CHAPTER

16

Future Trends in Sustainable Transportation

Jaume Barceló

Universitat Politècnica de Catalunya, UPC-Barcelona TECH, Barcelona, Spain

OUTLINE

Sustainable Transportation and Smart Logistics
https://doi.org/10.1016/B978-0-12-814242-4.00016-8

1. INTRODUCTION: SUSTAINABILITY AND SUSTAINABLE MOBILITY

The dominant idea throughout this chapter is, in essence, that it is not sufficient to address the sustainability of the social phenomenon called mobility as if it were an isolated component of our societies; and it is even less so in cities and large metropolitan areas. Sustainable mobility must be seen from the perspective of a complex component of a complex dynamic system; and this calls for a global, holistic approach that views the system as a whole.

In 1972 the United Nations organized the first United Nations Conference on the Human Environment, and commissioned Drs. René Dubos and Barbara Ward to author an unofficial report (Ward and Dubos, 1972) that was published by Penguin Books. The edition of the book that I bought had an appealing front cover for that time: one of the first pictures taken by the Apollo missions, showing the Earth as a round blue and brown spot, isolated and embedded in the blackness of space. Nowadays such pictures are common, and we have frequently seen even more spectacular views; but the power of the message conveyed by that picture perfectly fits that report remains valid today. One message that was repeated throughout the book as a leitmotif clearly formulated the basic concepts upon which the idea of sustainability is founded: the Earth is an isolated spacecraft, self-contained, traveling through the Universe, and it constitutes an ecosystem per se in which man can be considered a disturbing element. Therefore, our main task is to formulate the problems derived from the limitations of this spacecraft and to identify the collective behavioral patterns that are compatible with the flourishing of future civilizations. Man must accept the responsibility of serving as a steward of this vessel. The echoes of these ideas could be found years later in the definition of sustainability by the Brundtland Report (Brundtland, 1987): "Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs." Two key ideas were further expressed: that "man is only the steward of the vessel Earth," bearing in mind that the steward is neither the owner nor the captain; and that the Earth should be viewed as an isolated ecosystem. This view can be translated into a more precise formulation: that Earth thermodynamically behaves as a closed system, in other words, an open system with respect to the energy and closed with respect to matter.

At the same time, the global concept of sustainability can also apply to cities, those places in which are concentrated the greatest and most intense share of human activities that consume the resources of this vessel, Earth. A key idea that translates these concepts into the urban space is that of the "Urban Metabolism." The idea of modeling urban areas inspired in the analogy with biologic metabolism, explicitly formulated by Wolman (1965): "The metabolic requirements of a city can be defined as all the materials and commodities needed to sustain the city's inhabitants at home, at work and at play. [...] The metabolic cycle is not completed until the wastes and residues of daily life have been removed and disposed with a minimum nuisance and hazard. As man has come to appreciate that the earth is a closed ecological system [...] he has the daily evidence of his eyes and nose to tell him that this planet cannot assimilate without limit the untreated wastes of his civilization. [...] Metabolism of a city involves countless input–output transactions [...] concentrated on three inputs common to all cities, namely *water, food* and *fuel*, and three outputs, *sewage, solid refuse* and *air pollutants*."

Newman (1999) formalizes Wolman's idea by adding a more detailed description of inputs and outputs. This concept of urban metabolism conceived by Wolman has become fundamental for the development of cities and sustainable communities. Kennedy et al. (2007) synthetically redefine the concept as "the total sum of the technical and socio-economic processes that occur in cities, resulting in growth, production of energy, and elimination of waste [...] The metabolic requirements of a city can be defined as all the materials and commodities needed to sustain the city's inhabitants at home, work and play. [...] The metabolic cycle is not completed until the wastes and residues of daily life have been removed and disposed with a minimum nuisance and hazard. As man has come to appreciate that the earth is a closed ecological system [...] he has the daily evidence of his eyes and nose to tell him that this planet cannot assimilate without limit the untreated wastes of his civilization." From a practical approach, the study of urban metabolism implies building global models that quantify the inputs, outputs, and storage of energy, water, nutrients, materials, and residues of an urban region.

Kennedy et al. (2010) describe how research on urban metabolism had been marginalized over the decades but has recently experienced a strong rebirth, with the concept expanding from the analogy of an individual organism into that of a multitude of organisms, thus conceptualizing the city more appropriately to be like an ecosystem. According to these authors, if it is true that cities, like organisms, consume resources from their environment and return them in the form of residues, one should not forget that cities are more complex than isolated organisms; and they therefore propose that sustainable cities should be inspired by natural ecosystems and able to be energetically self-sufficient by balancing their inputs and outputs in a way that maintains their masses through specific recycling processes. This represents a step forward by turning these qualitative approaches into operational approaches of a quantitative nature, i.e., by translating these qualitative conceptual models into models that can be implemented on a computer. This sets the path for a quantitative analysis that evaluates the impacts of alternative city management policies and it makes a prognosis of the plausible future in terms of the alternative rational scenarios that can be formulated. But obviously, *any model aimed at achieving these goals must be a globally integrated model of the city, a complex system that accounts for all components as well as their interactions and interdependencies*. One of the most successful modeling approaches from this perspective takes into consideration the individuals and their activities, that is, a microscopic approach based on activity analysis, going beyond the conventional former analysis based namely on aggregated views of energy consumption related to dwellings and transportation, which are thus limited to dwelling selection, transportation models (including fuels and energy sources), and the use patterns. The proposed alternative approach considers that energy consumption depends on a more complex set of interactions between the urban form and human activities, which are also affected by external factors such as administrative policies, technology, the economy, investments, and regulatory conditions. The relationships between these factors and energy consumption are, in general, long term and endogenous. An increase in fuel prices, for instance, has an impact on a wide variety of short- and long-term decisions. In the short term, journeys composed by modal chains and public transport use can increase; but in the long term they could induce changes to residential locations that are closer to places of work. They may also lead to changes in automotive technologies seeking greater efficiency, such as hybrid vehicles; or they may simply exploit the opportunities offered by new technologies and replace physical mobility for virtual mobility by means of "telecommuting."

Energy consumption related to transport is thus a function of combined short- and long-term behavioral decisions, which can be influenced by a wide variety of policies, investments, regulations, technological changes, etc. *These complex interactions must necessarily be captured in order to build an integrated model of the urban form, human activities, energy uses, land uses, energy consumptions, and emissions, which will therefore allow a proper evaluation of sustainability goals*. Pandit et al. (2015) have proposed a conceptual model that captures the interactions between land use, transport, and energy for the "urban infrastructure system" (UIS). The main interrelations, depicted in Fig. 16.1, are the following:

- Energy ↔ Transportation. "A key example is the energy required to power the transportation fleet. The fuel used for transportation alters the demand in energy sectors. The paper estimates that a 50%

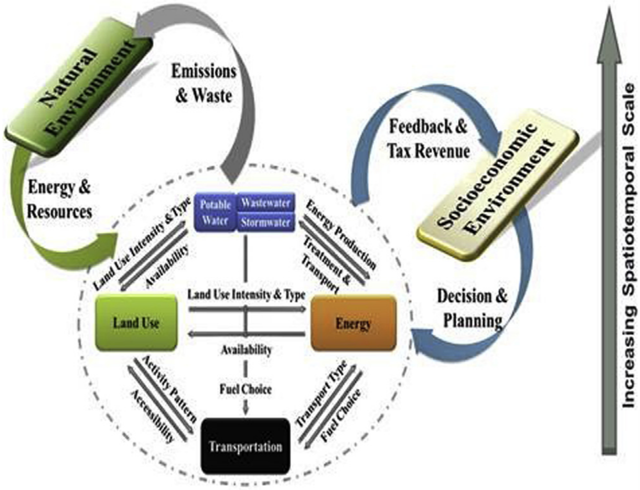

FIGURE 16.1 Interconnectedness within the urban infrastructure system (UIS) and the interrelation of UIS with natural environmental systems and socioeconomic systems. *Pandit, A., et al., 2015. Infrastructure ecology: an evolving paradigm for sustainable urban development. Journal of Cleaner Production. doi:10.1016/j.jclepro.2015.09.010.*

penetration of Plug-in Hybrid Electric Vehicles could increase the total electricity demand by 6%–9% depending on the region."

- Land use ↔ Transportation. "Land use patterns dictate the travel pattern of the residents. Increased regional accessibility for more central area residents results in a 10%–40% decrease in driving compared to their counterparts at the urban fringe. Transportation planning often has a prescriptive effect on the growth pattern of an urban region. Empirical estimates suggest that one new highway built through a central city reduces its central-city population by about 18%."
- Land use ↔ Energy ↔ Transportation. "The pattern of land-use affects the energy consumption pattern for transportation, household electricity use and home heating. Urban core residents emit, on average, 2–6 fewer tons of energy-related CO_2 per household than their suburban counterparts."

Interconnections and interdependencies that are frequently forgotten or only implicitly taken into account are the usual discourses on sustainable mobility, which are based on three main concepts:

- *Social sustainability*, implying the need to satisfy accessibility for activities inherent to any human society, namely for citizens living in urban and metropolitan areas.
- *Environmental sustainability*, which must ensure the healthy conditions necessary for maintaining quality of life.

- *Climatic change*, that is, the need to revise all technical aspects of vehicles and energy sources in transportation systems in order to guarantee mobility requirements.

