VIRTUAL MOBILITY LAB: a [illegible] c approach to Urban Mobility challenges

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1. INTRODUCTORY REM[illegible]

Mobility is currently one of t[illegible] concerns in urban areas, mobility can be considered *as the movement of people and goods efficiently and safely,* [illegible] *y be regarded as the ability to travel when and where the traveler or the goods need to in the most efficient way*. Th[illegible] that urban mobility is a means to ensuring an end, namely accessibility: citizens must reach destinations in order t[illegible] eir needs and access the locations of activities. Mobility must also be sustainable and account for technicalities as[illegible] ther means for achieving accessibility. Figure 1 depicts two fundamental aspects for consideration: first, the con[illegible] cheme 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. That implies that to understand mobility, its requirements, and how they condition life in urban areas, we must 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. 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) 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.

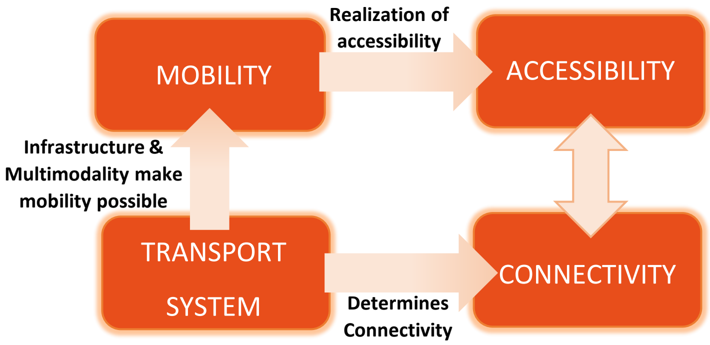
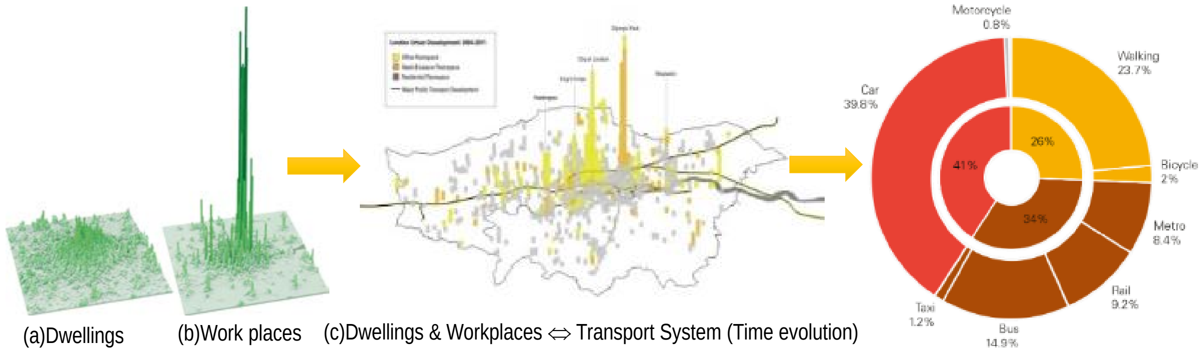


Figure 1. Conceptual scheme of the interrelationships between Mobility, Transport System, Connectivity and Accessibility

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 Society 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. Figure 2 graphically describes the following: the strong interaction between dwelling densities in Figure 2(a) and workplaces in Figure 2(b); the time evolution of dwellings, workplaces and their relationship with transport infrastructures in Figure 2(c); and the mobility patterns associated with combinations of modal uses and short journeys in Figure 2(d)



(a)Dwellings (b)Work places (c)Dwellings & Workplaces ⇔ Transport System (Time evolution)

(d) How the transport system is used

Figure 2. Relationships between urban form (Dwellings↔Workplaces), Transport System and Modal Splits in London (Source: LSE Cities, https://lsecities.net)

Figure 2(d) 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 we propose implies trying to find an “explanation” of the model by splitting Figure 2(d) from the information visualized in Figures 2(a), 2(b) and 2(c). The explanation is provided by models able of analyzing these relationships in terms of the dependencies between ownership of private vehicles, their use, 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 ridesharing 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. Figure 3 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?

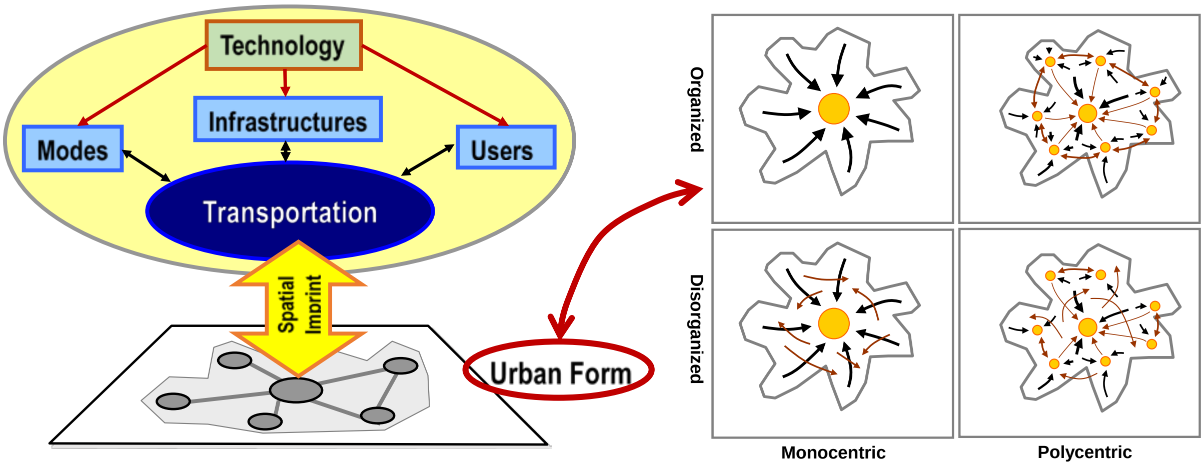


Figure 3. Transport System, Technology and Urban Forms (Adapted from Rodrigue et al., 2013, and Bertaud, 2001)

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 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.

2. PARADIGM SHIFTS

2.1. 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 non-isolated components, meaning that it is strongly interdependent and interacts with other components. Mobility must thus 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. 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 here 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.

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.
- 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.

2.2 From vehicle ownership to vehicle usage

On September 2015, Frost & Sullivan (2015) organized a two-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 forecasted 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 a Fortune magazine article (Fortune, 2015) that confirms the expected business volume by 2020 and predicts the positioning of companies such as Toyota, Ford, Daimler, BMW and General Motors.

These agreements could also be reinterpreted in the following terms:

- 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 travelling from any origin to any destination at any desired time, Figure 4 (left).
- However, what if a Mobility Service could satisfy the same needs or desires without one having to be the owner of a vehicle? In other words, the combination of new transportation technologies, and ICT applications, making possible a seamless door-to-door transportation without one having to be the owner of a vehicle, Figure 4 (right).

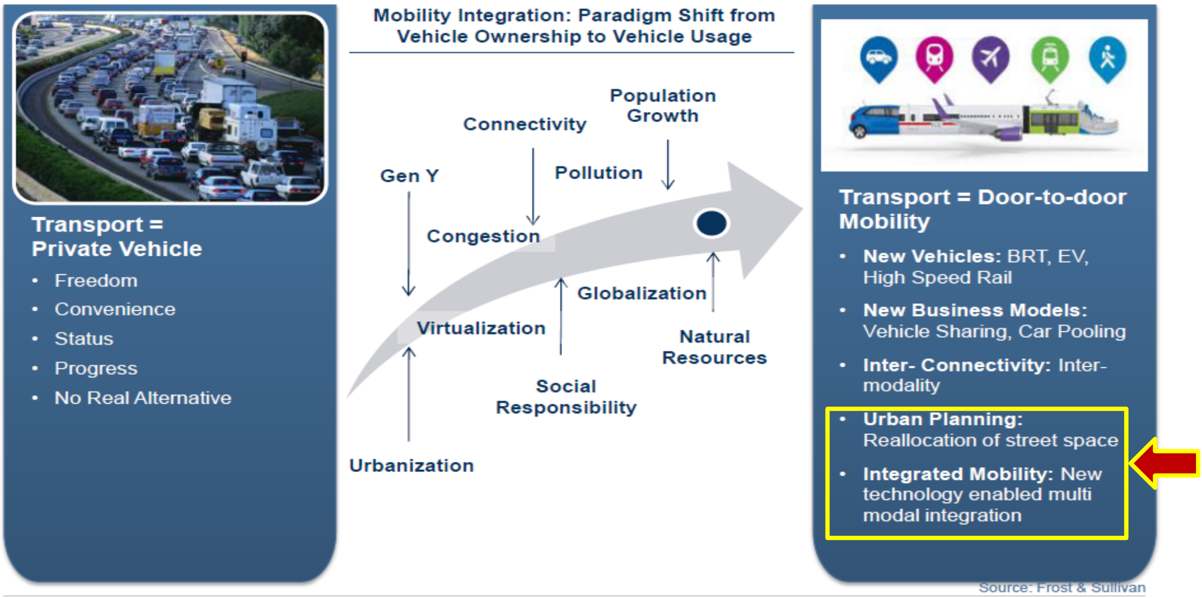


Figure 4. Paradigm shift from vehicle ownership to vehicle usage (adapted from Frost & Sullivan (2015)

This is what is currently starting to offer the emerging concept of “Mobility as a Service” (MaaS) resulting form:

- ICT enabled Travel Information Systems (i.e. Integrated Journey Planners)
- ICT Applications for service selection and provision (Car Sharing, Ridesharing, Demand Responsive Transport…)
- ICT based bookings and payment applications

In summary, 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 travelers 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. 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:

i. 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”.
ii. 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 Systems (DRT).

iii. New visions fostered by applications of Information and Communication Technologies (ICT) will make it possible to conceive of mobility as a service (MaaS) that is 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.

