10b]*

– A Package for rail transport (2013), intended to complete the creation of an open European railway area engaged through previous European legislations and concerning the governance of Member States' railway systems, competition in domestic passenger markets and railway safety and interoperability.

– A proposal to amend the legislation on biofuels to reduce the climate impacts of their production (2012–2013)[10].

– Proposals for European Directives on carbon-free vehicles, such as CO_2 limits for cars[11] and light trucks (2012–2013).

6.2.1. *Research support*

For research, the European Union has led the famous R&D Framework Program since 1984 (now Horizon 2020), an accompanying program of partnership initiatives in cycles of 5–6 years. In particular, through its transport component supported by at least three Directorates General of the Commission[12], FP7 (2007–2013) has helped fund a number of collaborative projects involving industry and laboratories on thematic lines corresponding to Commission objectives. Horizon 2020 (H2020), which is a continuation of FP7, is a multiannual program (2014–2020), which launched its first call for proposals in December 2013. Transport accounts for approximately 7–8% of the total budget of H2020[13], or €6.5 billion. "Sustainable transport" (*Smart, Green & Integrated Transport*) of course involves the basics: carbon-free energy solutions for engines and vehicles, intelligent transport systems, multimodal linking of transport solutions.

To support these themes, {public–private partnerships} (PPPs) have been established in mixed platforms involving major contributors (stakeholders) in industry, research, public policy, such as ERTRAC (road transport), ERRAC (railways), Waterborne (sea-river mode) or ACARE (air). All stakeholders define technological road maps to

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[10] As the biofuel market has grown, it has become scientifically established that all biofuels are not equal in terms of greenhouse gas emissions related to land use. Because of indirect changes in land use, the CO_2 emissions contribution of certain biofuels can be the same as that of the fossil fuels they replace. This is why the Commission was asked to examine the impact of indirect changes in land use (indirect land use change (ILUC))) and propose legislative measures to compensate for this effect.

[11] 95 g CO_2/km in 2020.

[12] DG Research, DG Move, DG Connect.

[13] H2020 has a budget of €70 billion over the entire multi-year period.

"pave the way" toward virtuous and sustainable transport solutions, both economically and socially or environmentally. The products of these organizations are translated into calls for collaborative development projects, annually. For example, the European Green Vehicle Initiative (EGVI) is a PPP that covers areas of research to further push technology solutions on the development of clean road vehicles and infrastructure, as well as the conditions for their implementation, including European and national public policies. It involves moving from research to innovation. In Chapter 5, we saw an overview of the projects funded within the budget: electrification, engine, fuel, weight reduction, safety and intelligence are all essential topics on which technologies, demonstrations, deployment of transport solutions are encouraged. Figure 6.2 shows an overview of the complexity of the governance structure of these platforms.

Other PPPs are taken into account in supporting H2020, including the one dedicated to maritime (PartnerSHIP 2020[14]) and another to rail (SHIFT^{2}RAIL).

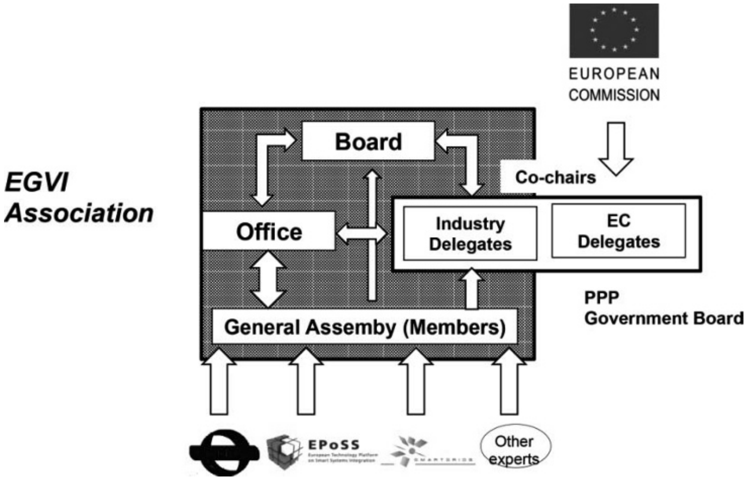

Figure 6.2. *Governance structure of the "European Green Vehicle Initiative Public-Private Partnership" platform to drive European research on road vehicles of the future [EGV 13]*

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[14] Designed in 2013.

6.2.2. *Taxation and financial policy*

European policy, which could be summarized by the {polluter = payer} principle, tries to objectify the external costs of transport in order to, through internalizing them, encourage solutions based on low emission levels of CO_2, other GHGs and other pollutants. The "Eurovignette" Directive[15], introduced for road freight transport, is an example: it establishes a framework for Community rules on the taxation of transport operations, based on vehicle use of road infrastructure, which is itself based on the distance and time traveled, as well as the emission class of the vehicle (one way to describe its impact in terms of external costs). The application of these rules, which aim at fair pricing and efficient use of infrastructure is, however, not widespread, and it remains a Community policy objective. Transposition of these rules varies between the countries of the European Union[16].

The same approach for harmonizing practices also applies to assessment methodologies for the impact of transport[17] or financial incentives to promote vehicles with low CO_2 emissions[18]. Recommendations are issued to avoid distortions between

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[15] Directive 1999/62/EC, as amended by Directive 2006/38/EC and Directive 2011/76/EU, gradually applies to vehicles more than 3.5 t. In 2011, the Eurovignette was operational for trucks of more than 12 metric tons traveling on motorways in countries such as Benelux, Sweden and Denmark.