An immediate consequence of this approach in regard to the future of mobility is that it is usually dominated by technological perspectives, which can generally be grouped into the following three dominant areas:

1. Vehicular technology: electric, connected, and autonomous (driverless) vehicles;
2. Energy sources and propulsion technologies;
3. Applications supported by information and communication technologies (ICT) that exploit the pervasive penetration of computation and sensing devices—namely all types of personal devices like mobile phones and related sensor networks.

However, thinking only—or predominantly—of technology implicitly implies that we will always do the same things but in a different manner, for example, simply replacing vehicles propelled by fossil fuels for electric vehicles under the assumption that the concept of mobility associated with personal motorization will not change. In other words, we assume that new technologies will be applied to various tasks without changing their character. The alternative that I plan to elaborate on and substantiate in this chapter is that technology can provide a different perspective by allowing for different things to be done or even doing the same things in a different way. Thus, we should neither surrender to nor be conditioned by technology. Instead, we must consider technology to be a necessary but insufficient condition. Therefore, the key question is: What are the sufficient conditions?

2. INTERDEPENDENCIES BETWEEN THE COMPONENTS OF THE URBAN SYSTEM AND THEIR IMPLICATIONS FOR TRANSPORT SUSTAINABILITY

Seeking these sufficient conditions leads us to a first approximation of trying to understand not only the interactions between land use, transport, and energy in the urban infrastructure systems, but also how these interactions determine mobility needs and the associated implications for transport sustainability. A first step may consist of analyzing the phenomena of urban sprawl from the second half of the 20th century, the technological changes that made this possible, and how this affected the current living conditions in metropolitan areas. The migration trend from rural to urban areas has existed forever; however, urban growth has accelerated during the referenced period up to a point that many experts have highlighted: the year 2008, when humanity crossed the threshold of having over 50% of the world population living in cities—a growing trend that is forecast to surpass 70% in 2050 (United Nations, 2014). These urban sprawl phenomena have generally occurred in an unplanned, anarchic way due to the combined results of various factors: the relative affluence drifting from rural to city populations, changes in life styles and, in particular, advances in personal mobility in the form of individual motorized mobility. This last factor implies a separation between dwelling and working areas, which is made possible by the development of transportation systems, which in turn are accompanied by the well-known consequences that we call traffic congestion. The current situation, of course, has had strong impacts on energy consumption and emissions (currently around 75% of greenhouse gases of anthropogenic origin are produced by cities [EU, 2016]) and, consequently, on the quality of life.

This growing trend toward urbanization has prompted the phenomenon of "megacities," regional conurbations that result from the growth and expansion of metropolitan areas, from the merging of two or more, or from both. The United Nations predicts that 2030 will see more than 41 megacities of more than 10 million inhabitants. Some of them, such as Tokyo and Jakarta, already have nearly 40 and 30 million, respectively. This phenomenon is having a relevant impact on spatial reorganization and, therefore, on the configuration of transport systems. This is a consequence of the mutual reciprocity between space and transport. Space configures transport just as transport shapes geography. These relationships between transport and spatial organization can be considered on three primary geographic scales: global, regional and local (Rodrigue et al., 2013).

At a global scale, the nodes of the transport network are the large input/output gates, ports and airports, which are linked by air and maritime routes while their relationships are characterized by investment, commerce, and production. At the regional scale the nodes—which were initially cities—are being gradually replaced by metropolitan areas and megacities, which are all connected by high-speed motorways, highway networks, and rail corridors. Regional scales are characterized by urban systems and their hinterlands. Finally, at the local level, the nodes are comprised of centers for economic, work and commercial activity. The road networks and public transport systems configure the links, and the relationships are characterized by traffic flows and their distributions.

This chapter will address the local level of these relationships between transport and territory. This approach considers *mobility as the movement of people and goods efficiently and safely, and it may be regarded as the ability to travel when and where the traveler or the goods need to in the most efficient way.* This means that urban mobility is a means to ensuring an end, namely

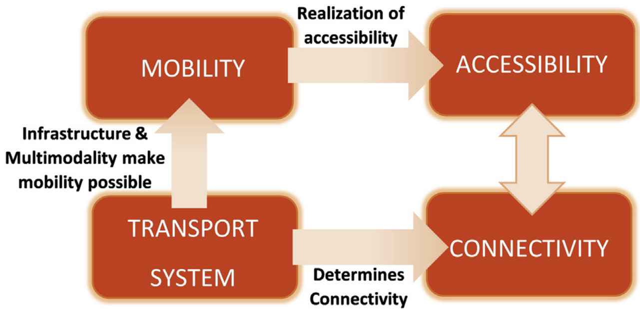

FIGURE 16.2 Conceptual scheme of the interrelationships between mobility, transport system, connectivity, and accessibility.

accessibility: citizens must reach destinations in order to satisfy their needs and access the locations of activities. Mobility must also be sustainable and account for technicalities as well as other means for achieving accessibility. Fig. 16.2 depicts two fundamental aspects for consideration: first, the conceptual scheme of the dynamics underlying the interrelationships between mobility, transport systems, and accessibility; and, second, the necessary structuration of the territory by means of the transportation system, which thus ensures the territorial connectivity essential to achieving accessibility.

From this standpoint, if one takes into account that one of the main reasons cities exist is to facilitate citizens' access to goods, services, and information, then one should keep in mind that the more efficient the access, the better the social and economic benefits of living in a city. This implicitly means that the aspects determining such access do not only depend on infrastructures and technology. In other words, a key characteristic of a city will be its degree of accessibility, either in terms of proximity between origin and destinations (for example, between dwellings and workplaces) or as a consequence of the transport solutions that efficiently overcome the distances between these origins and destinations. In consequence, the mobility patterns are determined by the activities, and the accessibility to their locations—in other words, by the configuration "model" of the city.

One example of how these implications are being analyzed is the one undertaken by Urban Age, a worldwide investigation into the future of ;cities carried out by LSE Cities and the Alfred Herrhausen Gesellschaft of Deutsche Bank. Let us consider, for example, density as a key measure of urban structure that can be used to quantify the large diversity of urban forms. High urban densities can improve the performance of services and their efficiency, and at the same time foster urban vitality that facilitates more sustainable public transport while increasing the chances of accessing activities by either walking or biking. However, these potential advantages also depend on how effective the city management and its urban design are at minimizing the negative costs of pollution from a super population. Because of urban forms and transport infrastructures, cities demonstrate a large variety of behaviors, namely with respect to the selection of transportation modes as well as the lengths and durations of journeys. These differences can be observed between cities with similar levels of development and welfare, which indicates that socioeconomic factors are only some of the multiple factors determining the phenomenon. One of the cases analyzed in the referenced study is the city of London. Fig. 16.3 graphically describes the following: the strong interaction between dwelling densities in Fig. 16.3A and workplaces in Fig. 16.3B; the time evolution of dwellings, workplaces, and their relationship with transport infrastructures in Fig. 16.3C; and the mobility patterns associated with combinations of modal uses and short journeys in Fig. 16.3D.

Fig. 16.3D provides a static view of how the transport system is being used in a city at a given time. This information is available in many cities, but the approach that this chapter proposes implies trying to find an "explanation" of the model by splitting Fig. 16.3D from the information

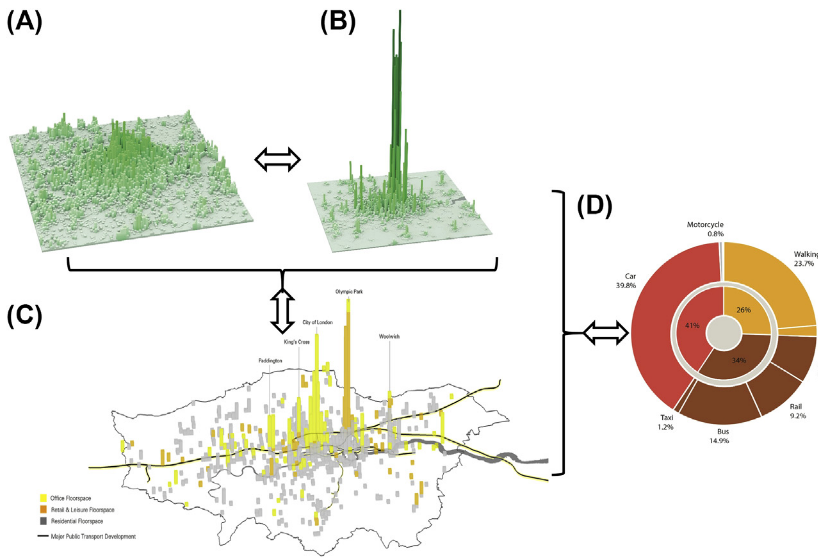

FIGURE 16.3 Relationships between urban form (Dwellings ↔ Workplaces), transport system, and modal splits in London. (A) Dwellings. (B) Workplaces. (C) Dwellings and Workplaces ↔ Time evolution. (D) How the transport system is used. *Urban Age/LSE Cities, LSECities.net; (A) Residential density, London https://LSECiti.es/u25691340. (B) Employment density, London https://LSECiti.es/u03a211f6. (C) London urban development 2004–11 https://LSECiti.es/u33181391. (D) London urban development 2004–11 https://LSECiti.es/u33181391.*

visualized in Fig. 16.3A–C. Examples of models analyzing these relationships can be found in Ewing and Cervero (2010), Zegras (2010), and, more recently, van Eggermond et al. (2016), among others.

These models indicate the dependencies between ownership of private vehicles, their uses, and the built environment of a city. A direct consequence of these analyses is that factors which are not strictly socioeconomic or technological affect the impacts of policies for fostering modal changes, namely in terms of introducing new modalities (such as multiple passenger ride-sharing or other variants of demand-responsive transport) or technology replacements (such as changing vehicles propelled by conventional fuels for electric vehicles).