3. THE DYNAMICS OF CHANGE IN URBAN MOBILITY

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. Already highlighted by the yellow rectangle in Figure 4 (right).
- 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 imply 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 destinations. 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 (ridesharing, tripsharing) 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 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, 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 et al., 2015).

However, one of the most potentially interesting aspects of restructuring mobility services under the concept of "ridesharing" 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 6 to 8 passengers and which are specifically designed using the new concept of public transport on demand based on "multipassenger ridesharing"

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, comes 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.

Ridesharing 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).

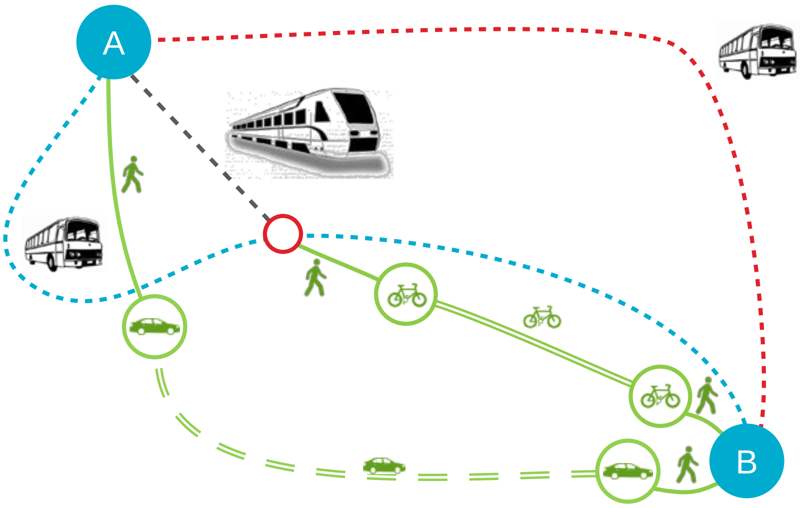


Figure 5. Mobility based on an integrated multimodal system

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 "Mobility as a Service" (MaaS) systems, which include both the transport applications on demand, such as ridesharing, 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. Figure 5 displays what should comprise these integrated multi-modal 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-sharing or ridesharing, biking, walking or any combination of these. Some examples of combinations illustrated in Figure 5 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.

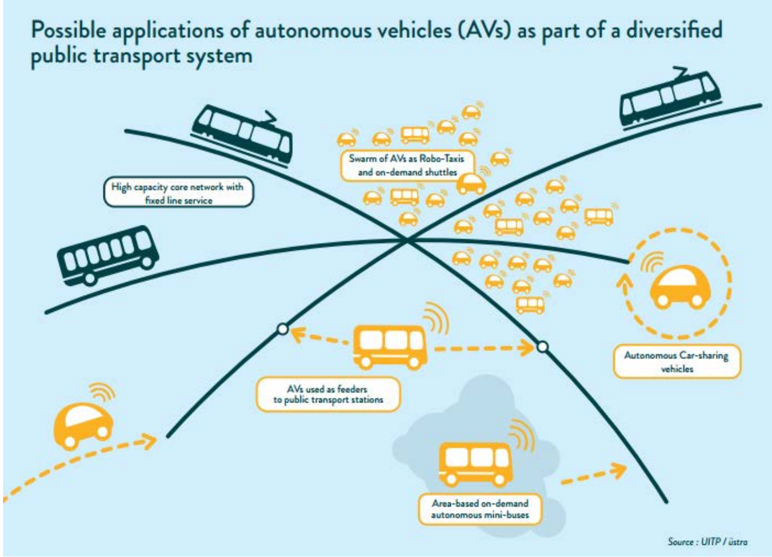


Figure 6. Autonomous vehicles as a diversified component of an integral System of public transport (source UITP)

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) in Figure 6.

4. VIRTUAL MOBILITY LAB

4.1 Conceptual approach

We have already stated that cities are complex dynamic systems, and therefore they are in constant evolution driven by policy interventions, socio-economic changes, technological innovation fostering changes in urban travel, lifestyles, the spatial structure, and the evolution on how urban population travels and, more recently, new forms of transport sharing services. This evolution is also fostering changes in urban planning policies, with current trends toward compact cities, densification, mixed-use, and inner-city revival. The consequences are *new aspects of travel behavior influencing travel dynamics not yet well understood whose future potential is uncertain*.

Our goal is to provide a common framework to assist in the design, and assessment of the impacts of new mobility concepts arising as a consequence of the combination of the urban dynamics, the changes in travel behavior, and the applications of ICT. In other words, formalize this framework in terms of a tool suited to assist us in understanding that future potential. It must be able of accounting for the new mobility concepts, which can be generically classified into two categories:

a. Mobility concepts based on the forthcoming automotive technologies, e.g.:

  - Electric vehicles
  - Connected vehicles
  - Autonomous (Driverless) vehicles

b. Mobility concepts based on new transportation systems supported by ICT applications, e.g.:

  - Car-sharing, Multiple Passenger Ridesharing and other forms of Mobility as a Service (MaaS) and Demand Responsive Transport
  - New forms of multimodality
  - Multimodal exchange nodes and parking management

Categories that obviously are not mutually exclusive, since a car sharing service, for example, can be provided by conventional vehicles as well as by electrical, connected or autonomous vehicles. To achieve such goal we propose the development of the ad hoc tool, that we call “Virtual Mobility Lab”

> *“The Virtual Mobility Lab is an integrated multimodal simulation model aimed at assisting in the design and evaluation of impacts of new mobility concepts, either based on automotive technologies, ICT applications, or both, for scenarios evolving over time”*

Examples of questions that can be properly addressed with such tool could be:

- How will this affect our strategic goals and long term plans?
- How much parking will be freed up and how to utilise the space?
- What additional infrastructure is needed to facilitate pick-up/drop/off?
- How to co-ordinate mobility services for the good of the city?
- What will be the impact of phased autonomy / mixed traffic?
- Will congestion improve or intensify and over what time period?
- How will this impact on our current committed and planned schemes?
- How best to regulate ride-sharing companies such as Uber?
- Can the city profitably run its own mobility service?
- Can you forecast a ‘most-likely’ future that includes vehicle and ride-sharing?
- Do you know what travel behavior changes vehicle and ride-sharing will bring?
- Does your transit plan include autonomous on-demand buses?
- Have you considered how to integrate vehicle and ride-sharing in to your transit plan?
- Is your scheme still profitable under these conditions?
- Do you know how to simulate mixed AV and regular traffic?
- Are you confident that your planned transit line will be profitable in 20 years’ time?

- Have you considered the reduced parking need in your land-use forecast?
- Will the introduction of shared, autonomous and electric fleets allow my city to meet its safety and environmental objectives?
- Do we have sufficient charging infrastructure?

Figure 7 depicts a primary version of the conceptual architecture of such system. From left to right the main building blocks would be:

- Input data:
    - From conventional sources (i.e. household surveys, traffic counts, speeds measurements…)
    - From ICT sources (GPS vehicle tracking, Bluetooth travel time measurements, Smartphone data….)
- Tools to capture and translate in modeling terms the evolution of the urban form and the transportation system, as conceptually depicted in Figure 3 with the example of LSE Cities.
- Tools fusing and processing these inputs to:
    - Build, or update, the supply model of the selected transportation system.
    - Estimate the modal splitting and the resulting modal OD matrices for the time horizon under consideration
- Tools to link to the resulting multimodal model the user defined applications implementing the selected mobility concepts (i.e. multiple passenger ridesharing) to be tested.
- The result of these steps is the "Virtual Mobility Lab", the simulation laboratory modeling the current situation with the new mobility concepts that will be analyzed.
- The lab has a suitable GUI to define the KPIs that will be used for the quantitative analysis of the simulated scenarios, and the tools to define them, and run the simulation experiments.
- Whose outputs will be analyzed in the context of a decision support system. This is why, from this conceptual perspective the "Virtual Mobility Lab" is conceived to work iteratively. Let's assume, for instance, that the mobility concept to be tested is a multiple passenger ridesharing system. Once are defined the design factors of the simulation experiment, i.e., expected transport demand to be attracted by the new mode, operational conditions, size of the fleet of shared vehicles, capacities of the fleet vehicles, and so on, two of the aspects to be analyzed could be:

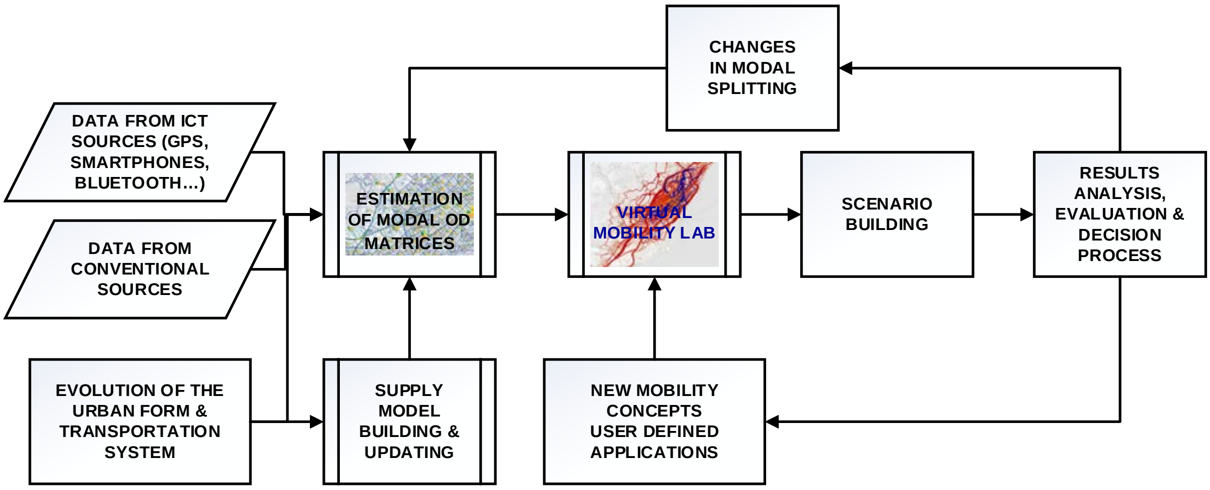


Figure 7. Preliminary conceptual approach to the architecture of the "Virtual Mobility Lab"

    - The suitability of the business model in terms of the design factors, and
    - From a transport management perspective whether the operational conditions for the new mode will affect the modal splitting and how. For example, will the new mode compete with public transport or will transfer private trips to the new mode, decreasing the number of vehicles in the network, and reducing accordingly the amount of parking space necessary?

Then depending on the results provided by the simulation experiment, its evaluation can lead, for example, to either, determine that changes in the arguments of the utility functions estimating the modal splitting could be necessary, or that a redefinition of the operational conditions of the planned system could be recommendable. In the first case the decision will result in a change in the modal splitting, and therefore in the expected intermodal change. While in the second modifications of size of the operational fleet, or the capacities of the vehicles, will define a new scenario to be simulated. These changes will determine the conditions of the next iteration of the Lab, as indicate the arrows in the flowchart of the conceptual diagram.

Figure 8 provides a more detailed description of the envisaged system architecture drawing the attention to the modeling tools required to implement the “Virtual Mobility Concept” and their functionality.

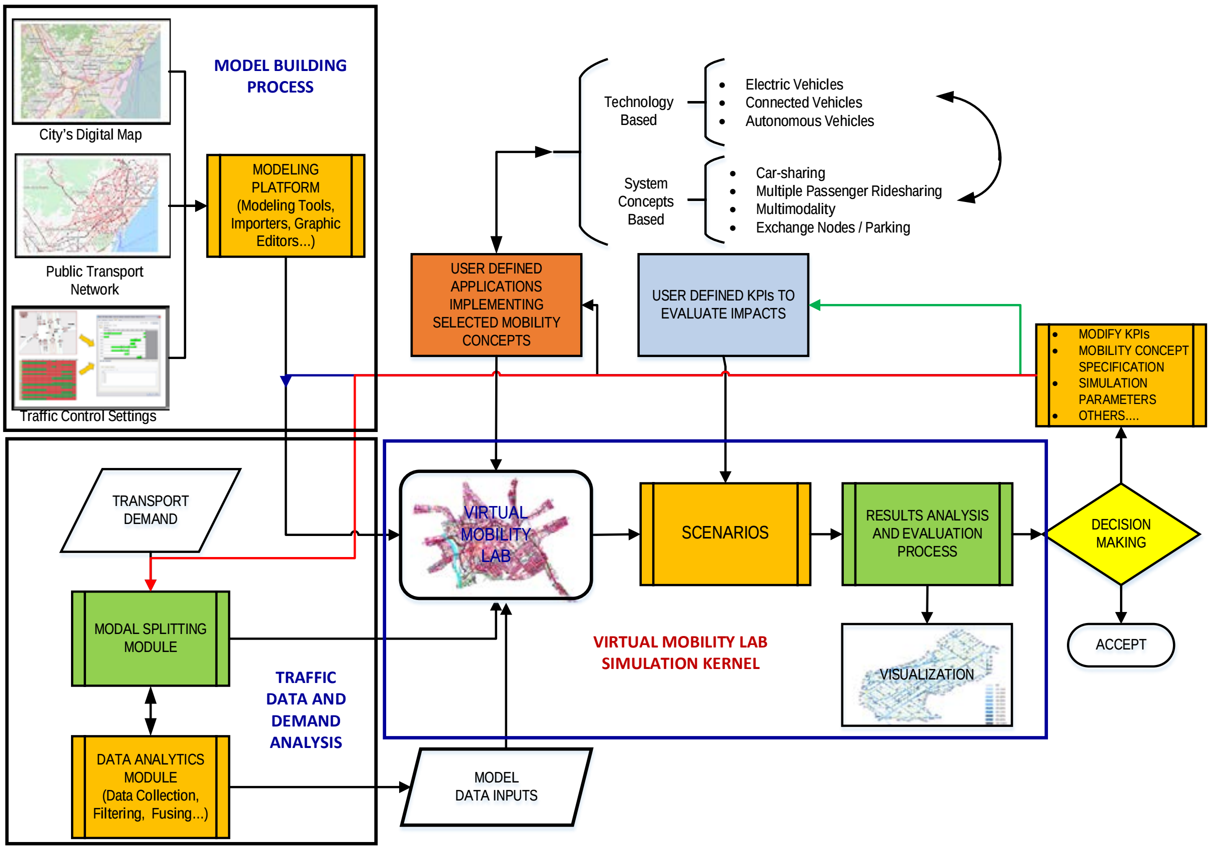


Figure 8. “Virtual Mobility Lab” building blocks

We can differentiate four families of building blocks:

1. “**The Model Building Process**” corresponding to the supply modeling. Three main data sets should be imported into the Modeling Platform owning the required modeling tools:
    a. Those to import and edit the City Digital Map that will be the basis of the Supply Model of the road network, and its attributes
    b. Those to import and edit the Public Transport network, usually in form of GTFS files, and
    c. Those to import and edit the data of the “traffic Control Settings”
2. A “**Traffic Data and Demand Analysis**” module, that could consist of:
    a. An importer of old, likely outdated, transport demand information (i.e. OD matrices from previous planning studies)
    b. A “Data Analytics Module” which desirably should include a variety of functions like:
        i. Data collection capabilities from conventional technologies (i.e. magnetic loop detectors, magnetometers, radar…)
        ii. Data collection capabilities from ICT applications (i.e. Bluetooth, GPS, Smartphones…)
        iii. Data filtering capabilities to check the consistency of the recorded data, remove outliers, complete missing data…..
        iv. “Data Fusion” capabilities, to generate homogeneous, complete, consistent data series from various heterogeneous data sources
        v. “Dynamic OD Estimation” capabilities, to estimate and adjust OD matrices from the recorded data
    c. A “Modal Splitting Module”, for example based on Discrete Choice theory to estimate the percentages of trips using each mode based on random utility functions.
3. The “**Virtual Mobility Lab Simulation Kernel**”, that simulates the behavior of the multimodal demand model under the prescribed conditions of use of the multimodal supply network. The hypothesis is that an ad hoc GUI allows the user to define alternative scenarios, run the simulation, and analyze and visualize the results in the context of:

    a. A Decision Support System that on basis to the values of the selected KPIs estimates the performance of the system and proposes alternative actions:
        i. Redefine the mobility concepts to be tested in terms of the operational factors
        ii. Reevaluate the utility functions and estimate how the modal split will change
        iii. Etc.
    b. This makes the system work iteratively, as the flowchart shows.
4. The auxiliary software tools enabling the linkage between the user defined applications implementing the mobility concepts as specified by the user, and make the changes and modifications derived from the decision making process.

4.2 A Methodological approach to build the “Virtual Mobility Lab Simulation Kernel”

The exercise of developing the Visum model Barcelona for the implementation of the “Virtual Mobility Lab” is a use case of “Data Driven Model Building” supported by the available Visum tools and utilities, to implement the “Virtual Mobility Lab Simulation Kernel” for Barcelona. The process starts by identifying the geographic region to be modeled, which is the target area of the lab. The methodological steps of the process are described in the flow diagram in Figure 9.