[16] The application of these rules, however, is not widespread; it remains a Community policy objective (June 2013). In France for example, the transposition of the Directive into French law introduces the possibility of modulating tolls based on traffic congestion and vehicle category in terms of the Euro X standard, but it does not plan to internalize the external costs of transport (air pollution, noise) in road tolls.

[17] Thus, CEN, the European committee for standardization, published a standard method for calculating CO_2 emissions for the calculation and reporting of energy consumption and greenhouse gas (GHG) emissions of transport services (passenger and freight).

[18] The European Directive 2009/33 provides a new criterion for environmental assessment based on the external cost of emissions (including health and global warming impact). This "Buy Green" Directive involves Public Procurement including the acquisition of low-emission vehicles; it calls for the purchase of vehicles that value societal costs of emissions (NOx, PM, CO_2): a cost is associated with each emitted pollutant: NOx = 0.44 c€/g, PM = 8.7 c€/g, CO_2 = 0.003 c€/g (calculations based on the ADEME-RATP cycle). The use of biofuels (biodiesel B30 or B100, biomethane) can also be valued.

EU countries when it comes to grants, loans, tax deductions, etc. They cover all categories of road vehicles.

Investment is also encouraged, notably through the involvement of the European Investment Bank, to support public policies promoting transport infrastructure[19] and vehicle fleets for public transport.

European funding accompanies the director scheme of TEN-T that is mainly concerned with promoting cross-border transport, treating the locks that impede effective mobility along major corridors and strengthening multimodal platforms. Transfers from road to rail or waterway are encouraged, as well as the development of interoperable and intelligent operating systems.

6.3. Link between the European level and local level

Policies at national or regional or local level are similar on the territorial and administrative level to those carried out at European level. However, the principle of subsidiarity applies[20].

Many relationships exist between different territorial and administrative levels. They help to ensure consistency, in an upward and a downward direction. On the one hand, the European Commission conducts programs[21] or forums[22] directly involving *European cities or regions*, either directly or through networks such as Eurocities or POLIS for cities. Conversely, they are the initiative of

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[19] The Marco Polo program supports infrastructure projects to encourage a modal shift toward more sustainable transport. The call for projects in 2013 aimed for the development of maritime or river transport or railway wagon solutions.

[20] Applied to the European Union, the principle of subsidiarity is designed to favor the lower decision-making power as long as the upper level cannot act in a more effective way.

[21] Thus, the CIVITAS program launched in 2001, for which the aim is "to promote the implementation of policies for sustainable, clean and efficient urban transport through the demonstration and assessment of an integrated set of technological measures and ambitious policy" (www.civitas.eu).

[22] In the Covenant of Mayors meeting on February 10, 2009 at the European Parliament, in partnership with the Committee of the Regions, 400 cities committed to facilitate a proactive policy to go beyond the objectives of reducing energy consumption (the "−20%" of CO_2 by 2020) of the European Union.

local or regional actions that implement public policies in favor of sustainable mobility, which become a best practice and can be disseminated elsewhere in Europe. In contrast, some regions or cities are stigmatized because they do not meet objectives set by European policy and may be subject to financial penalties. This is the case, for example, for pollution levels from transport, such as nitrogen oxides for which the limits are regularly exceeded in some highly urbanized regions of the EU.

In Chapter 4, we saw that some cities have now imposed restrictions or access tolls to their territory for vehicles according to place and time, for reasons related to sustainable mobility. They govern urban transport plans and related investment, and even shifts in terms of urban logistics. Many examples of good practice can be reported for the field of electromobility (cities such as Stuttgart and Copenhagen), for the promotion of alternative modes (Strasbourg), parking policy (Nice), for organized urban logistics (Padua), etc. A city such as Lyon establishes its “Climate Plan” and uses actions concerning transport in particular: it leads a multistakeholder dialogue to promote sustainable transport through a coordinated range of solutions (transport systems, multimodal organization, development of data on travel and mobility, promotion of related services). It links, because of European funding[23], with cities such as Turin, Madrid, Gothenburg, Birmingham and Wroclaw to develop services for optimizing urban mobility and enhance sustainability.

All this is an illustration of bilateral coupling between local (cities or regions) and European policies. Between the two, there are the Member States of the Union, who certainly did not remain inactive but whose involvement in its diversity lack clarity, each country displaying its own policy.

Let us consider France: the decentralization that began in the 1980s gave local authorities greater powers in the field of travel. The regionalization of public policy, that is to say, their adaptation to the local context, was a *leitmotif* of this decade. However, the late 2000s saw, with the presidency of Nicolas Sarkozy and the so called

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[23] Opticities Project 2013–2016.

"Environment Round Table"[24] (2008–2009), the resurgence of the affirmation of national and even international issues around issues related to global warming [CER 12]. It spawned a series of expert reports, legislative tools and action plans for sustainable transport[25]. The next President, François Hollande, in turn promised a national debate called "the energy transition" (2013), leading to an action plan for the transition to a low-energy system that is less dependent on fossil and nuclear fuels.

Regarding the section on vehicle technologies and innovative transport systems, these are developed in clusters encouraged by public funds[26] such as Mov'eo, Vehicule du Futur or ID4Car (for passenger cars), LUTB (for urban transport systems), I-TRANS (for rail), Aerospace Valley (for aircraft), Mer-PACA and Mer-Bretagne (for ships).