These considerations may help provide nuance to the previous statement that technology is a necessary but insufficient condition for substantiating approaches to sustainable mobility. And this has led to us seeking something that could be sufficient. From this point forward, we can understand that a relevant component of that sufficiency is the way in which the urban form and urban dynamics determine mobility. Fig. 16.4 visualizes the conceptual diagram of such approaches.

Taking into account that the main goal of mobility is to provide access to activities more so than making the journey itself possible, the key question when asking about the future of mobility is therefore: What should change?

ICT applications also provide possibilities for change, since they can enable the replacement of journeys by virtual accessibility. In addition, ICT also allows for more efficient trips by improving the capacity of the transport system as well as by changing the way in which passengers use the transport system through new mobility concepts.

This analysis led to us supporting the thesis that any intervention in a city must be founded on a deep understanding of the urban entity, which can be obtained by analyzing the mobility patterns and associated

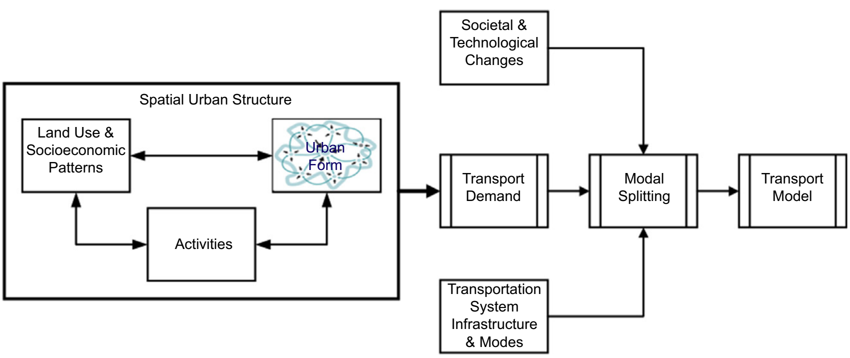

FIGURE 16.4 Transport system, technology, urban forms, and transport models.

processes that are determined by systemic interactions between the transport system and land use. All this occurs despite a reduced need for physical journeys, increased efficiency for those that are needed, and changes in vehicular technologies. In other words, transport infrastructures and modes that enable the urban trips of persons and goods are not the only contributions to consider when determining the degree of accessibility. Spatial interactions must also be taken into account (such as those in the previous examples) as well as their dependencies among land use factors determining trip attractions and generations, which are also a function of economic and demographic attributes.

However, the system components are dynamic and therefore continuously change over time, because of changes that are technological, political, economic, demographic, cultural, and perceived value. These changes imply changes in the interactions between land use and the transport system that result from multiple decisions made by inhabitants and companies as well as those that municipal governments make regarding logistics. All studies and references mentioned confirm these results and identify them as key components and interactions of urban dynamics. A summary view is depicted in Fig. 16.5, which is based on Rodrigue et al. (2013), and is quoted from the following:

- **Land use.** The most stable component of urban dynamics, as changes are likely to modify the land use structure over a rather long period. The main impact of land use on urban dynamics is its function as a generator and attractor of movements.

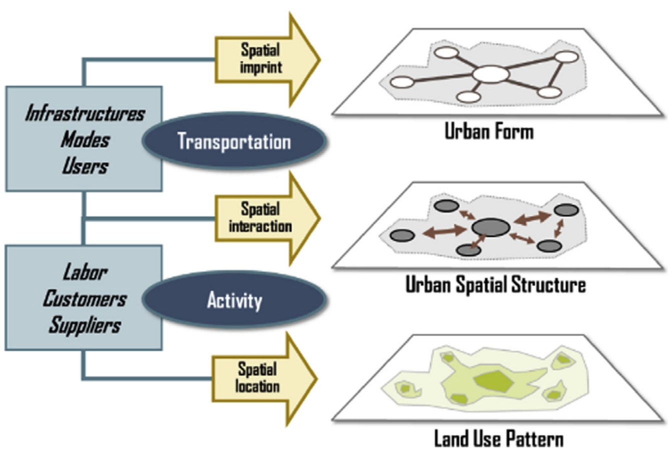

FIGURE 16.5 Transportation, activity systems, and land use interactions. *Rodrigue, J-P., et al., 2013. The Geography of Transport Systems, Routledge.*

- **Transport network.** This is also a rather stable component of urban dynamics, as transport infrastructures are built for the long term. The main contribution of the transport network to urban dynamics is the provision of accessibility. Changes in the transport network will impact accessibility and movements.
- **Movements.** The most dynamic component of the system since movements of passengers or freight reflect almost immediately changes. Movements thus tend more to be an outcome of urban dynamics than a factor shaping them.
- **Employment and workplaces.** They account for significant inducement effects over urban dynamics since many models often consider employment as an exogenous factor linked with specific economic sectors. Commuting is a direct outcome of the number of jobs and the location of workplaces.
- **Population and housing.** They act as the generators of movements, because residential areas are the sources of commuting. Since there is a wide array of incomes, standards of living, preferences, and ethnicity, this diversity is reflected in the urban spatial structure.

A first approximation to the analysis of these relationships can take into account the evolution of changes in urban form and their influence on urban mobility problems, which very often have grown exponentially because of the concentration of mobility demand in specific areas resulting from changes in socioeconomic scenarios (new type of employment, new economic activities, new lifestyles, etc.). Growth in the urban form, demography, and mobility has usually been configured by the capacity of the transport system to provide a response to requirements. These responses have originated in a large variety of urban forms and special structures, namely those induced by the evolution of transportation technologies. As has been pointed out before, urban sprawl leads to increases in traveling needs and demands for mobility, to which cities have usually responded by increasing the transport supply through an expansion of the transport network and allocating an increasing number of vehicles.

3. SUSTAINABLE MOBILITY BASED ON SMART MOBILITY: A KEY PILLAR OF SMART CONNECTED CITIES

In spite of all that has been explained so far, most approaches to sustainable urban mobility are still formulated from an almost exclusively technological perspective. Even when alluding to other aspects, there remains the assumption that they will be integrated and coordinated more or less spontaneously and in unexplained ways. For example, a visit to the web site of "Sustainable Mobility" (www.sustainable-mobility.org) reveals that priority is given to vehicles (electric taxis, "green" corridors for electric vehicles, hybrid vehicles, autonomous vehicles—namely for public transport—and so on). ICT applications complement this priority, especially for transport information systems, with the goal of identifying the most suitable combination of transport modes for making a trip. The so-called "Integrated Personal Journey Planners" have also emerged. These are personalized mobility planners that enable users to decide the most convenient way of making a trip by combining the available transportation modes in accordance with their needs and preferences.

These ideas underlie the concept of the Smart City that is emerging from a reflection on how the development and pervasive application of ICT can influence urban development, socioeconomic conditions, and quality of life. A commonly accepted definition of a Smart City is that "*it is a city which has responded to the challenges derived from the development and penetration of ICT, specifically in terms of how they affect urban and socioeconomic developments as well as quality of life.*" This definition implicitly assumes that the response is spontaneous or—in a best-case scenario—fostered by market laws. This vision led analysts like Chen-Ritzo et al. (2009) to formulate a primordial conjecture about "Smart Cities," in which they stated that the proposed solutions are usually based on instrumentation and interconnection of mobile devices, sensors, and actuators; and, further, that these solutions should enable the collection of data in unprecedented amounts, which in turn will require that their analyses resort to new techniques (Big Data, Analytics, Data Science, etc.) and thus substantially improve the ability to predict and manage urban flows, thereby leading to intelligent management of the city.

Critical reactions to this concept of "Smart City" appeared very soon. First Belissent (2010), and then soon after Schaffers et al. (2011), denounced the solutions proposed for "Smart Cities," stating that they were dominated predominantly by technology vendors instead of municipal authorities; that is, they were market-driven proposals that did not take into account the citizens' needs and interests. This led to them declaring that "*smart city solutions must start with the city not the smart.*"

In spite of these critiques, the defenders of the usual concept of the "Smart City" conceptualize it in terms of the integrated vision synthesized in Fig. 16.6. The integration represented by the inner graph suggests interactions among the components of the "Smart City." However, beyond the suggestive picture, one very seldom finds additional explanations specifying either which types of interactions link the components or the nature of the corresponding interdependencies among them. For example, for the type of analysis that is the objective of this chapter, it would be relevant when looking at this diamond to identify the relationships between "Smart Mobility" (sold as one of the key pillars of a

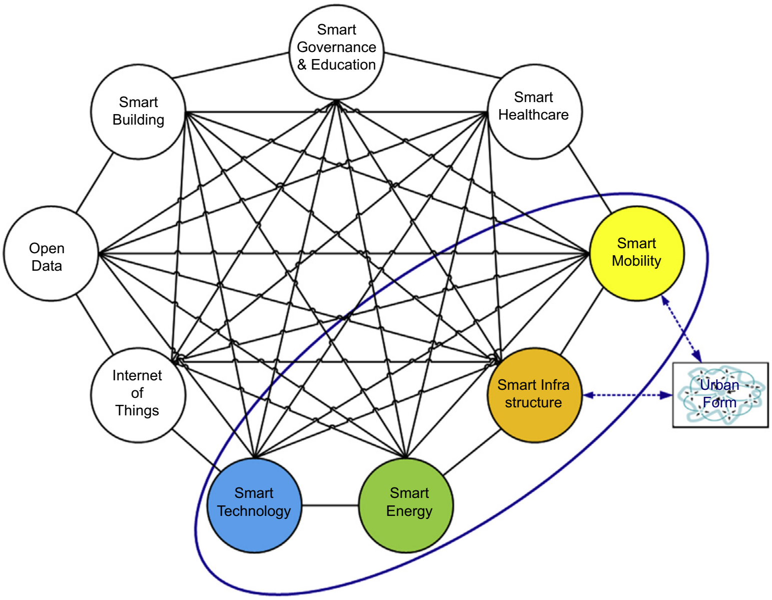

FIGURE 16.6 The "Smart Components" of a Smart City and their relationships.