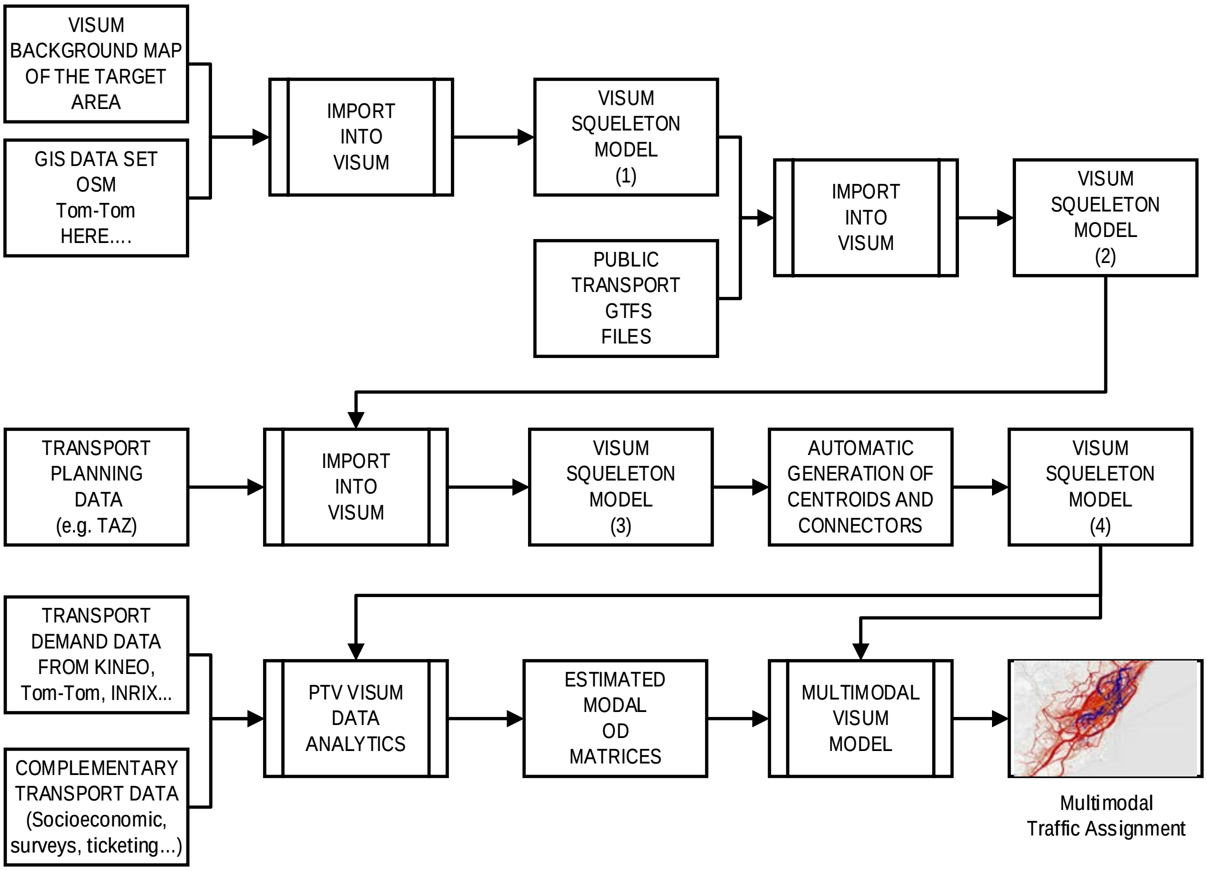


Figure 9. Workflow diagram of the “Data Driven Model Building Process”.

- Once the Visum background map of the selected target area is imported into Visum, the supply model of the road network of the target area can be imported from any of the available GIS, as for example OSM, HERE, Tom-Tom, or other similar.
- The import of the GIS Data Sets into Visum, along with the eventual editing to repair errors and complete missing information, generates a First Visum Skeleton Model of the road network component of the supply.
- Public Transport supply network can be imported from GTFS files, which usually will also need some additional editing to repair error and complete missing information.
- Road Network Supply Model and Public Transport Network Supply Model can be merged in the Visum working area to build a Second Visum Skeleton Model, which is essentially a complete model of the supply.

- The selected target area must be split into Transport Analysis Zones (TAZ) that will be in correspondence with the Demand Model in terms of an Origin to Destination OD Matrix whose entries will be the number of trips from origins to destinations, for each time interval, trip purpose and transportation mode.
- These TAZ specified in terms of shape files are the imported into the Visum Skeleton Model 2, and merged with the supply model to build the Visum Skeleton Model 3. . Origins and Destination trip zones are represented in the Visum model in terms of dummy nodes, centroids, and dummy links, connectors, injecting and retrieving the trips from the supply model. Ad hoc utilities in Visum enable an automatic generation of Centroids and Connectors, a step in the process that produces the Visum Skeleton Model 4. This is the complete supply model ready for operation when fed with the corresponding demand model.
- The last steps of the process correspond to the generation of the demand model, and its combination with the supply model, to complete the multimodal Visum model ready for the multimodal assignment executions.

4.3 Use case example: the model of the First Crown of the Metropolitan Area of Barcelona

The methodological “Data Driven Model Building Process” generically described in Figure 9 has been applied to build the Visum model of Barcelona for the “Virtual Mobility Lab” project. As described in Section 4.2 the first step has been the selection of the target area. Figure 10 depicts the candidates:

- Metropolitan Region of Barcelona (blue borders)
- Metropolitan Area of Barcelona (red borders)
- First Crown of the Metropolitan Area (Green Borders)
- City of Barcelona (Dark Grey Inner Area)

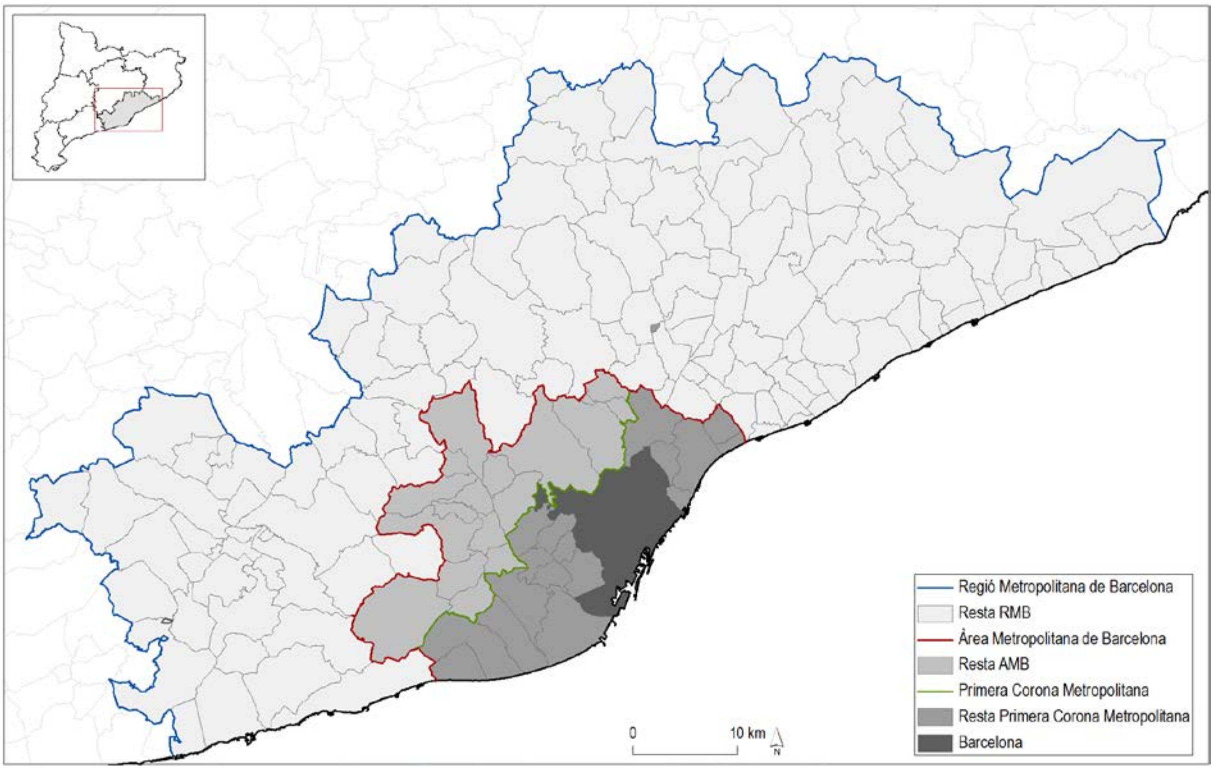


Figure 10. Candidates to target area of Visum Model for the “Virtual Mobility lab”

The decision for a first implementation of the Virtual Mobility Lab has been to select the First Crown of the Metropolitan Area, which is composed by 18 *municipalities*: Barcelona, Badalona, Sant Adrià del Besòs, Santa Coloma de Gramenet, L’Hospitalet de Ll., Tiana, Montgat, Montcada i Reixac, Esplugues de Ll., Sant Just Desvern, Sant Feliu de Ll., Sant Joan Despí, Cornellà de Ll., El Prat de Ll., Sant Boi de Ll., Viladecans, Gavà i Castelldefels. This decision doesn’t precludes a future expansion of the model either to the Metropolitan Area or to the Metropolitan Region. The main reasons for this choice are:

- **Population.** The Metropolitan Region of Barcelona has 164 municipalities and 4,747,035 habitants. The Metropolitan Area of Barcelona, with 36, municipalities has 3,239,337 habitants. The First Crown of the Metropolitan

Area, with the 18 municipalities listed above, has 2,836,925 habitants, therefore it represents the higher concentration of population. The details of the population distribution by municipalities is shown in Table 1.

- Transport supply. It concentrates the main road network, and public transport network (more than 200 bus lines, with over 4,000 stops, 10 metro lines, 15 railways lines - 9 of the Generalitat Railways and 6 of Renfe – and the two tramway networks).