The national Eurovignette variant is called Ecotaxe[27]: its product, managed by the Infrastructure Financing Agency in France (AFITF), must contribute to the implementation of a modal shift policy on long-distance transport, devoting the bulk of spending to modes other than road transport. From the perspective of transport infrastructure, the national variation of the European TEN-T is the "Schéma National des

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[24] Also called "Grenelle de l'Environnement".

[25] We include iconic "productions" such as the "Syrota report" (2008), the Plan for electric vehicles, or the Future Investments Plan that funded demonstrator projects for carbon-free vehicles.

[26] Competitivity clusters were created in France in 2005 by the Ministry of Industry (DGCIS). Public support funds for R&D are managed by agencies such as ANR (Research), ADEME (Environment and Energy), OSEO-BPI France (Innovation), with an interdepartmental governance to animate networks of experts from public and private spheres such as PREDIT (Department of Transportation) for land transport (2013).

[27] Initially planned to enter into force in 2013, the new tax was originally imposed to encourage shippers to use alternative modes of transport to road transport. Simulations show, however, that the main change in transport patterns will be limited mainly to an arbitration between current taxed roads and the highway. It will affect 10,000 km of national network, and 5,000 km of local network. With an average rate of 0.012 € per kilometer, the estimated revenues are approximately €1 billion per year [MAR 11]. Both technical reasons (due to late equipment of trucks) and principally economic and political reasons (due to resistance to accepting them) convinced the French government to delay the enforcement of Ecotaxe after 2013.

Infrastructures de Transport" (SNIT)[28], which in France addresses the structuring lines of the evolution of national transport networks. The variant of the ITS Directive (2010) applies to intelligent transport systems, ratified by the relevant law[29]. National variations for recommendations relative to the declaration of energy and GHG consumption for transport services (passenger and freight) leads to a decree published in the *Official Journal*[30] relating to information on the amount of carbon dioxide emitted in the course of a transport service.

The example of France is transposed elsewhere in various EU countries, with their specificities and similarities. The most active countries play a more influential role in shaping European policy. Each, through its administrative or political originality, declines it in its own way. However, there is a comprehensive commissioning approach to public policy where the role of the States (and their regions) are, in a progressive manner, exercised in favor of the fundamentals that could set the framework for sustainable transport:

– across Europe: general policies, long-distance corridor infrastructure, hubs, multimodality;

– regional or local level: the variation of these policies in their geographical, cultural, economic or social particularisms, urban transport infrastructure, local initiatives with strong operational capabilities;

– between the two, on the state level, which work on common themes (environment–climate, energy independence, etc.), and simultaneously compete (energy policy, industrial policy, expectations

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[28] The SNIT resolutely displays the priority of rail over road, especially for freight: increase in capacity on the rail network with ERTMS, improved freight paths and implementation of phasing, reduction of passenger traffic on big lines due to the commissioning of high-speed lines (LGV).

[29] Ordinance No. 2012-809 of June 13, 2012 on intelligent transportation systems. It transposes the Directive of the European Union of July 7, 2010 into French law, governing the deployment of Intelligent Transport Systems in the field of road transport and for interfaces with other modes of transport. This ordinance comes with a report to the President of the Republic.

[30] Decree No. 2011-1336 of October 24, 2011 provides for an obligation to inform customers of transport services (passenger and freight) of the amount of CO_2 emitted by the mode(s) used (rail, road, sea, river, air). It entered into force on October 1, 2013.

of citizens, etc.). There is a question of general interest, but also national policy and competitiveness, whether it involves industrial activities related to transport or logistics activities to capture flow and do business.

6.4. Public policy and economics

Therefore, the issue of sustainable transport and its positioning in the necessary energy transition (including future generations) cannot be dissociated from that of economic growth and maintenance, or even increase, of contemporary collective or individual well-being. The evolution of a mobility ecosystem involves economic stakeholders whose good health depends on – but also guarantees – the quality of life of citizens, who are also transport users: these stakeholders are equally manufacturers and managers of vehicles and their equipment, infrastructure and their equipment, but also transport and infrastructure operators, developers and managers of services (mobility assistance, insurance, rental and leasing), community and authority organizers, logisticians, etc.

Economic policy is an integral part of public policies. Its effects are measured in terms of direct and indirect benefits of public action, according to different economic components. Economic policy is put into the context of necessary links between short-term and long-term effects. It should also be appreciated in relation to the capacity of stakeholders to finance these actions (and we know that government deficits in some countries of the European Union are a major impediment to certain accompanying measures, which are nevertheless essential to promote rapid emergence of these solutions). We mention a few examples[31].

Aid in terms of investment may cover the development of industrial facilities to produce the equipment needed to implement transport solutions (vehicles and components, power systems, intelligent systems). We can mention the production of elements such as batteries, fuel cells or photovoltaic cells, which require substantial funding in the emergence phase for a profitable market. These aids also have the objective of supporting local jobs relating to the

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[31] Its thorough consideration is beyond the scope of this document.

industrial production of these products; they are subject to competition and competitivity proceedings that were designed to avoid the development of illegal practices.

Aid may also apply to the direct purchase of virtuous vehicles or transport systems, for which the purchase price is higher than the conventional market price[32], but the public authority intends to promote development by acting on their financial support. It naturally involves all applications relative to public transport (rail or road vehicles), but also public fleets for street cleaning services (such as refuse collection), or aid to individuals in the form of a bonus for the purchase of electric vehicles. In this case, the aid is subject to European Community appeal offer procedures where relevant.