"Smart City") citizens, technology, economic development, and urban forms, as discussed in the previous section, and highlighted in the figure. In general, all the "smart" solutions presented are usually local solutions to occasional problems for each "Smart Component." The case of "Smart Mobility" (clearly identified as a key contributor to achieving the targeted sustainability) usually consists of a wide variety of functions that compete amongst each other in their efforts to assist transport system users in finding routes, selecting transport modes, finding parking lots, and making electronic payments, among others.

In brief, mobility concerns a more or less wide set of singular applications with a relatively low level of integration. A more advanced view of "Smart Cities," like that addressed by the White Paper of the Federal Highway Administration (FHWA) (White Paper, 2014), defines the "Smart/Connected City" (highlighting the role of the interconnection of mobile devices, namely those associated with the new generations of vehicles: connected and autonomous vehicles) as a network of interconnected systems, each one corresponding to a link in the graph in Fig. 16.6. However, this focuses connectivity merely on what the ICT applications provide in terms of the transmission and processing of data arising from all kinds of activities occurring in a city. This view of the "Smart City" restricts it to a city in which ICT applications will enable a better understanding and control of the different systems affecting citizens' lives. It explains in detail the technological contents of each component, but it eludes the analysis of how these links will themselves enable integration and thus make it possible to properly coordinate a complex system.

Further steps can be taken only through insights into what could be the future of mobility, the prognosis that in the near future connected vehicles and travelers will be able to share not only transport data but all kinds of data as they become part of the "Internet of Things." And from here it is assumed that this integration will provide support to a more efficient decision-making process, both for transport managers and for connected travelers. But how? Apparently all these analyses assume that this integration will happen as a kind of autonomous, spontaneous process, yet to be discovered.

However, this report does not forget to consider the most relevant emerging nontechnological trends that will likely make some of these changes possible:

- Mobility as a Service (MaaS) will change behaviors by replacing vehicle ownership or long-term commitments to using specific transportation modes with more flexible options, depending on the traveler's needs at each time.
- The implications of shared mobility demand responsive transport, meaning user-dependent mobility that accounts for the changing societal perceptions of the relationships between driving and moving.

Ever since the term "intelligent transport systems" was more or less officially coined in 1994, we have witnessed the deployment of technology but not so much of intelligence, as becomes evident by the fact that technologies—including vehicular technologies—have evolved while congestion still remains a critical problem in urban and metropolitan areas, one of the key recurrent problems conditioning our societies and ways of living. Again, the potential solutions will not come only from technological progress but from the way technology is used, while taking into account various combinations of factors:

1. Social changes concerning the role of the automobile and the relationships of humans to car ownership will become a determinant component of individual mobility. This is currently considered to be a "paradigm shift," replacing the concept of "vehicle owner" with that of "vehicle user."
2. The emergent concept of "multiple passenger trip-sharing" and its implications for new public transport concepts based on flexible transport systems will adapt the supply to the requirements of demand under the concept of demand-responsive transport (DRT) systems.

3. New visions fostered by applications of ICT will make it possible to conceive MaaS supported by:
   a. Information systems and associated services enabled by ICT applications that make it possible for the user to plan their trips as well as manage them dynamically. An "Advanced Personal Integrated Journey Planner" would be an example of such an application.
   b. The tools enabling the user to access and utilize this information in order to receive the needed service wherever and whenever it is needed.

The dynamics of urban development and the well-known phenomenon of urban sprawl have been made possible by the developments of transportation systems, thus ending a vicious cycle in which urban expansion is facilitated by transport systems and at the same time calls for an increase in traveling requirements for accessing socioeconomic activities, as we have already described. A key component of this phenomenon has been individual motorized mobility made possible by owning private vehicles. Beyond satisfying mobility requirements and in spite of the induced congestion effects, it is widely recognized that these two factors make this mobility solution even more attractive: the image of social success associated with owning a vehicle, and the sense of freedom associated with the possibility of traveling from any origin to any destination at any desired time. However, what if a MaaS could satisfy the same needs or desires without one having to be the owner of a vehicle?

On September 2015, Frost and Sullivan (2015) organized a 2-day workshop on "Emerging Mobility Concepts," in which the attendants reached a broad consensus on what they could generally agree:

- There is evidence of deep transformations that are considered irreversible, specifically regarding behavioral changes in meeting the needs of mobility, all of which are leading to the emergence of new business models, most notably, including the growth of shared vehicle use (car sharing).
- It is forecast that the growth of "carpool" variants (ride or trip-sharing, carpooling services on demand, Uber, SideCar, Lyft, etc.) will dominate 20% of the market for global taxi services and the like. This implies a market based on using a virtual device such as a computer or mobile phone to request a service from a vehicle, taxi, limousine, or any other form of transport that picks up passengers. This finding is demonstrated by the continuously growing number of companies that offer these types of services: E-HAIL, Arro, Easy Taxi, Uber, Lyft, Carmel, GetTaxi, GrabTaxi, TaxiMagic, minicabit, G-Ojek, …

- The above leads to a new concept of integrated mobility (technology-enabled integrated mobility) made possible by ICT applications supported by any device capable of conveniently and efficiently providing multimodal travel door to door, in real time, before, during and after the trip, which saves time and reduces costs for users of mobility services.
- This makes it possible to consider public transportation in other ways that will allow reducing queues and congestion during peaks in demand.
- This change regarding car ownership, i.e., the shift from property and exclusive use of the vehicle to becoming a user of mobility services, leads to us considering new approaches for car manufacturers, since the provision of what makes individual motorized mobility possible no longer depends on the car manufacturers but on "mobility assistants."

These trends, especially with regard to business models and their future prospects, have been corroborated in recent reports (Center for Automotive Research, 2016; von Venkat et al., 2017), that confirm the expected business volume by 2020 and predict the positioning of companies such as Toyota, Ford, Daimler, BMW, and General Motors.

The dynamics of change that we have already discussed, specifically regarding the phenomena of urbanization, congestion, connectivity, etc., are highlighted by the components that make change possible:

- *Integrated mobility*, made possible by the multimodal integration of ICT applications.
- *The new business models*, car sharing, travel sharing, etc.
- *Interconnectivity*, made possible by the ad hoc design of the infrastructure and the intermodal exchange nodes.
- *Urban planning* and its implications in the reorganization in space and time of the activities and the redistribution of road space. This concept involves reaffirming the perspective of sustainable urban mobility, namely that planning should play a key role in reducing the lengths of trips.
- Proximity is a key consideration when it comes to locating new activities or rearranging existing ones (Banister, 2011).
- *The new automotive technologies*, considered to be one of the key engines of change, are what we believe must be combined appropriately with other components in order to establish their role and achieve synergies that allow system optimization. Taking into account the role played by the range of an electric vehicle and its limitations regarding the traveling distance to destinations (Fearnley et al., 2015), it is evident that *the combination of urban planning with*

new automotive technologies implies that the role of the automobile in the city must be reinterpreted (Banister, 2011).

Travelers in a metropolitan area usually have a variety of modes of transport to move from their origin to their destination. When deciding which modes of transport to use, they consider a number of criteria such as cost, travel time, flexibility to changes in trip planning, and convenience (distances from origins to the starting point of the journey, or from the end of the journey to the destination), among others. The shared journey (ride-sharing, trip-sharing) modality refers to a mode of transport in which single travelers share a vehicle and the associated costs for making a journey. From a conceptual point of view, it is a system that can combine the flexibility and speed of private vehicles with the low cost of the fixed system of public transport, while also favoring convenience.

Many of the existing services have emerged in an informal and spontaneous way, more as a result of ingenious private initiative than as a consequence of a study and subsequently appropriate design. As a result, the coordination of a vehicle-sharing service is a casual and disorganized activity that works best when used as a regular transport alternative. *The greatest challenge still lies in coordinating and timing itineraries in a systematic way that explicitly takes into account user requirements and interests* (Furuhata et al., 2013).

A practical example of rethinking public transport based on this concept of transport on demand (Basnal et al., 2015) is that of the KUTSUPLUS project in Helsinki.

This has become a "hot trending topic," not only because it represents a potentially very efficient way of restructuring mobility services, but because from the perspective of sustainable urban mobility it can represent a very efficient way to reduce the number of private vehicles on a road network. The reason for this is that shared vehicle services can reduce the use of private vehicles and thus reduce congestion, environmental impacts, and energy consumption while increasing service efficiency (Ma and Zheng, 2015).

However, one of the most potentially interesting aspects of restructuring mobility services under the concept of "ride-sharing" is the possibility of combining it with changes in automotive technologies, in terms of both propulsion technology (such as electric vehicles) and the vehicle itself (as in the case of autonomous vehicles). Above all, both types of changes will combine in the form of autonomous electric vehicles with capacities of between six and eight passengers and which are specifically designed using the new concept of public transport on demand based on "multipassenger ride-sharing."