Once the target area is selected the next step in the methodological process has been the definition of the Transport Analysis Zones (TAZ). Since one of our objectives, according with the purpose of using new methods to generate the OD matrices, was to exploit the mobile phone Call Data Records from Orange telephone operator to produce OD matrices, it was necessary to define a zoning system accounting for three goals:

1. A well balanced TAZ in terms of population, splitting the target area into zones with similar mean populations and standard deviations. Following the common practice recommendations of transport demand analysis, we have used the reference population figures of population averages close to 5,000 habitants per zone.
2. At the same time we had not to forget that TAZs will be larger than census tracts, and will result from clustering the census tracts into the zones.
3. Last but not least the relationships between census tracts and telephone cells must also be taken into account, in order to not divide cells between two or more census tracts.

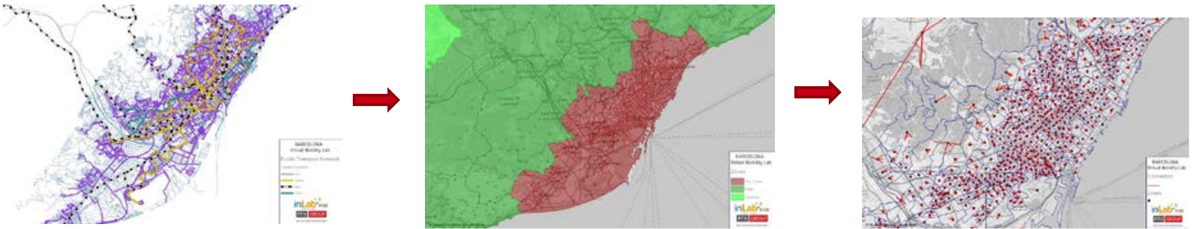
Municipis	**#Sec 2015**	**# Dis**	Pob16/SecC	**Pob 2016**	**ZAT EMIT**	**ZAT CARNET**	**Pob/ZC mean**	**Pob/ZC stdev**
Badalona	146	9	1477	215634	10	43	**5015**	**1552**
Barcelona	1068	10	1506	1608746	68	359	**4256**	**1457**
Castelldefels	26	5	2496	64892	1	14	**4635**	**1634**
Cornellà de Ll.	70	6	1230	86072	6	21	**4099**	**1881**
Esplugues de Ll.	29	10	1577	45733	3	14	**3267**	**1653**
Gavà	28	4	1652	46266	1	9	**5141**	**1920**
Hospitalet de Ll., l'	192	6	1327	254804	11	49	**5200**	**1871**
Montcada i Reixac	22	6	1582	34802	2	8	**4350**	**1350**
Montgat	4	1	2905	11621	1	2	**5811**	**203**
Prat de Ll., el	40	5	1586	63457	2	14	**4533**	**2390**
Sant Adrià de Besòs	24	6	1521	36496	2	8	**4562**	**2999**
Sant Boi de Ll.	50	6	1648	82402	1	15	**5493**	**2071**
Sant Feliu de Ll.	30	7	1470	44086	1	10	**4409**	**1804**
Sant Joan Despí	21	5	1595	33502	2	8	**4188**	**2665**
Sant Just Desvern	9	1	1881	16927	1	3	**5642**	**1847**
Santa Coloma de Gramenet	99	6	1183	117153	6	24	**4881**	**1444**
Tiana	5	1	1711	8553	1	2	**4277**	**486**
Viladecans	45	2	1462	65779	1	13	**5060**	**1554**
Gates					11	12		
Total	**1908**	**-**	**1487**	**2836925**	**131**	***628***	**4468**	**1652**

Table 1. Summary of the proposed zoning system (TAZ) of the target area

Each row in Table 1 corresponds to a municipality. Column “#Sec 2015” identifies the number of census tracts per municipality as in 2015, column “#Dis” corresponds to the number of administrative districts in which the municipality is divided, the next column “Pobl16/SecC”, the average population for Census Track in the municipality, and Pob2016, is for the 2016 Population of the Municipality. Column “ZAT EMIT” is a reference zoning system from an old study. “ZAT CARNET” is the proposed number of zones for CARNET Virtual Mobility Lab model. The resulting number of proposed zones is 628. Columns “Pob/ZC” and “Pob/ZCstdev” correspond, respectively, to the average population per zone in the proposed TAZ and its standard deviation satisfying the proposed balancing criteria.

Once the TAZs have been defined the next step consist in its translation in terms of a shape file delimiting the geographic location and extension of each TAZ, as shown in Block (5) in Figure 11. We are then in conditions of putting to work the “Data Driven Model Building” methodology whose conceptual workflow diagram has been depicted in Figure 9. Figure 11 illustrates the application of the first steps of this methodology, using the available Visum functions and utilities, to the first phase in the building the Visum model of Barcelona for the “Virtual Mobility Lab”:

(1) Visum Background of target area (2) HERE Map Data imported into Visum (3) Adding GTFS Public Transport Data

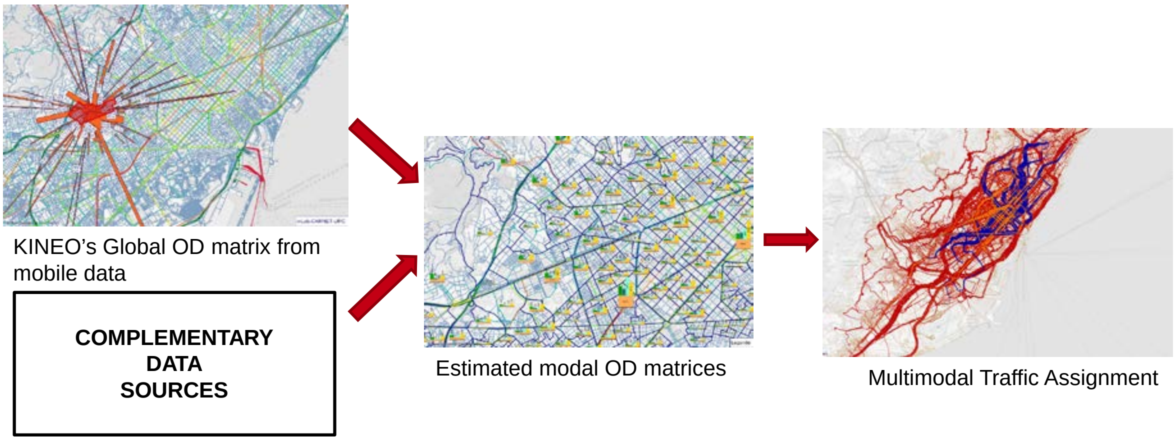


(4) Visum Model of PT (All Modes) (5) Importing TAZ into Visum Model (6) Automatic Generation of Centroids and Connectors

Figure 11. Application of the “Data Driven Model Building” methodology to the first phase of building the Visum model of Barcelona for the “Virtual Mobility Lab”

(1) The Visum Background of the selected target area is imported into Visum
(2) This background is used to import into it the HERE map data sets to build the part of the supply model corresponding to the road network of the target area. The road network supply model can be generated importing in Visum the data sets of different GIS maps, for the data driven model building process it is relevant the quality of the data sets in terms of the information related to the transportation attributes (number of lanes of road links, turnings at intersections, speed limit on links, road hierarchical classification, etc.) obviously the richer and more accurate the data the higher the quality of the directly built supply model, and lesser the amount of manual editing to fine tune and complete the supply model.
(3) Public transport supply model can be generated through a similar process importing the public transport networks from the available GTFS files, which usually contain the definition of the public transport lines in terms of stops, lines served at each stop, frequencies, etc. Again, the higher, and more accurate, the quality of the information contained in the GTFS files, the lesser the amount of editing necessary to fine tune and complete the public transport supply model.
(4) GTFS files do not directly provide the definition of the public transport lines in terms of the routes, that is the street links of each route, this a task realized with the corresponding Visum utilities, as shown in this block depicting the Visum public transport network for all transport modes operating in the target area: private vehicles, buses, metro, railways and tramways in this case.
(5) The supply model is then merged with the TAZs importing into Visum the corresponding shape file
(6) The supply model is then completed, and prepared to work in conjunction with the demand model generating the dummy nodes and links representing, respectively for each TAZ, the centroids, origins and destinations of them transport demand, and the connectors, injecting this demand into the supply model and removing it at destinations.

The second phase in the data driven model building process correspond to the generation of the demand model, as illustrated in Figure 12.



KINEO’s Global OD matrix from mobile data

Estimated modal OD matrices

Multimodal Traffic Assignment

Figure 12. Phase 2 of the Data Driven Building Model process: building the demand model

Household surveys are typical data sources for the OD matrices in conventional transport planning studies however, there is a wide agreement in that the new ICT data sources can become a valid alternative. An extensive research has been conducted in recent years, especially focused in the exploitation of mobile phone data for mobility analysis, examples of that could be the references Friedrich et al. (2010), Çolak et al. (2015), Gundlegård et al. (2015), Chen et al. (2016), Jiang et al. (2016). In some cases, García-Albertos (2016), the research work become the support of commercial available products, as in the case of the company KINEO that uses the mobile phone data from the Call data Records of the Orange telephone operator to generate OD matrices. An agreement with KINEO in the CARNET's framework supplied the data of a global OD matrix for the target area. Table 2 summarizes the aggregated trip matrix from-to all the municipalities in the target area, as a global matrix it accounts for the total number of trips, independently of the mode used, not distinguishing by transport modes. The corresponding disaggregated OD matrix has been the primary input for building the transport demand model in phase 2, as depicted in Figure 12.