The investment incentives are also due to the implementation and provision of facilities such as rail and road corridors or multimodal land, port or airport platforms. They primarily concern the basic infrastructure such as the TEN-T (Europe) or SNIT (in France) and – at the local level – urban planning and urban development plans built according to the public procedures that are in vigor.

Through its actions, the public authority must consider that some decisions only have effects in the long term. For example, the lifetime of vehicles is typically two – or three – decades[33,34]. The scope of these decisions is particularly to be estimated at the margin for vehicle fleet renewal (typically 3–5% per year). The same applies to the time between the decision to invest in transport infrastructure and its operational implementation. Again, it may take several decades[35] and

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[32] Demonstration of the economic relevance of such equipment requires taking into account the value of the duration of use, the life cycle value (with maintenance costs, the cost of energy, CO_2 tax, value of resale, recycling, and the question of the internalization of external costs). The lack of feedback in the short term usually makes them non-competitive with more conventional equipment.

[33] The average lifespan of an aircraft is 30 years, that of a ship is 28 years and that of a train is 35 years [PRI 10].

[34] This is the main reason for the slowness of the beneficial effect of “clean” technologies on road vehicles, fleets still containing “old” vehicles (20 years of age) emitting as much pollutant as several (and even many) newer vehicles.

[35] Project documentation for a high-speed rail link between Lyon and Turin began in 1990. The implementation of the “basic tunnel” (53 km in length, estimated to cost €8.5 billion) is planned for around 2025. The completion of the entire line is a more distant goal.

require substantial amounts of money[36]. However, there is no guarantee that the public power has all the elements of expertise and projection capability required to indisputably prioritize its choice of infrastructure financing within the limits of our knowledge and possible scenarios.

This is why the development and deployment of services (web platforms for mobility aid such as access to multimodal information or carpooling, parking management, implementation of urban access control, increase of existing infrastructure capacity through intelligence[37], etc.), for which the effect is immediate and the environmental, social and economic impacts are quickly perceptible, are also acclaimed for public investment and should be more so, compared to policy based on equipment investment, albeit which is more dramatic, more "meaningful" perhaps in terms of image and communication, but ultimately less "productive". Reducing congestion costs (in terms of hours lost), as well as reducing health care costs (in terms of care, of life expectancy reduction), are indeed clearly displayed short-term economic objectives, which are superimposed onto the long-term goal of shifting climate impacts[38]. However, their widely debated assessment establishes orders of magnitude to guide economic policy action.

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[36] The cost of the construction of a motorway is currently €5 million/km to €9 million/km, it can reach up to €27 million/km [SET 11, WIK, GEL 07]. That of a BRT line on its own site is €2 million/km to €10 million/km. For a tram, €13 million/km to €22 million/km. For light rail, €60 million/km to €80 million/km. For a heavy metro, €90 million/km to €120 million/km [CER 11]. A TGV line is between €8 million/km and €66 million/km [WIK].

[37] We could significantly increase the capacity of heavy infrastructure that is today too close to saturation, such as high-speed railway lines, by a different management of convoys, integrating the new capabilities of ITS technologies.

[38] In its study "*The economic costs of gridlock*" (January 2013), conducted on behalf of Inrix, the British firm Cebr estimated costs of road traffic, from the direct cost (fuel and time) and indirect costs (product price increase for which the route was delayed). Congestion would cost over a year in Germany €7.8 billion, €4.9 billion in the United Kingdom and €5.5 billion in France (where, in addition to the financial cost, they would lose a yearly average of 45.4 h/vehicle) (www.inrix.com).

Conclusions – Directions

In the previous Chapter we covered different aspects of the questions: what should we propose for a more sustainable transport system? What are the components? How to implement them? What performances do we expect?

We want to conclude this book with some considerations on the positioning of proposed actions: these clearly interfere with other goals. They ought to be brought forward through linking with many other aspects. They imply engagement from today and over the long term. Alone, they cannot afford to cope with all the consequences of our society's choices.

Confronting contradictions between objectives

The difficulty in obtaining a balance between the different components of public policies (economic, environmental, social, etc.) reflects our individual and collective behavior which is inconsistent in terms of expectations and practices vis-à-vis transport. This inconsistency must be considered from various perspectives. The short-term objectives (satisfy our needs) in relation to long-term objectives (save the planet), local community objectives (preserve the neighborhood) compared to a more general structure (be easily served by transport means), our attitude changes, our mobility requirements and daily constraints are all dispersive factors compared to a scenario based only on the implementation of sustainable transport conditions.

However, in spite of this overall incoherence, "we are all in the same boat" from a sustainability perspective (whether the scale is the neighborhood or the planet), and each person has a paddle to steer. Finally, the main question is whether we can coordinate "rowing" together in the appropriate direction for sustainable transport, or if each person carries on individually. This diversity is for people throughout different attitudes and intra- and interindividual positions; political, economic and social organizations, from local to global level, even whole nations. It is combined with a behavior for which the "schizophrenia" is explained by the apparent diversity of objectives to be met, their differences or their inconsistencies: according to places, times and deadlines; and according to social groups and their understanding of particular interest in relation to public interest.

The search for more sustainable transport is therefore, according to our balance, contradicted or encouraged by some of our individual and collective goals. Here, we are confronted with the problem of our complex interconnected systemic structures, and their multiple scales, which involve conflicting solutions in the field of transport as in other areas.