The International Transport Forum of the OECD is explicitly committed to this type of mobility service. A recent report titled Urban

Mobility System Upgrade (2015), based on a simulation model of the city of Lisbon, came to the conclusion that an autonomous vehicle fleet of 12,000 vehicles can remove 9 of every 10 private vehicles circulating through the city, which is consistent with the results of the study by Boesch et al. (2016), for the region of Zurich.

Ride-sharing mobility services, car-sharing, and the like are examples of services supported explicitly by ICT mobile apps that allow the user to communicate with the system and ask for a specific service. The conceptual architecture of the system includes other applications that are also based on ICT, which together inform the system of details in the road network that allow it to estimate its state and perhaps its evolution over the short term. However, a truly efficient mobility service should provide the user with a "view" of the entire transport system's state, which is to say of all the modes of transport operating in the metropolitan area where the user wants to move. This would allow him or her to make the best decision regarding which transportation mode (or combination of modes) to use: private vehicle (car, motorcycle), conventional public transport (train, metro, bus, shared vehicle), or other modes of transport (walking, bicycle).

This approach, which will impact the previously mentioned paradigm shift, implies that pursuing social activities does not have to depend exclusively on the use of personal vehicles, that is to say, on individual motorized mobility. Instead, it can be satisfied by a variety of public and private mobility providers, especially those that can be integrated into a wide variety of alternative mobility services that could include modal chains and the possibility of making payments electronically. Providing this type of service allows the user to meet their mobility needs in the most efficient way while replacing individual motorized mobility based on vehicle ownership property with a service that allows users to travel where they want when they need to. This leads to the development of the so-called MaaS systems, which include both the transport applications on demand, such as ride-sharing, and "personal integrated journey planners," also known as "personal mobility assistants." These are multimodal mobility planners that access all the necessary information and present it efficiently for making decisions based on user-defined criteria, travel time, generalized costs, energy efficiency, environmental impact, and combinations of various criteria, among others. At the moment, Google and other private services such as "citymapper," "TransitApp," and "Moovit" are early examples of these types of services, although they still lack many of the functions that we have mentioned so far. Fig. 16.7 displays what should comprise these integrated multimodal systems in which travelers can use any transport mode or combination of modes to move from origin A to destination B, whether by public transport, bus, metro, railway, tramway, private transport, including methods of car-

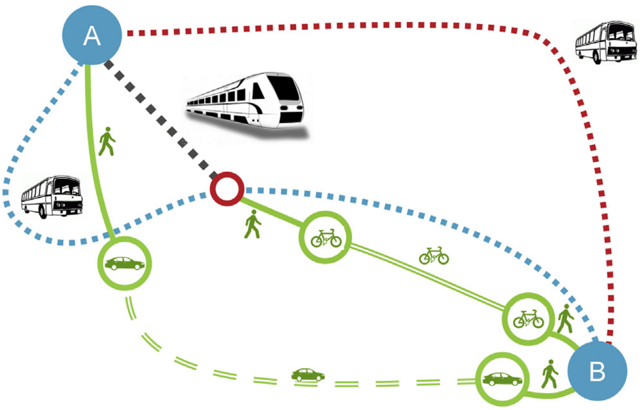

FIGURE 16.7 Mobility based on an integrated multimodal system.

sharing or ride-sharing, biking, walking, or any combination of these. Some examples of combinations illustrated in Fig. 16.6 may be beginning the trip by tram and reaching an exchange node (red circle), continuing by bus or bicycle and walking to a parking lot where there is a shared bicycle service. Another possibility would be walking to a point that provides a shared vehicle service of any of the available modes. The selection of the alternative, or combination of the most appropriate alternatives, is provided by the "advanced journey planner," which additionally allows choosing combinations, booking and paying for the services by means of the corresponding apps.

However, these combinations of multimodal transport could also be provided by various automotive technologies, such as autonomous vehicles. The question is: How to provide a global system that is harmonically integrated? An "idealized," but plausible vision of the future of these systems is proposed by UITP (Union Internationale des Transports Publics) Policy Brief (2017), in Fig. 16.8.

4. THE PARADIGM SHIFT: THE CITY AS A COMPLEX DYNAMIC SYSTEM

The considerations made so far have led us to conclude that cities are dynamic, complex systems; and, as such, they are composed of multiple interrelated subsystems that interact with each other through different kinds of interdependencies. The cities then must be conceived as "systems of systems" in which mobility is one of the most complex and nonisolated components, meaning that it is strongly interdependent and interacts with other components. As I have shown in the previous sections,

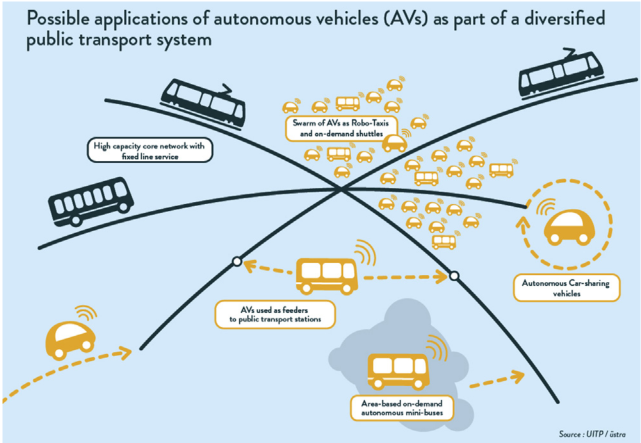

FIGURE 16.8 Autonomous vehicles as a diversified component of an integral system of public transport. *UITP.*

mobility must be placed in the context of these interactions so that its implications can be correctly analyzed.

Accordingly, solutions for complex systems based on local approaches cannot be seriously conceived without a systemic, holistic vision that explicitly does not take into consideration all of the components and their mutual implications, in other words, ignoring that the whole is more than the sum of the parts. In fact, the proposal to analyze cities from the systemic perspective is not new. Back in 1969, Forrester (1969) already raised the alert: "*It has become clear that complex systems are counterintuitive. That is, they give indications that suggest corrective action which will often be ineffective or even adverse in its results. Very often one finds that the policies that have been adopted for correcting a difficulty are actually intensifying it rather than producing a solution. The intuitive processes will select the wrong solution more often than not.*"

Forrester continued developing this same thesis (Forrester, 1971), especially with regard to cities as social systems that have counterintuitive behaviors. An approach shared and explored more in depth by Wilson (1974): "*The natural tendency is to* 'solve' *the urban problems, but usually in an oversimplistic way, without any detailed understanding of the problems and their interdependence, and without any ability to predict the consequences of implementing the 'solutions'.*"

Therefore, seeking solutions for sustainable urban mobility should be based on research into the complexity of cities and the role that mobility plays in them. As we have already mentioned, this means that *technology is a necessary condition, but it is insufficient in forecasting the future mobility.*

Sufficiency shall be found by analyzing the complexity of the system, a task that requires an appropriate methodological approach. The proposal that we put forth in this chapter is supported by a methodology based on the construction of models, that is, formal representations of complex systems. In the case of cities, a version of urban dynamics known as system dynamics allows taking into account the dynamic nature of the interdependencies between the components. This methodology is able to treat multiple variables, the feedback loops between the components and the role of factors influencing behavior.

Interpreting these interactions and thus being able to formulate a modeling hypotheses can begin by analyzing the driving forces of urban developments. A concise description of these can be found in the report by the United Nations Human Settlements Programme (2013), which summarizes them in a few simple hypotheses:

- More trips at greater speeds that allow traveling longer distances are supposed to generate economic prosperity.
- The equation "mobility ⇔ transport" has promoted the trends towards the growth of individual motorized mobility, and the propensity to expand the networks of metropolitan roads.
- The belief that the growth of motorization will not follow a declining trend as a consequence of improvements and developments in either transport systems or, above all, in automotive industry technologies.

The factors that have in fact been formulated with more precision are those underlying the urban dispersion phenomena mentioned in Section 2. However, despite the increasing levels of urban mobility resulting from these hypotheses, the fact is that access to jobs, activities, and the provision of services becomes increasingly difficult. The question, then, is: "*What are the essential conditions for promoting the sustainable movement of people and goods in urban settlements.*" The search for an answer leads us to a fundamental finding: "The vast majority of trips are not made for no reason but in order to reach destinations or, more generically, to meet needs." In other words, the fundamental implication that we have already discussed above is that "*transport and mobility are derived demands, that is to say they are a means that allow citizens access to other citizens and to places where activities happen […] Mobility, as already mentioned, must be considered properly as a means to achieving the end of accessibility.*"

The consequences of these implications initially involve a radical change of approach to analyzing urban mobility and, consequently, to proposing solutions to its main challenges: instead of focusing attention primarily on the means for realizing mobility, focus on the purpose of mobility, i.e., realizing accessibility. And therefore:

- Making accessibility the focus emphasizes the need for a holistic and integrated approach to sustainable urban mobility, which is determined by the degree that a city, as a whole, is accessible to all its citizens.
- This holistic view must establish the links between the urban form (in terms of its form, structure, functions, and demography) and urban transport systems—as we have discussed in Section 2 and illustrated qualitatively in Fig. 16.4.
- The approaches taken from the perspective of accessibility draw special attention to the potential of the urban form to support the increasing proximity of places and movements, thereby minimizing the need for travel.
- The backbone of urban mobility based on accessibility is public transport, particularly public transport systems of high capacity that are well integrated into a multimodal structure.
- Any approach must also consider promoting alternative modes such as walking or cycling and, especially, reducing the need for travel.