Municipality	Badalona	Barcelona	Castelldefels	Cornellà de Llobregat	Esplugues de Llobregat	Gavà	Hospitalet de Llobregat	Montcada i Reixac	Montgat	Prat de Llobregat	Sant Adrià de Besòs	Sant Boi de Llobregat	Sant Feliu de Llobregat	Sant Joan Despí	Sant Just Desvern	Santa Coloma de Gramenet	Tiana	Viladecans	Total
Badalona	332219	110064	332	1024	7728	3669	1496	799	219	372	47778	5373	474	1126	438	3886	33305	351	**550653**
Barcelona	110557	4795769	15127	37150	27257	3522	53679	24720	9761	11870	88291	3605	15967	38564	13467	209700	55112	13519	**5527637**
Castelldefels	410	15226	74380	743	69	15	3424	3369	270	327	135	23	8194	1562	23141	3198	94	518	**135098**
Cornellà de Llobregat	851	36699	700	34026	235	48	2194	2714	1790	10820	465	62	1228	18872	849	35377	258	5643	**152831**
Esplugues de Llobregat	7645	26665	84	347	32025	92	357	257	108	104	7091	141	165	356	116	970	933	141	**77597**
Gavà	3614	3066	9	59	114	1370	25	11	0	7	465	1555	18	43	18	135	355	26	**10890**
Hospitalet de Llobregat, l'	1438	52892	3443	2082	320	56	98299	9951	1187	698	670	56	7745	6733	5307	13345	492	1963	**206677**
Montcada i Reixac	768	25008	3416	2705	237	16	10120	117777	5806	2959	329	30	13606	11896	4643	8836	197	9686	**218035**
Montgat	195	11017	279	1769	82	7	1338	5848	26699	7994	118	10	652	3903	355	3281	98	7025	**70670**
Prat de Llobregat, el	392	11150	315	10518	105	12	872	3037	8270	8517	189	13	439	6007	277	3259	116	9025	**62513**
Sant Adrià de Besòs	48173	87392	143	642	7140	536	710	273	112	208	113529	710	165	536	176	1844	3999	208	**266496**
Sant Boi de Llobregat	5509	3462	21	79	158	1580	66	29	2	20	633	1248	23	40	29	118	340	17	**13374**
Sant Feliu de Llobregat	470	16005	8553	1158	206	38	7664	13363	635	475	202	32	89222	2819	26339	5408	166	971	**173726**
Sant Joan Despí	1122	39439	1606	18331	407	43	6947	12569	3721	5685	513	53	2725	91402	1753	35969	405	17062	**239752**
Sant Just Desvern	381	13171	23552	865	117	15	5327	4750	382	285	156	15	26417	1633	37958	3823	106	458	**119411**
Santa Coloma de Gramenet	3721	209231	3064	34830	965	131	14058	9135	2967	3220	1651	135	5498	36706	3859	318534	1100	4257	**653062**
Tiana	33208	56402	90	246	764	320	506	189	83	103	3902	328	185	335	89	1154	17342	79	**115325**
Viladecans	364	13894	485	5823	140	20	1838	9754	7384	8703	142	15	1018	17119	502	3990	117	12630	**83938**
Total	**551037**	**5526552**	**135599**	**152397**	**78069**	**11490**	**208920**	**218545**	**69396**	**62367**	**266259**	**13404**	**173741**	**239652**	**119316**	**652827**	**114535**	**83579**	**8677685**

Table 2. Summary global OD matrix from-to each municipality in the target area from Orange mobile phone data

To generate the proper multimodal demand model KINEO's data must be fused with data from other data sources, as indicated in Figure 12, to generate the suitable modal splits. We have used this experience to develop an ad hoc methodology whose conceptual diagram is depicted in Figure 13.

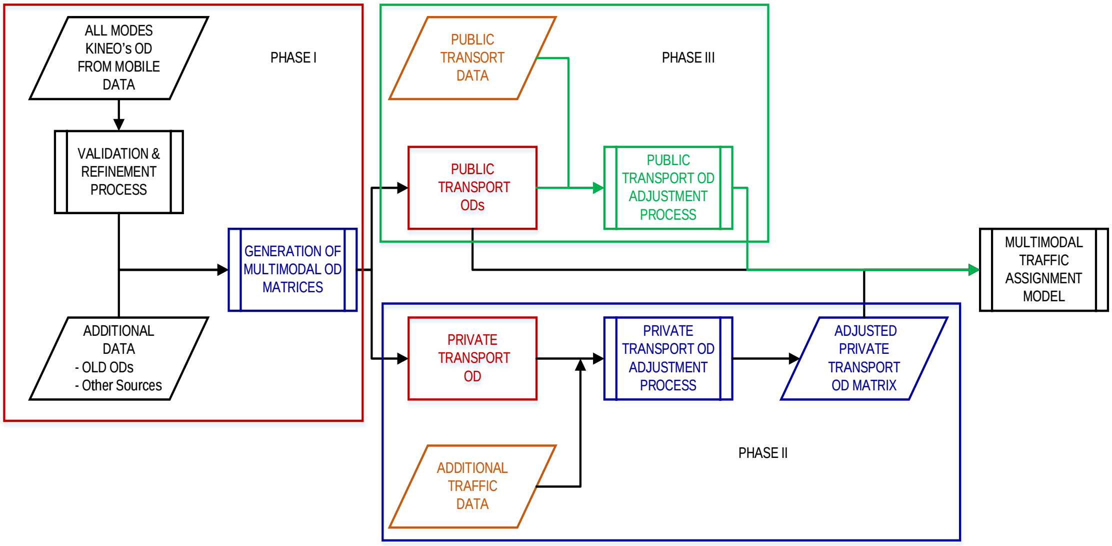


Figure 13. Methodological framework for the generation of multimodal OD matrices from mobile phone data and other transport data sources

In synthesis the process consists of three phases:

- PHASE I: the seminal OD matrix from mobile phone data is subject to a structural analysis for validation and, if necessary, repairing, to be consistent with the underlying transport system. Once the validation process is completed the global OD matrix must be split into as many modal OD submatrices fusing it with data from other sources, as for instance, modal splitting parameters from previous studies, statistical data sources, etc.
- PHASE II. Can consist of a refinement and adjustment of the OD matrix for private transport when other traffic data are available, as for example, link flow counts, travel time measurements between pairs of Bluetooth antennas in the road network, GPS tracking of a sample of vehicle in the target area, etc. This is also a fertile field of research, Barcelo and Montero (2015), or Antoniou et al. (2015) are just references of the progress in this domain.
- PHASE III, could be similar to Phase II for public transport when additional public transport data is available, i.e. ticketing. An example of what could be done if specific public related ICT measurements are available can be found in Montero et al. (2016).

An added value of ICT data, with respect to data from conventional sources, is that they provide a straightforward time variability of the transport demand, as shown in Figure 14, depicting the hourly percent distribution of the transport demand in the target area. That means that the methodological process described above can be repeated for selected time intervals, as shown in Figure 14, and get in this way a family of OD matrices for different time of the day what enables a more detailed analysis.

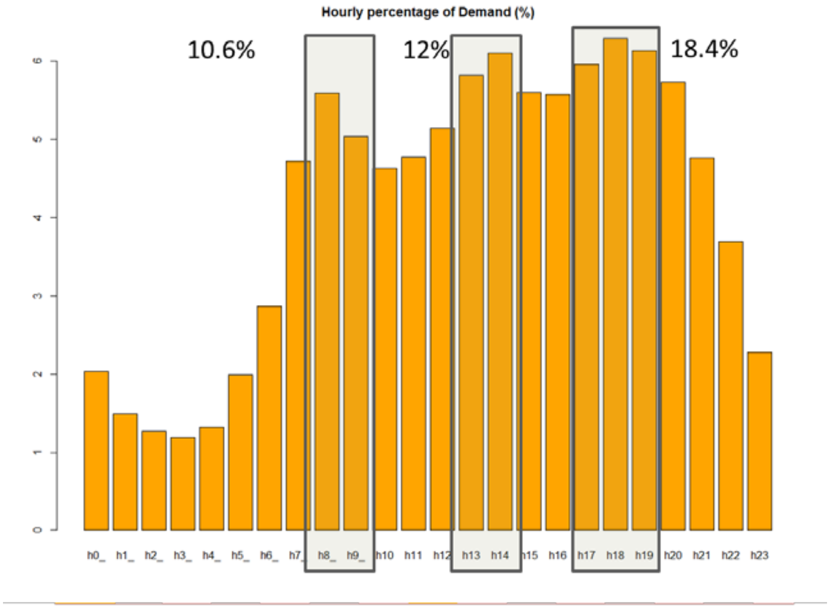


Figure 14. Hourly variability of the global demand during the day

The output of these steps is a family of modal OD matrices for a selected time period, as shown in Figure 12, which conform the input to a multimodal traffic assignment procedure, whose results are also shown in Figure 12.

The process must be completed by the corresponding calibration of the traffic assignment model in order to ensure the quality of the results and therefore their usability in decision making processes.

5. A use case of “MaaS Modeler Scenario”

5.1 PTV MaaS Modeller

In Section 3 analyzing the dynamics of change in urban mobility we have already considered MaaS has one of the major forces driving that change, and shared mobility in its various forms, as one the main components of MaaS. In addition to these consideration it would worth add some of the main conclusions of the report “Exploring the Opportunity for Mobility as a Service in the UK”, from Transport Systems Catapult (2016). The report, after underlining the considerable scope of change that MaaS represents, identifies some key finding “that can be considered by policy makers when examining MaaS opportunity”, that we quote below.