Figure C.1 illustrates the {sustainable transport system} relationship, which we have investigated in this book, and which is summarized here. The dimensions show which relationships to coordinate between stakeholders {who?}, transport systems themselves {what?}, the fields of application and implementation {where?}, objectives to achieve {why?} and the means to achieve them {which way?}. As for the {how?}, it provides necessary innovation systemic bricks. Transport solutions and sustainable mobility are built on this multidimensional space. They interact with other areas of society: land or city development that structures the space and determines the needs for mobility is a foundation. Education, which accompanies the training of citizens as well as professionals, is also one.

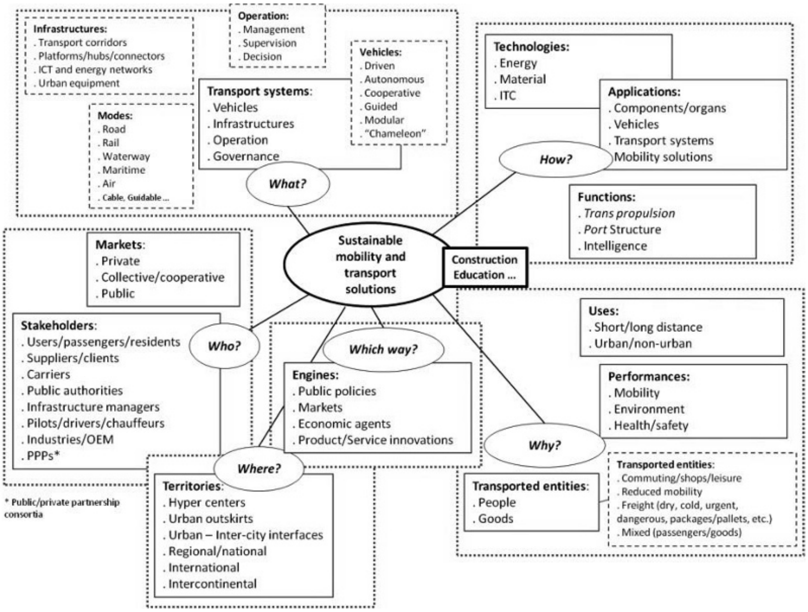

Figure C.1. *Multidimensional space of sustainable transport solutions [FAV 13]*

Future scenarios for sustainable transport

Sustainable transport projects us into the future; it can only be understood from prospective scenarios based on our knowledge and observed trends. Futurists are guided by cross-reference analysis according to the highlighting of various aspects involved in the development of transport: supply or demand for mobility; ecology, economy, technology and society, etc. The development of these scenarios leads us to imagine a variety of possible futures and it helps us to enlighten particular public powers[1], communities and large companies (Shell (Game Changer) http://www.shell.com/global/future-energy/innovation/game-changer.html; Volkswagen AG http://www.volkswagenag.com/content/vwcorp/content/en/innovation.html) [DHL 12] on the various options and their likely consequences, but of

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[1] See, for example, the scenarios developed under PREDIT 4 (France); or the study by Chardon [CHA 10], who designed three scenarios for a fleet of 1 million vehicles in 2020 in France.

course it is not possible to ensure its advent. Naturally, the general trend is increasingly more uncertain the further we project into the future[2]. Moreover, transportation roadmaps rarely plan beyond a horizon of 15–20 years, which is the time required to deploy an innovation, but much lower than the actual useful lives of possible transport equipment, vehicles and infrastructure! Vehicles put into circulation in 2015 will, for the most part, continue to circulate for 20–30 years (depending on the mode of transport), at the current rate of fleet renewal. What is our collective ability to predict transport as it will be in 30 years? As for infrastructure, they seem unalterable over these short durations compared to the history of humanity, at least in their technical characteristics: path, right of way, land footprint, etc. But their mode of operation, maintenance, upkeep in operational conditions adapted to technological and organizational requirements, equipment in terms of energy and intelligence, however, raise many questions and adjustment variables on future performances.

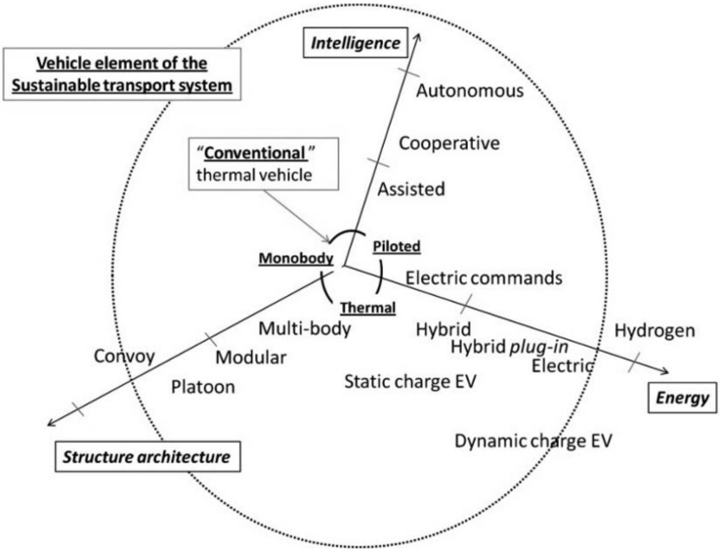

Figure C.2. *Evolution of the vehicle in the context of a sustainable transport system*

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[2] While it is easy to imagine that "tomorrow" will be different from "today", the exercise of clarifying how and when it will happen during the interim period is much more difficult.

