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

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.