- MaaS COULD CHANGE OUR TRAVEL BEHAVIOUR
    - The impact of MaaS is unknown.

    - MaaS could result in more journeys and distances travelled by car or potentially less; it could support national and local transport policy or challenge it, but further research is needed.
    - MaaS offers the potential to address many of the transport challenges facing society by engaging new business models and technology – it offers policy makers an opportunity for achieving travel behavior change and managing travel demand.
- MaaS COULD CHANGE THE TRANSPORT SECTOR
    - Existing transport operators face significant opportunities but also threats from MaaS growth. Transport operators may move from a business to consumer model, to focusing on supplying transport capacity direct to MaaS providers
    - MaaS has the potential to provide transport authorities with rich data to help them manage their transport systems and networks
- MaaS GROWTH COULD BENEFIT FROM POLICY INTERVENTION
    - There are significant barriers that are preventing MaaS growth and policy interventions may be required to address them.
    - The benefits of MaaS success are compelling and there are many potential pathways for policy makers to engage the private sector to achieve desired MaaS outcomes.
    - MaaS value propositions can be developed to suit a range of target customers, however the private sector may develop business models that do not align with existing policy goals.

How to properly address all these questions? How to assist urban policy makers as private sector to find the right answers? This has been the main objective for developing “PTV MaaS Modeller”, a planning tool supported by PTV Visum and PTV X-Server, specifically suited to analyze:

- How will MaaS change urban transport?
- Whether will MaaS complement or compete with classical transit?
- At what times and on which routes do MaaS offer attractive alternatives?
- How do people will use MaaS?
- How to design MaaS in terms of fleet size, operating area and fares?

PTV MaaS Modeller has been designed and implemented purposely addressing to cases:

- The Operator Business Case, to provide answers to relevant questions in defining a business model, assisting in calculating the business performance of the operator’s fleet
    - How to model MaaS fleet operations
    - Reporting fleet operational KPIs
- The City Business Case, to calculate the impact on, and the performance of the city
    - Modelling the entire multimodal traffic system performance
    - Estimating the congestion impact
    - Evaluating the competition with other modes
    - Capturing the business model potential
    - Integrating MaaS in existing models and data provided by cities
    - Estimating the society impact

Maas Modeller is a web application running in the Microsoft Azure Cloud.

Figure 15 displays the workflow of MaaS Modeller. The driving engine is a Visum Model of the city, in other words a “Digital replica of the city” accounting for:

- A detailed and accurate model of the city’s transport supply
    - City road networks
    - City public transport networks
    - Key city hubs and interchanges
- A detailed and accurate model of the multimodal city’s travel demand
- A suitable model of typical traveler behavior, e.g. mode choice

A specific version of GUI enables the user to define the service specifications as design factor of the simulation experiment to evaluate performance in terms of the defined KPIs. Examples of these design factors can be: pre-booking time, departure time, detour time, fare, vehicle capacity, maximum fleet size, boarding/alighting time, pick-up/drop-off points, geographical coverage, etc.

The defined MaaS Demand consists of a set of trip requests distributed in time and space which, along with the data provided by an assignment performed with the Visum model of the city, e.g. a skim distance matrix, are input in an adapted version of

PTV X-SERVER, that acting as route server calculates the feasibility of the services, and the most suitable routes according with the defined values of the design factors, and calculates the KPIs that will support the decision making process.

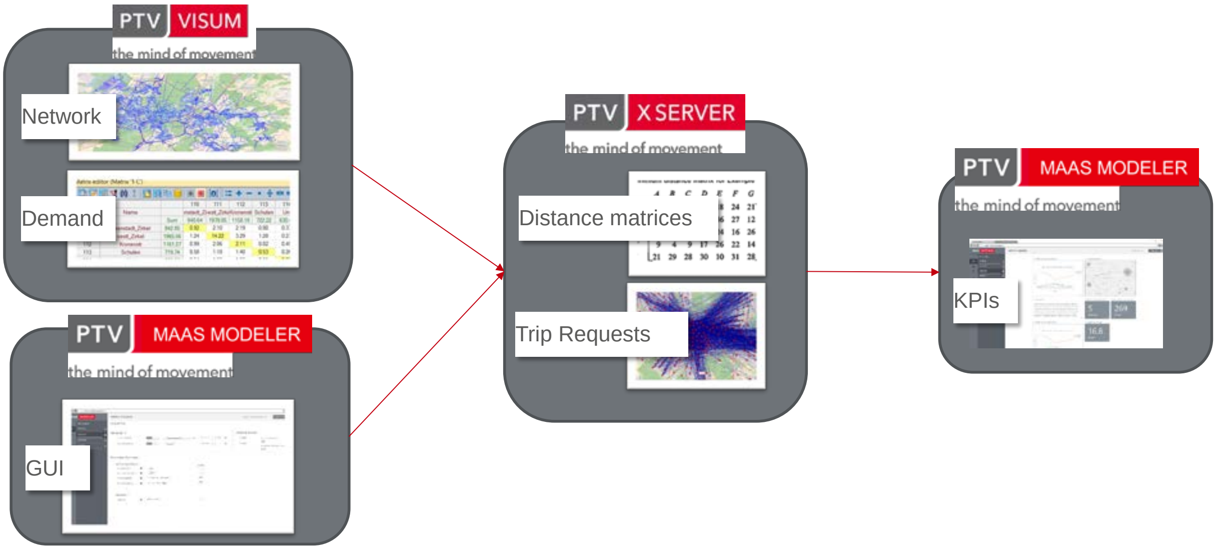


Figure 15. PTV MaaS Modeller workflow

Outputs provided by MaaS Modeller in terms of the selected KPIs can be of three types, measuring respectively:

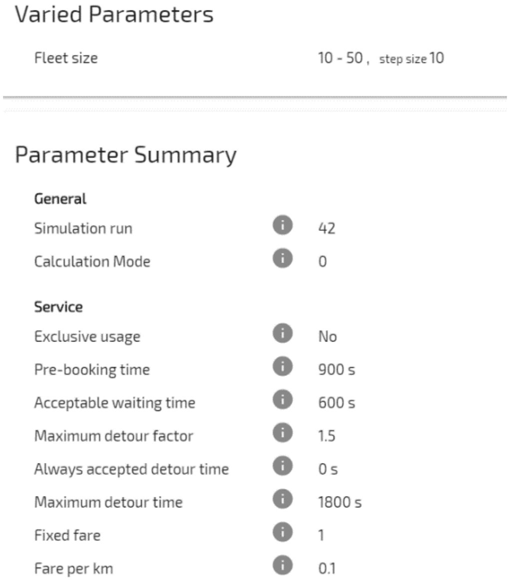
- Operational efficiency
  - Actual number of vehicles used
  - Schedule for each vehicle
  - Estimated number of vehicles required
  - Individual or total KPIs:
    - Operating time
    - Service time
    - Idle time
    - Drive time
    - Board/alight time
    - Vehicle wait time
  - Operating cost – time-dependent, distance-dependent, fixed, total
  - Revenue
- Service quality in terms of individual or total KPIs:
  - Waiting time
  - Travel time
  - Journey time
  - Revenue
  - Unserved demand
  - Maximum number of other passengers in vehicle during trip
- Impact on society
  - Congestion impacts
  - Energy requirements
  - Potential for decarbonisation
  - Potential shift from existing modes
  - Potential reduction in car trips and subsequent consequences on parking requirements
  - Impact on existing transport providers

5.2 Implementing PTV MaaS Modeller with the "Virtual Mobility Lab Simulation Kernel"

The MaaS Modeller workflow defined in Figure 15 has been implemented as a proof of concept with the Visum Multimodal Model of Barcelona implemented as "Virtual Mobility Lab Simulation Kernel", and its potential use has been analyzed in a set of scenarios defined as follows:

Scenario 1: Barcelona Central Business District

The first scenario consists on setting on a fleet of Sharing Vehicles on Barcelona's main district, Eixample. In this case, MaaS modeler environment has been used to determine the optimal fleet size. In Figure 16, the dashboard where one can set the parameters for the scenarios' management is shown. There are a big number of parameters that can be set as a fixed number or as a varied parameter to generate different scenarios.