Figure C.2 shows an overview of what the development of road vehicles could be. According to each of the dimensions of energy, architecture and intelligence, it has the potential, as we have seen, to pass critical milestones through the gradual integration of systemic features. The car of the future will be, compared to today's vehicle (which can, through simplification, still qualify as a conventional thermal vehicle), a component of the transport system.

To pave the future of transport, the milestones in terms of strategic objectives – the next decades (2020, 2030, (sometimes) 2040 and (often) 2050) – are usually mentioned. In particular, these projections concern the relationship between transport and energy; they focus on different energy scenarios and their consequences and links in terms of technology and environmental impact. In addition to energy, mineral or natural resources that we presented in the introduction, the observation of individual and collective demographic and social change introduces major shift vectors and equally powerful inertia. As for technology, we know how it can evolve over the years, based on a cycle from invention to market[3], according to its systemic depth and mobilized technical (hard or soft) or organizational resources. The flow and abundance of innovative solutions from current technological research, from the microscopic (or nanoscopic)[4] level to the macroscopic level (that of a transport system integrated into the systemic environment), will change the landscape of possibilities, but their potential as well as their rate of achievement remains unpredictable. Beyond 2050, production scenarios are rare; they reveal long-term trend levels that stretch to 2100, the emblematic virtual year where our capacity to imagine the future of transport tends to disappear[5].

The search for efficiency is the heart of the sustainable transport challenge. The three functions of transport – effective speed, effective mass, effective intelligence – are to be targeted; the materials are to be designed and their nominal features optimized, their operation needs

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[3] This is what the Hype cycles illustrate [GAR 13].

[4] Microscopic level: sensor, fuel cell for batteries, fuel cell membrane, etc.

[5] METI (Japan) produced a 2100 scenario on the future of transport energy, and how to achieve it through technological breakthroughs.

to ensure fair use, which is the guarantee for minimizing emissions, congestion and accidents levels for each transport unit, per passenger per kilometer or ton·km[6]. Flows are to be facilitated, streamlined at interconnections, and transfers must be secured. Transportation must spread across the whole mobility chain. This approach allows us to identify significant potentials for improvement and optimization by combining technology and organization: the innovation and emergence of sustainable transport solutions have largely systemic features, primarily involving the users themselves, including a shift in their lifestyle, or their relationship to transport. However, these potentials are largely dependent on areas of transport: urban or long distance, people or goods. Thus, long-distance transport of people is highly dependent on aircrafts, for which the prospects in terms of sustainable transport are, as discussed, particularly problematic.

Proper conduct of stakeholders between public power and private initiatives remains an important motor for development and promotion of sustainable transport, and a prerequisite for systemic innovation. Its coordination and good governance are key factors for success to introducing, wisely and in the correct time frame, technical and organizational innovations that require economic, legal, regulatory accompaniment or essential public facilities: infrastructure that includes parking, energy distribution networks or communication networks. Similarly, new champions of mobility[7] are emerging. They offer integrated solutions combining transport and services to meet a variety of user needs and logistics. This trend is a reality in motion that will quickly revolutionize the approach to mobility and transport[8], particularly in urban areas. It will shift the current balance between manufacturers (of vehicles, infrastructure and transport systems), operators, exploiters, users, etc.. But this goes hand in hand with the emergence of local and collaborative solutions across a street or

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[6] But this must also be done by minimizing the surface area consumed per unit of “linear distance”. This space refers to the area of land affected by a moving vehicle, its footprint. Examples include – noise-related land impact (6,000 m^2 of instant surface for a road vehicle, see Chapter 3); – energy-related land impact (between 0.12 and 0.7 m^2 of ground to produce the biofuel required per km traveled for an automobile, see Chapter 2).

[7] We refer to, for example, Google, TomTom, Apple, IBM, etc.

[8] See http://transportsdufutur.typepad.fr/blog (Gabriel Plassat, ADEME).

neighborhood, where social proximity networks could play a significant role. They will promote the passage of “owned” mobility to pooled mobility services. Beyond this dynamic that we see “boiling” before our eyes, how can we predict its evolution?

To conclude, we return to what we said in the introduction to this book: transport requires energy and matter. Modern times have added intelligence, with which we can imagine sustainable transport. This seems essential because it could save us. Not only technology intelligence as it is brought by IT means, but much more intelligence of human thought and that of the individual and collective reason. By further appropriating ourselves with the necessary awareness of the two issues that are the source of our difficulties to imagine sustainable transport: population explosion coupled with our mobility bulimia.

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Glossary for Alternative Fuels

Alcohol a general term used to design any organic compound that links a hydroxyl group (−OH) to a carbon atom, which is then linked to other H and/or C atoms (see also Ethanol and Methanol).

B5 a fuel consisting of 5% biodiesel mixed with diesel. B5 is known for not requiring engine modifications. Higher mixing ratios are denoted in the same way: B20, B30, etc.

Biodiesel a renewable and biodegradable fuel made from various vegetable oils, animal fats and recycled frying oils. It is the product of a chemical process called transesterification, in which glycerin is separated from fats and vegetable oils. The most widely used biodiesel is made from soya bean oil. Biodiesel is either sold pure or mixed with traditional diesel.

Biofuels renewable fuels derived from agricultural products (first generation), or biomass resources such as residues and waste from agriculture, forestry and animals, as well as from city dumps (second generation). Biofuels can be used to produce electricity via combustion and transformation, although they are particularly renowned for their use in transport. They include alcohols, esters, ethers and other products of biomass.