All of this leads to a first approximation of the same high level conceptual diagram of interrelations, which we have already identified in a different way in Figs. 16.2–16.4. One immediate conclusion that emerges from this analysis is that sustainable mobility (efficient, “smart,” intelligent, or any other adjective you want to add) must go far beyond the purely technological aspects if we want to consider all these other aspects related not only to how mobility demand is generated but also the related transport needs, all of which must be properly satisfied. This leads to seeking and understanding the relationships between urban transport systems and land use. In Section 2 we have described a first approach, which we can delve into by following, for example, the discourse in Chapter 6, “Urban Transportation,” of the cited book “The Geography of Transport Systems” by Rodrigue et al. (2013), which identifies the following constitutive elements of these relationships:

- Land use, the nature and location of which is related to the activities that are carried out. These activities involve functions such as production, consumption, and distribution, which take place in specific locations and define a system of activities and levels of spatial clumping that indicate their intensities and concentrations. An example of activities related to work is illustrated in Fig. 16.4.

- The behavior patterns of citizens, institutions, and companies have an imprint on land use, depending on their choice of site.
- Given that each type of land use has its specific mobility requirements, transport is a factor in locating activities and, consequently, it is intimately associated with land use.
- The interactions between transport and land use are mostly considered retroactive relationships between activities, which are related to land use, transport-related accessibility, and the connectivity of the territory determined by the transport network.

As a result (Rodrigue et al., 2013), the key to understanding urban institutions lies in the analysis of the patterns and processes of land use/ transportation systems, highly complex systems which include the relationships between:

- *The transport system*, which takes into consideration the set of infrastructures and modes that support urban transport of people and goods. It can be considered that, in general, it represents the degree of accessibility.
- *The spatial interactions*, which consider the nature, extent, origins, and destinations of the movements of people and goods. This takes into consideration the attributes of the transport system and land use factors that generate and attract the movements.
- *The land use*, which considers the spatial degree of accumulation of activities and their mobility requirements. This is linked to demographic and economic attributes.

This is a highly dynamic system subject to external influences, such that each component of the system is constantly evolving due to changes that are technological, demographic, economic, political, and—as has recently become evident—cultural as well as changes in values. Fig. 16.3 represents a conceptual diagram that formalizes these relationships in a simplified way.

The recognition of the strong interdependencies between decisions about locations and activities of travelers has led to the conviction that the models of transport and land use must be integrated so that they can properly represent the "feedback cycle land use ↔ transport." Fig. 16.9 can be interpreted as a first conceptual approach to the understanding of the city as a complex dynamic system that goes beyond the classic "paradigm of spatial interaction," on which traditional transport planning is based (Wegener, 2004). This conceptual diagram reveals not only the interactions, but also where the technological and sociological changes influence them, which are highlighted by the enclosed components of the diagram.

- *Car ownership* in the immediate future may be strongly affected by the emerging paradigm shift "from the ownership of the car to the

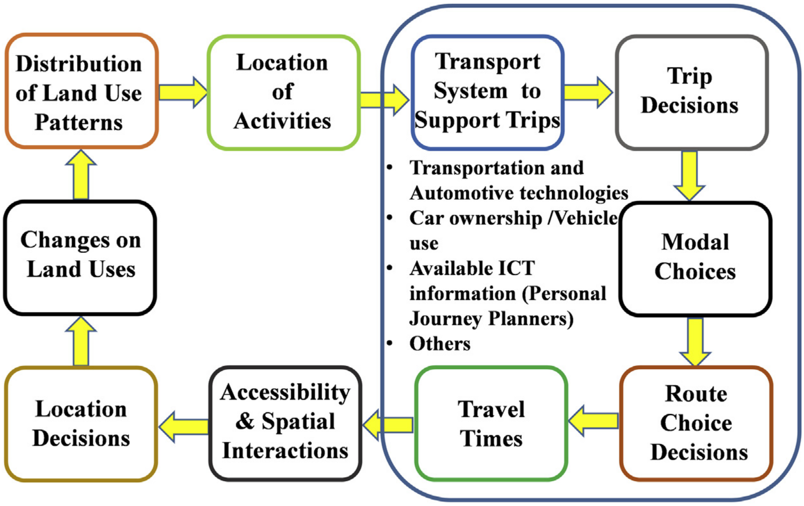

FIGURE 16.9 The feedback cycle "Land Use ↔ Transport."

use of the vehicle," according to the report from Frost and Sullivan (2015) that we discussed previously. Such a paradigm shift would be confirmed by the increasing trends in car-sharing and ride-sharing, which can be strongly affected by the penetration of the new technologies of the automotive industry, such as electric vehicles or connected and driverless autonomous vehicles.

- *The decision about making the journey* (trip decision), which reflects the decision-making process that determines whether the trip is really necessary or not. Among other factors, it takes into account the possibilities of virtual accessibility that ICT can offer, but it can also be strongly affected by the possibilities of reducing the number of motorized trips as a consequence of changes in forms and urban dynamics that make it possible to access activities through other alternative modes such as walking or biking.
- *The selection of mode and route* ("mode and route choice"), which are also aspects that are heavily influenced by ICT applications, as is the case of "personal journey planners" or the new concept of mobility as a service, which allow us to operate with multimodal options more efficiently, as for example when using transport systems on demand.

This approach represents a significant change in conventional transport planning approaches that, according to Alberti (2008), "break the cities down into their components and then study each component separately." These approaches also deal with land use and the socioeconomic variables related to them as if they were constant (or at least change only in discrete intervals of time) and corresponding to predefined scenarios while ignoring the processes of urban transformation and the changes in the urban dynamics between scenarios. The traditional methods of strategic transport planning (Ortúzar and Willumsen, 2012) adhere to the well-known four-stage model and its submodels of travel demand analysis, trip distribution, and trip assignment. Although based on these concepts, they take a static perspective, which does not take into account the dynamic nature of the involved relationships and their feedback. "*However, the cities are the archetypes of integrated systems, the individual components which interact, and therefore they cannot be understood by simply understanding each of their parts separately.*" To include the dynamics and the interdependencies, we need to change the methodological approach and adopt the perspective of system dynamics. In the same reference (Ortúzar and Willumsen, 2012), the authors formulate a proposal that represents an adaptation of the conventional models of strategic planning and integrates the models of land use with transportation, explicitly including multimodality and the existence of multiple classes of users, a key factor in current urban scenarios. It is therefore a framework proposal for modeling the dynamic relationships between land use and transport systems with the aim of overcoming the described limitations of the conventional approaches, the conceptual diagram of which is shown in Fig. 16.10.

Efforts to update these modeling perspectives have led to the conviction that—in order to understand the city as a complex dynamic system—it is necessary to use the appropriate modeling tools to treat it. This renewed interest in the dynamics of systems and their specialization, urban dynamics, which were initially formulated by Forrester (1969), and specifically designed to take into account the complexity of cities in terms of multiple variables, feedback cycles between the components, and the role of factors of influence such as *changes in social and technological paradigms*.

There are many reasons to support this thesis: the consistency of a system dynamics approach for modeling complex dynamical systems, the availability of data that in the past were inaccessible or nonexistent, and the evolution of computational power in computational platforms that now make it possible to work with complex, large dimensional models with the assistance of newly developed modeling languages that allow building and managing the computer models.

The validity of this approach for the treatment of cities as complex systems is clearly expressed by the same Forrester as in the introduction to his chapter (Forrester, 1971), "This paper addresses several social concerns: population trends; *quality of urban life; policies for urban growth; and the unexpected, ineffective, or detrimental results often generated by government programs*. Society becomes frustrated as repeated attacks on

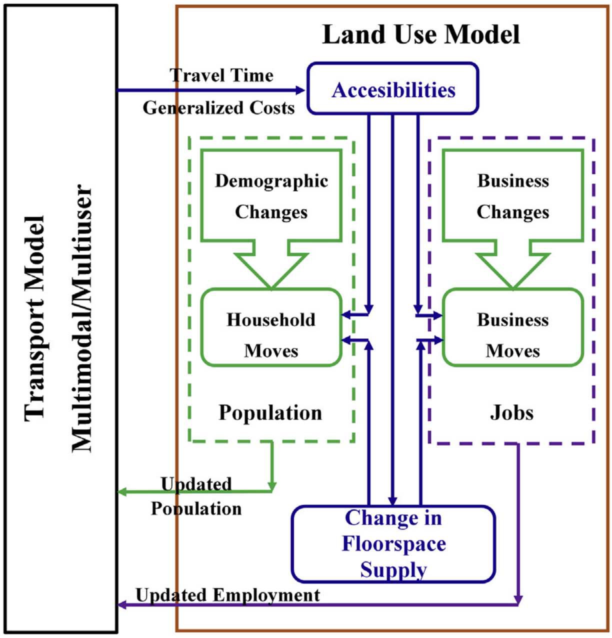

FIGURE 16.10 Conceptual scheme for the dynamic integration between land use and transport models. *Adapted from Ortúzar, J.D., Willumsen, L. 2012. Modelling Transport, John Wiley.*

deficiencies in social systems lead only to worse symptoms. Legislation is debated and passed with great hope, but many programs prove to be ineffective. Results are often far short of expectations. *Because dynamic behavior of social systems is not understood, government programs often cause exactly the reverse of desired results."*

The field of system dynamics now can explain how such contrary results happen. Fundamental reasons cause people to misjudge the behavior of social systems. Orderly processes in creating human judgment and intuition lead people to the wrong decisions when faced with complex and highly interacting systems. Until we reach a much better public understanding of social systems, attempts to develop corrective programs for social troubles will continue to be disappointing. It is by no means insignificant that this article by Forrester was resurrected by the McKinsey Report: "McKinsey Classics December 2016," under the heading "Inventing the Future."