Biogas it can be produced using many types of biomass. Biomass ferments anaerobically and changes into gas. Raw gas is purified and methane is produced as the end product.

Biomass any available organic matter that can be renewed or that is recurrent.

Biomass-to-liquid (BTL) refers to liquid fuels derived from biomass. This includes DME, methanol, synthetic diesel oil, ethanol, etc.

Carbon dioxide (CO_2) a (non-toxic) product of fuel combustion. The levels of CO_2 originating from fossil oil increase as the oil is used; this is one of the main proven causes of global warming. As for carbon monoxide (CO), it is a poisonous product of incomplete combustion. An important part of CO is emitted by transport, leading to the obligation of using devices for the after-treatment of exhaust gases and of using "oxygenated" gasoline, such as mixtures incorporating ethanol.

Coal-to-liquid (CTL) refers to the category of liquid fuels that are produced from coal. This includes DME, methanol and synthetic diesel.

Crude oil oil in its native state, such as it comes out of oil deposits prior to treatment and refining.

Dimethyl ether (DME) a non-toxic fuel, with "clean" combustion; an interesting alternative solution produced by gasification of natural gas, coal or biomass. DME is a liquid at a pressure of 5 bars (ambient temperature).

Ethanol an alcohol that is a renewable and biodegradable fuel produced by fermenting grains containing sugars or starch; maize and sugarcane are the most commonly used. Residues from paper mills and food factories (potatoes, breweries, etc.) are also used as sources for ethanol.

Fatty acid ethyl ester (FAEE) the product of a catalytic reaction between fats or fatty acids, and ethanol. FAEEs have the same properties as FAMEs.

Fatty acid methyl ester (FAME) the product of a catalytic reaction between fats or fatty acids, and methanol. Molecules in biodiesel are mainly FAMEs.

Fischer–Tropsch the name of a process used to create synthetic hydrocarbons using biomass, natural gas or coal. It is namely used to produce synthetic diesel named Fischer–Tropsch diesel: a high-paraffin, sulfurless product.

Fuel cell an electrochemical device that does not have moving parts; it converts the chemical energy from a fuel, such as hydrogen, and an oxidizer, such as oxygen, directly into electricity. The main components of fuel cells are electrodes that are catalytically activated for the fuel (anode) and oxidizer (cathode), as well as an electrolyte that conducts ions between the two electrodes, thus producing electricity.

Gas-to-liquid (GTL) refers to fuels produced when natural gas is treated using gasification.

Hydrogen in its natural state, hydrogen is chemically bonded to other atoms. Hydrogen gas H_2 can be produced via water electrolysis, biomass gasification, from coal or natural gas. It can be stored as a gas under pressure or as a cryogenic liquid at a temperature of −253 °C.

Liquefied petroleum gas (LPG) a mixture of gaseous hydrocarbons, particularly propane and butane, which is kept in liquid form at a moderate pressure. It is a by-product of oil refining or production of natural gas.

Methanol the lightest member in the alcohol family: light, volatile, colorless, liquid, inflammable and poisonous. Methanol is produced by gasification processes.

Methyl tertiary butyl ether (MTBE) a chemical compound obtained from the chemical reaction of methanol and iso-butylene and is an oxygenate that is widely used by refining industries.

Natural gas in fossil form, natural gas consists of methane, ethane, butane, propane and other gases. LNG and CNG are abbreviations for liquefied natural gas and compressed natural gas, respectively.

Non-conventional oil a liquid hydrocarbon obtained by means of techniques other than drilling rigs. It is more difficult to extract in general, and the environmental consequences are more serious than those of conventional oil. Non-conventional techniques include the extraction of sand from oil shale. This category also includes thermal depolymerization of organic matter and the transformation of coal or natural gas into liquid hydrocarbons.

Reformulated gasoline gasoline mixed with oxygenates (especially MTBE and ethanol) for cleaner combustion.

Shale oil a generic term attributed to fuels obtained from shale, which are sufficiently rich in bitumen in order to obtain petroleum oil by distillation.

Tar sands a combination of sand, clay, water and bitumen. It is extracted by means of mining procedures, unlike traditional oil that is extracted by drilling. This is due to bitumen's viscosity and the rock's lack of porosity.

Unleaded E10 a mixture of 90% gasoline and 10% ethanol. Other E_X are also possible and consist of a mixture of gasoline containing x% ethanol (for example E85).

Appendix

LUTB Transport and Mobility Systems[1]

Example of a multiplayer approach to sustainable transport

"LUTB Transport and Mobility Systems" is a cluster aiming to rollout innovative products originating from R&D-type initiatives, which are brought about by the problems faced by industry, research and training organizations, and national public organizations. It works to develop transport solutions that are based on mass transport, and was initially focused on applications for urban trucks and buses (under the name of Lyon Urban Truck and Bus). It gradually became interested in the entire set of systems for transport and urban mobility.

The project aims to meet the challenges raised by the increase in mobility needs of people and goods by providing innovative and balanced environmental, societal and economic answers, proven and assessed for territories.

LUTB Transport and Mobility Systems programs cover the development of designs for transport systems, technological building blocks and their interactions, in addition to the assessment of their performance and optimization.

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[1] www.lutb.fr.

Think tanks

Since 2006, *LUTB think tanks* have debated the necessary evolution of transport systems for people and goods in urban agglomerations: how to improve and coordinate all the elements (vehicles, infrastructure, organization and operating modes) in order to guarantee transport services that are adapted to their use. Solutions (or the solution?) for urban transport (must) satisfy all the different types of mobility: of people (individual, mass, interactive) or of goods (freight distribution, refrigerated systems, roads and services, dangerous substances, etc.) and utilities for roads and services, and construction, by using both private and public vehicles as well as transport organizations and the combination of public–private partnerships.

One of the objectives being followed by LUTB think tanks was to create conditions that support high-quality interactions between players by associating academic worlds, the industrial worlds and public organizations. Bringing together multidisciplinary experts with complementary backgrounds and making them meet, listen to each other and come up with proposals has proven to be conducive for the emergence of a communal collective language. Transport systems and the conditions required to attain sustainable transport systems have therefore been provided with their own vocabulary. It has been possible to strengthen the ability of a shared network to elaborate a distributed expertise founded on the same basis, while authorizing links with the specific experienced communities of various players. Collaborative projects have been initiated and implemented with the aim of implementing and executing innovations in transport in order to improve mobility.

The first cycle (2006–2007) consisted of dissecting the ingredients of a systemic approach in order to identify their outline: the players involved in elaborating sustainable transport systems; vehicles, infrastructure and moving entities; the transport system's interfaces and environment; generic technologies; targeted performance; influencing factors; and territorial scales.

The second cycle (2008) consisted of detailing the technological domains that set the conditions for future mass urban transport systems:

– concepts for articulating transport systems: architectural design of a system according to its mode (road/rail/waterway/airway/subway/cable) and its status (public/collective/organized private), assessment of its performance (mobility, environmental impact, safety, reliability, resilience, economy) and development of the system's modal connections (urban–non-urban, interoperability);

– vehicles, adapting and operating them: chameleon vehicles[2], mixed {passenger/goods} use, deployment of connected V2V, V2I vehicles and associated operating strategies;

– integration of regulatory, communicating and adaptive infrastructure, and its adjustment to intelligent corridor and, green corridor concepts;

– exchange platforms, their architecture (sizing, physical and land coverage, transfers, handling, storage), approaches, maneuvers and station stops, parking areas, inter-modal capacity and associated services;

– vehicle-infrastructure connections, defining physical interfaces in terms of structure, energy (supply of static or dynamic electricity, of liquid or gaseous fuel) and intelligence (data, transfer and tariffing rules);

– the management of governance, supervision, decision support: identifying and locating entities (vehicles, people, goods, operating conditions), managing systems (real time/indicators), preparing and optimizing itineraries, mobility links and logistics.

During *the third cycle* of LUTB's think tanks (2009–2013), some of these technological paths were thoroughly considered and studies

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2 A chameleon vehicle "takes on the color of its environment". It optimizes its connection with its ecosystems, while respecting principles of massing. It has "zero-emissions" in zones that need it, it is silent in zones of moderate noise, it adapts its speed to the infrastructure's nominal speed, becomes agile on narrow and sinuous roads, etc. An example is the tram-train: it behaves like a tramway when using tramway infrastructure and as a train when using rail infrastructure.

were led to develop innovations related to vehicles, transport systems and mobility. The challenge of these projects was to find a set of innovative products pertinent to vehicles, services, infrastructure and the optimization of tools, data and knowledge, in order to manage and make possible the urban movements. The assembly and systemic integration of these technological building blocks led to solutions that have been tried and assessed on site, and cover a wide range of needs and transport systems (different types of users, goods, territories and transport organizations).

The purpose of these approaches is to *make transport systems evolve* in order to strengthen its "sustainable" aspect:

– improving the performance of vehicles (minimizing gas and sound emissions, ergonomics, user comfort and safety, capacity), and programming their evolution with respect to energy, architecture and intelligence;

– improving infrastructure (physical performance, energy, communication) and to make {vehicle/infrastructure} interfaces evolve in harmony;

– promoting good use and evolving operating modes and rules, connections between transport modes (road, rail, water), specifications and operation of corridors, hubs and platforms; time and space management, by privileging virtuous modes and vehicles; authorizing a better distribution of infrastructure and parking; and promoting green areas and green corridors.

– implementing certification modalities for parameters related to factors that determine a vehicle's performance in its systemic organization: environmental status (noise, emissions, etc.), operating efficiency in terms of mobility "capability" (traffic, occupation, load, filling rate and available capacity) and operational autonomy (in the context of electromobility);

– facilitating the development of multiplayer services (in an environment of type 2.0 mobility, "2.0 proximity"[3], etc.), defining and

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[3] In the wait for future evolutions: 3.0, 4.0, etc.

assessing supervision or governance modes, and involving public/ private partnerships.

This imposes a *multiplayer approach* that covers the chain of interventions required for a harmonious rollout. Testing solutions at real scales before they are implemented on the market is considerably difficult as the integrated solution must be subjected to tests with the conditions present in multidimensional space, and must be assessed from different angles: its level of performance (namely environmental) and reliability, economic pertinence, resilience, governance and acceptability of its various player categories. Several platforms allow transport solutions to be configured in a dedicated environment that restores all or part of the conditions present in real environments. Such platforms are currently being deployed in the world[4].

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[4] The platform project TRANSPOLIS, aiming to develop effective mass transport systems, is an example, which intends to simulate the conditions present in an urban environment, see www.lutb.fr.

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