A relevant example of this approach being applied is MARS (Metropolitan Activity Relocation Simulator; Pfaffenbichler et al., 2010), an integrated land use and transport system model constructed by combining system dynamics techniques (as reformulated by Sterman, 2000) and synergetic techniques (Haken, 1983). It is a diagram model of causal cycles, and the basic underlying hypotheses are that settlements and their activities are auto-organized subsystems. The model was designed and developed to assess the impacts of exogenous land use and transport policies such as: the implementation of a new significant infrastructure of urban transport (such as a new subway line or a belt of ring roads); new developments in residential or business areas; changes to public transport or to the travel card system; changes in the costs of travel by private car as well as those derived from urban tolls to city centers or from parking fees, etc.; demographic changes (population growth, migration); and new economic scenarios (growth/decline, economic changes in fuels prices, etc.). Fig. 16.11 shows the basic conceptual structure of the specialized version of MARS (Shepherd et al., 2010)—which integrates SATURN (Van Vliet, 1982) as a transport model—and its high-level translation in terms of causal feedback cycles of system dynamics. Integration with the transport model allows estimating the travel times between origin–destination (OD) pairs, and the cost functions are compatible with a much more detailed urban network model. The travel generation phase of MARS calculates the total number of trips that begin or end in each of the zones, depending on their socioeconomic characteristics. Then, a trip distribution process assigns them to each of the OD pairs, and the modal selection distributes them among the different models of transport, taking

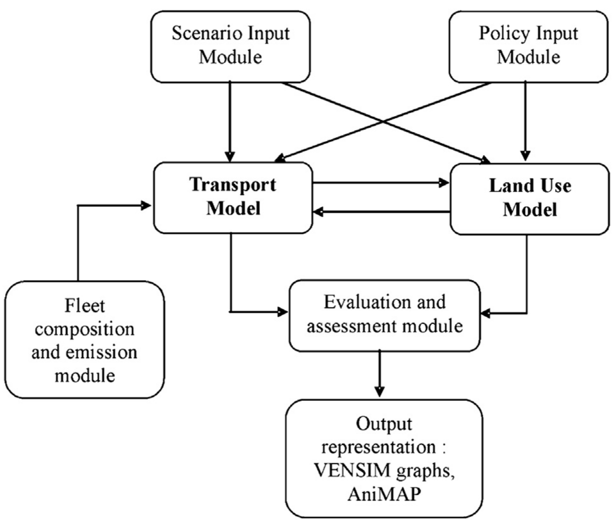

FIGURE 16.11 Basic conceptual structure of the MARS model and its submodels. *Pfaffenbichler, P., Emberger, G., Shepherd, S., 2010. A System Dynamics Approach to Land Use Transport Interaction: The Strategic Model MARS and its Application, System Dynamics Review, vol. 26, No. 3, July-September 2010, pp. 262–282.*

into account the utility functions that each mode has for the users. Generation, distribution, and modal selection are calculated simultaneously in MARS using entropy maximization models. The initial version of MARS also took into consideration the slow transport modes (which represents the nonmotorized modes of walking or biking), car, and public transport (bus). The result of each iteration of the simulation corresponds to a certain period of time and it consists of the average travel speeds, the distribution of the distances traveled, average costs, and the number of journeys by mode of transport per OD pair for each purpose of trip. All this information is combined in a "general measurement of accessibility" and passed on to the land use submodel of MARS.

In Fig. 16.12, the CAUSAL LOOP DIAGRAMS (CLD) are diagrams of causal cycles (right) in accordance with the logics of Forrester's System Dynamics (1969), and they are used to represent the interactions between the components through positive and negative feedbacks. The transport model represents situations in which there is an increase in "commuters" traveling in private vehicles as a result of the increase in the attraction of private vehicle use, which in turn increases the search time of parking,

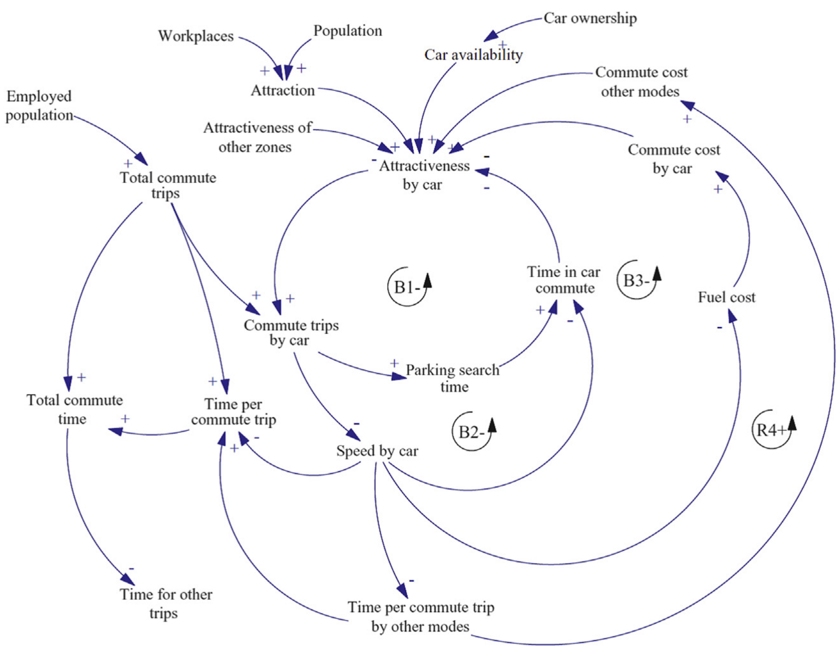

FIGURE 16.12 CLD for the transport model: commuter trips by car in MARS. *Pfaffenbichler, P., Emberger, G., Shepherd, S., 2010. A System Dynamics Approach to Land Use Transport Interaction: The Strategic Model MARS and its Application, System Dynamics Review, vol. 26, No. 3, July-September 2010, pp. 262–282.*

which thus implies an increase in congestion, thereby resulting in a decrease in the appeal of using a private vehicle. In general, increased use will result in a decrease in speed and therefore a decrease in the attractiveness of private vehicle use.

5. CONCLUSIONS: FROM "SMART CITIES" TO "WISE CITIES" AND THE ROLE OF SUSTAINABLE TRANSPORT

The fundamental thesis of this chapter that I have attempted to substantiate and justify is that sustainable urban mobility is not just a matter of technological change, but that technological change is a necessary but insufficient condition, and that sufficiency is provided by understanding the causes of mobility, and their relationships with and dependencies on structure and urban dynamics. In addition, this affects every related aspect: energy efficiency, reductions in the climatic impacts of urban transport, in emissions that are harmful to health, and the ability to satisfy mobility objectives. In other words, all the activities necessary for urban dynamics are accessible to everybody. Consequently:

- The study of these phenomena has to be addressed in all its complexity, from a holistic, systemic perspective that considers the city as a complex dynamic system and that is able to understand the dynamics of the implied interactions.
- Dynamic systems (in particular, the updated versions of the urban dynamic systems) are the right tools for achieving this understanding and for analyzing the implications of decisions taken to find solutions to sustainable urban mobility problems, such as combinations of changes in forthcoming automotive technologies, urban systems, and lifestyles.
- Despite the evolution of computational tools that find solutions for models based on the system dynamics of urban systems, there are still gaps that need to be overcome. Some are those resulting from simplified transport models and their relationships with land use as well as with spatial and temporal redistributions of activities.
- More detailed studies are still required for assessing the implications that technological alternatives have on urban mobility, such as the penetration of alternative propulsion technologies (especially electric vehicles), of autonomous vehicles, and of mobility services based on generalized concepts such as ride-sharing. This will facilitate arriving at clear conclusions and correctly defining policies and lines of action that are supported by the appropriate models for

a variety of urban settings, which will in turn allow a better understanding of the structural and urban dynamics conditions.

Finally, let us take a last look at the ideas of Rodrigue et al. (2013) and Bertaud (2001), regarding urban forms and their influence on mobility, which have been summarily represented in Fig. 16.4. This will allow us to see that while many cities (especially in Europe) have inherited urban forms of the past that are most commonly polycentric but in some cases monocentric, the contemporary urban expansion patterns associated with land use changes have spurred urban sprawl. As a consequence, activities have become dispersed and decentralized while strong relationships have been established between urban density and private car use as a result of high population growth rates. Private motorization and public transport have experienced deficits, resulting in increased travel and expanded peripheral road networks for facilitating exchanges between the outskirts and the center rather than between only the outskirts. This has resulted in congested access roads and growth in urban spaces for cars to circulate or park; and this is despite the fact that 98% of the time the private vehicles are not used and remain parked. However, the pressure on sustainability is currently changing our perspective. According to Banister (2011), technological evolution is fostering a time–space convergence that promotes centralized and specialized forms of economic activity in locations that can offer comparative advantages: "*Within the sustainable mobility paradigm, planning has an instrumental role in reducing trip lengths so that proximity or closeness becomes a key consideration in the location of new activity or in the reorganization of existing activities.*"

This change in the planning models has occupied an important part of this chapter, and it underscores a shift in the objectives that are now different from what was formerly conventional: the main purpose is no longer to divide household labor but to promote the role played by mixed land uses in maintaining local services while ensuring accessibility. As a consequence, this reduces individual motorized mobility. The aim is therefore to create quality spaces associated with accessibility concepts that are related to what citizens want and want to do instead of being concerned only with the physical properties of the urban structure. This involves transforming the urban space footprint by improving and increasing areas for pedestrians and bicycles, while minimally interfering with the urban space for vehicles, public transport, and areas of interchange.

These policies imply that the potential role of automotive industry technologies must not be to increase journey distances but to reinforce the trend toward shorter distances using new types of vehicles that are adapted to the city. This requires reinterpreting the role of the vehicle in the city, which, combined with changes concerning ownership and use of vehicles, can be key contributions to the solution. At the same time, changes can be made to the conventional approaches for modeling and analyzing transport, which has been argued in this chapter. The traditional formulation of transport models has always pivoted on travel time, a concept that has been associated with the trip as a private demand. This suggests that the costs (understood in a very broad sense) for reaching a destination were more than compensated by the benefits received at the destination. Therefore, the central concept in any analysis of transport has been the desire "to save time," with the results of the assessment depending almost exclusively on the potential benefits received as a consequence of savings in travel time. In consequence, all results led to solving how to increase traffic speed in order to reduce travel time.

As this chapter has argued, the alternative paradigm resulting from analyzing the complexity of cities implies a better understanding of the relationships between land use and transportation, which leads to a concept of sustainable transport that requires:

- Policies based on "*reasonable travel time*" instead of on minimizing travel time;
- Moving towards urban forms that keep travel distances below the thresholds required for maximizing modes of transport on foot and by bicycle;
- Giving preference to multimodal public transport;
- Accessible corridors close to public transport interchange nodes;
- Meeting the requirements of economies based on information and services;
- Reinterpreting the role of cars in the city, with new types of urban vehicles for both single and shared use, which take into consideration social changes;
- Moving away from policies that involve increases in a transport infrastructure aimed at private vehicles and instead encouraging policies aimed at reducing demand for private vehicle transport, thereby redistributing the demand in space and time.

This prompts a change in perspective that replaces the concept of "Smart City" with "Wise City." The first is a market-driven concept in which "Smart Mobility" is almost exclusively supported by technological changes in automotion and ICT applications. This implicitly assumes that technology alone will drive the changes. "Wise Cities" is a concept aimed toward the citizen, with WISE being an abbreviation for:

W: Wellness and Walkable. That is to say, it takes into account the role of urban forms and imprints determined land uses, activities, and transport systems.
I: Intelligence and ICT, placing technology at the service of citizens.

S: Sustainable and Safety, supported by an appropriate combination of planning based on the concepts of reasonable travel time, urban vehicle technologies, and mobility as a service.
E: Ecology, Energy, and Economy, supported by balancing concepts of the urban metabolism.

In other words, WISE returns the citizens to the center of the microcosm that is the city.

Acknowledgments

This research has been partially funded by the Spanish Ministry of Economy, Industry and Competitiveness, within the National Programme for Research Aimed at the Challenges of Society (grant ref. TRA2016-79019-R).

References

Alberti, M., 2008. Advances in Urban Ecology. Springer.
Banister, D., 2011. The trilogy of distance, speed and time. Journal of Transport Geography 19 (4), 950–959.
Basnal, P., Singh, V., Shukla, A., Kumar, D., Kadam, A., 2015. Demand responsive transport. IJISET - International Journal of Innovative Science, Engineering & Technology 2 (4).
Belissent, J., 2010. Getting Clever about Smart Cities: New Opportunities Require New Business Models. Forrester for Vendor Strategy Professionals.
Bertaud, A., 2001. Metropolis: A Measure of the Spatial Organization of 7 Large Cities. Possible Urban Movement Patterns.
Boesch, P.M., Ciari, F., Axhausen, K.W., 2016. Required Autonomous Vehicle Fleet Sizes to Serve Different Levels of Demand, TRB 2016 Annual Meeting.
Brundtland Report, October 1987. World Commission on Environment and Development.
Center for Automotive Research, 2016. Spulber, A., Dennis, E.P., Schults, M., Wallace, R. The impact of New Mobility Services on the Automotive Industry, Transportation Systems Analysis Group.
Chen-Ritzo, C.H., Harrison, C., Paraszczak, J., Parr, F., 2009. Instrumenting the planet. IBM Journal of Research and Development 53 (3), 338–353.
EU Reference Scenario, 2016. Energy, Transport and GHG Emissions Trends to 2050, Directorate-general for Energy, Directorate-general for Climate Action and Directorate-general for Mobility and Transport.
Ewing, R., Cervero, R., 2010. Travel and the built environment. Journal of the American Planning Association 76 (3), 265–294.
Fearnley, N., Pfaffenbichler, P., Figenbaum, E., Jellinek, R., 2015. E-vehicle Policies and Incentives—Assessment and Recommendations. Institute of Transport Economics, Oslo, Norway. www.toi.no.
Forrester, J.W., 1969. Urban Dynamics. In: System Dynamic Series. Pegasus Communications Inc. FORTUNE.
Forrester, J.W., 1971. Counter intuitive behavior of social systems, January 1971, (issue of the Technology Review published by the Alumni Association of the Massachusetts Institute of Technology).
Frost, Sullivan, 2015. Intelligent Mobility 3.0, Future of Mobility & New Mobility Business Models. https://ww2.frost.com/event/calendar/intelligent-mobility-2015/.

Furuhata, M., Dessouky, M., Ordoñez, F., Brunet, M.-E., 2013. Ridesharing: the estate-of-the art and future directions. Transportation Research Part B 57, 28–46.
Haken, H., 1983. Advanced Synergetics: Instability Hierarchies of Self-organizing Systems and Devices. Springer, Berlin.
Kennedy, C.A., Cuddihy, J., Engel Yan, J., 2007. The changing metabolism of cities. Journal of Industrial Ecology 11 (2), 43–59.
Kennedy, C.A., Pincetl, S., Bunje, P., 2010. The study of urban metabolism and its applications to urban planning and design. Environmental Pollution. https://doi.org/10.1016/j.envpol.2010.10.022.
KUTSUPLUS. http://www.muotoilutarinat.fi/en/article/käyttäjälähtöinen-suunnittelu/.
Ma, S., Zheng, Y., 2015. Real-time city scale taxi ridesharing. IEEE Transactions on Knowledge and Data Engineering 27 (7), 1782–1795.
Newman, P.W.G., 1999. Sustainability and cities: extending the metabolism model. Landscape and Urban Planning 44, 219–226.
Ortúzar, J.D., Willumsen, L., 2012. Modelling Transport. John Wiley.
Pandit, A., et al., 2015. Infrastructure ecology: an evolving paradigm for sustainable urban development. Journal of Cleaner Production. https://doi.org/10.1016/j.jclepro.2015.09.010.
Pfaffenbichler, P., Emberger, G., Shepherd, S., 2010. A system dynamics approach to land use transport interaction: the strategic model MARS and its application. System Dynamics Review 26 (3), 262–282.
Rodrigue, J.-P., et al., 2013. The Geography of Transport Systems. Routledge.
Schaffers, H., Komninos, N., Pallot, M., Trousse, B., Nilsson, M., Oliveira, A., 2011. Smart Cities and the Future Internet: Towards Cooperation Frameworks for Open Innovation.
Shepherd, S., Koh, A., Balijeplli, C., Pfaffenbichler, P., 2010. Use of Modelling Tools to Deliver a Sustainable Transport System, 12th World Conference on Transportation Research.
Sterman, J., 2000. Business Dynamics: Systems Thinking and Modeling for a Complex World. Irwin/McGraw-Hill, Boston, MA.
UITP Policy Brief, January 2017. Autonomous Vehicles: A Potential Game Changer for Urban Mobility. www.uitp.org.
United Nations Human Settlements Programme, 2013. Planning and Design for Sustainable Urban Mobility. Global Report on Human Settlements.
United Nations, 2014. World's Population Increasingly Urban with More than Half Living in Urban Areas. http://www.un.org/en/development/desa/news/population/world-urbanization-prospects-2014.html.
Urban Mobility System Upgrade: How shared self-driving cars could change city traffic, 2015. International Transport Forum. OECD. www.internationaltransportforum.org.
van Eggermond, M.A.B., Erath, A., Axhausen, K.W., 2016. Vehicle ownership and usage in Switzerland: the role of micro and macro-accessibility. In: Paper 16–4761 Presented at the 94th TRB Annual Meeting.
Van Vliet, D., 1982. SATURN: a modern assignment model. Traffic Engineering and Control 23, 578–581.
von Venkat, S., Fine, C., Faster, G.D., 2017. Smarter, Greener: The Future of the Car and Urban Mobility. The MIT Press.
Ward, B., Dubos, R., 1972. Only One Earth: The Care and Maintenance of a Small Planet, Great Britain, a Pelican Book. Penguin.
Wegener, M., 2004. Overview of land-use transport models. In: Henscher, D.A., Button, K. (Eds.), Transport Geography and Spatial Models. Pergamon/Elsevier Science, pp. 127–146.
White Paper FHWA-JPO-14-148, October 2014. The Smart Connected City and its Implications for Connected Transportation.

Wilson, A.G., 1974. Urban and Regional Models in Geography and Planning. John Wiley & Sons.
Wolman, A., 1965. The metabolism of cities. Scientific American 213 (3), 179–190.
Zegras, C., 2010. The built environment and motor vehicle ownership and use: evidence from Santiago de Chile. Urban Studies 47 (8), 1793–1817.