Varied Parameters

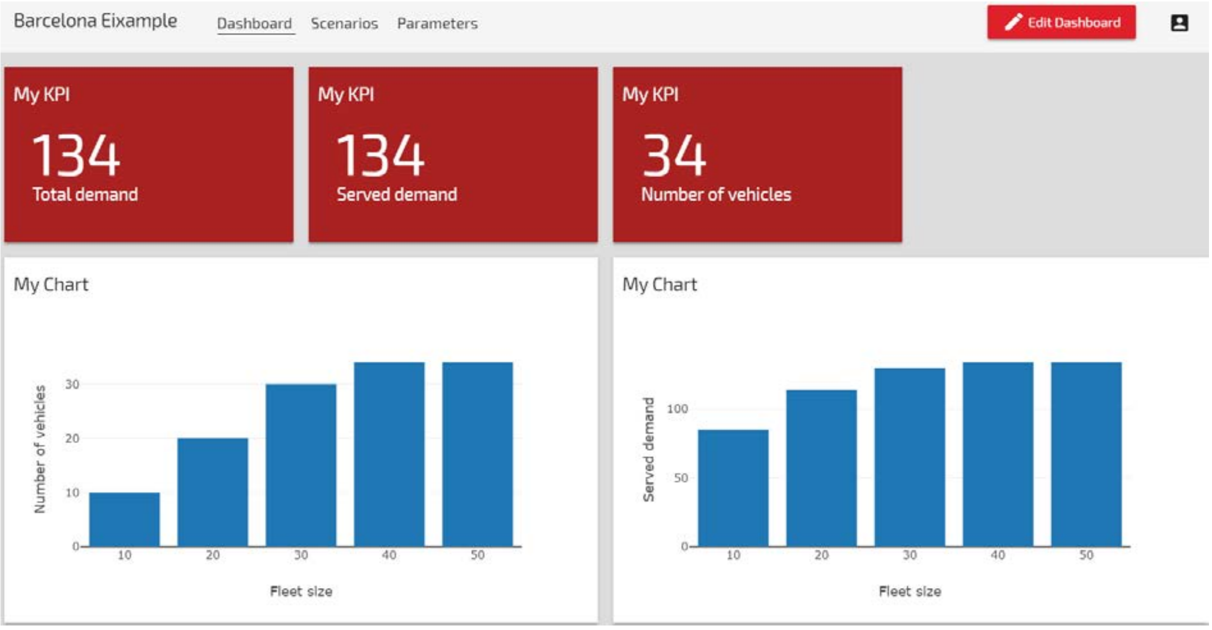
Fleet size	10 - 50 , step size 10

Parameter Summary

General	
Simulation run	42
Calculation Mode	0
Service	
Exclusive usage	No
Pre-booking time	900 s
Acceptable waiting time	600 s
Maximum detour factor	1.5
Always accepted detour time	0 s
Maximum detour time	1800 s
Fixed fare	1
Fare per km	0.1

Figure 16. PTV MaaS Modeller Parameters Inizialiation

In this particular example, only the Fleet Size is a varied parameter and simulation results can be fully analyzed in the KPI's and graphs' dashboard that PTV MaaS Modeller allows to build. In Figure 17, this example's dashboard is shown. With this tool, the user can check, for instance, the optimal number of vehicles in order to serve the requested demand.



Barcelona Eixample

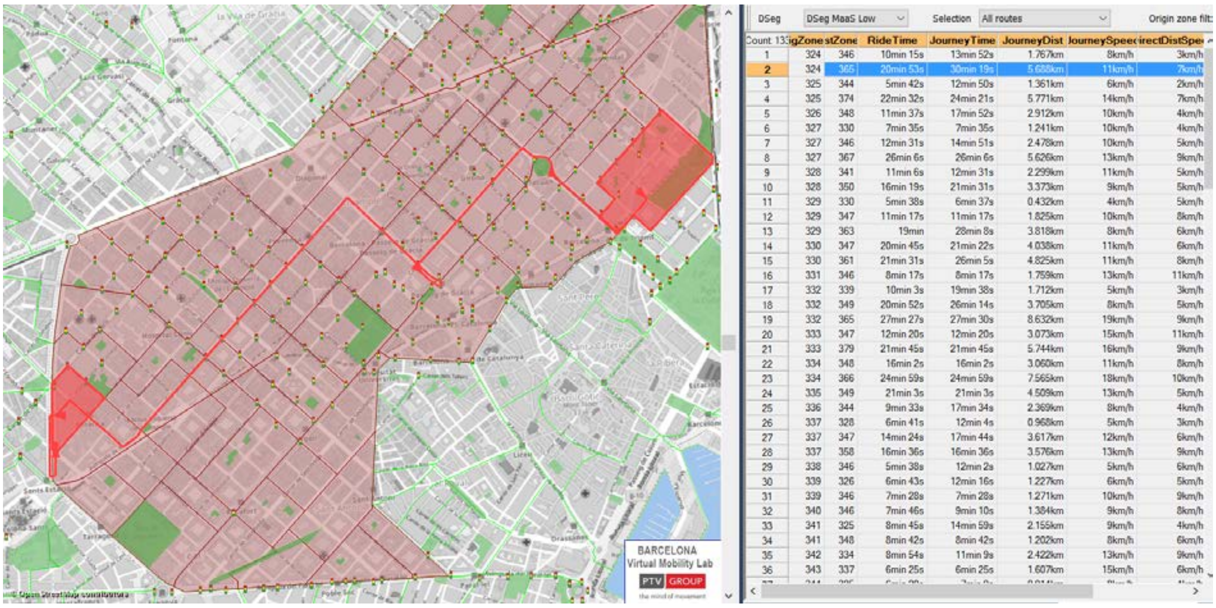
My KPI
134
Total demand

My KPI
134
Served demand

My KPI
34
Number of vehicles

Figure 17. PTV MaaS Modeller KPI's and graphs' dashboard

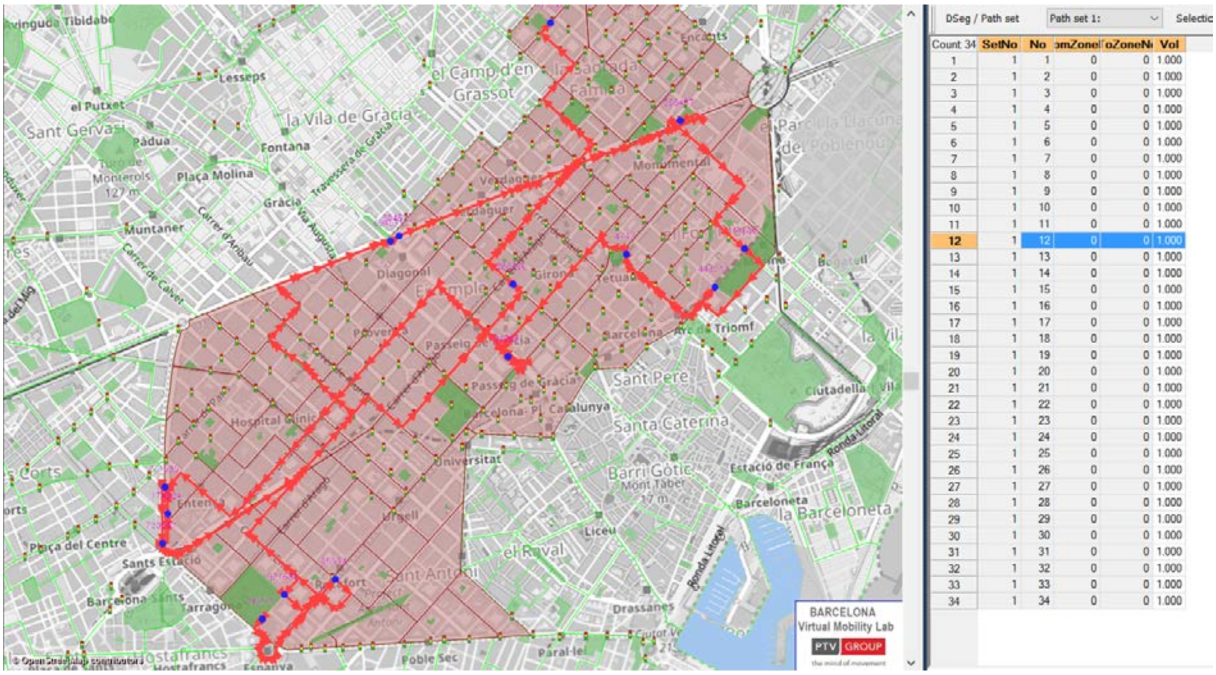
Other nice features allow to download a determined scenario to PTV VISUM in order to check further results and check the demand requests for the service, Figure 18, or the vehicle route during all the journey with the different stop points, Figure 19.



DSeg: DSeg MaaS Low Selection: All routes Origin zone filt

Count 13	igZone	stZone	RideTime	JourneyTime	JourneyDist	JourneySpee	irectDistSpe
1	324	346	10min 15s	13min 52s	1.767km	8km/h	3km/h
2	324	365	20min 53s	30min 19s	5.688km	11km/h	7km/h
3	325	344	5min 42s	12min 50s	1.361km	6km/h	2km/h
4	325	374	22min 32s	24min 21s	5.771km	14km/h	7km/h
5	326	348	11min 37s	17min 52s	2.912km	10km/h	4km/h
6	327	330	7min 35s	7min 35s	1.241km	10km/h	4km/h
7	327	346	12min 31s	14min 51s	2.478km	10km/h	5km/h
8	327	367	26min 6s	26min 6s	5.626km	13km/h	9km/h
9	328	341	11min 6s	12min 31s	2.299km	11km/h	5km/h
10	328	350	16min 19s	21min 31s	3.373km	9km/h	5km/h
11	329	330	5min 38s	6min 37s	0.432km	4km/h	5km/h
12	329	347	11min 17s	11min 17s	1.825km	10km/h	8km/h
13	329	363	19min	28min 8s	3.818km	8km/h	6km/h
14	330	347	20min 45s	21min 22s	4.038km	11km/h	6km/h
15	330	361	21min 31s	26min 5s	4.825km	11km/h	8km/h
16	331	346	8min 17s	8min 17s	1.759km	13km/h	11km/h
17	332	339	10min 3s	19min 38s	1.712km	5km/h	3km/h
18	332	349	20min 52s	26min 14s	3.705km	8km/h	5km/h
19	332	365	27min 27s	27min 30s	8.632km	19km/h	9km/h
20	333	347	12min 20s	12min 20s	3.073km	15km/h	11km/h
21	333	379	21min 45s	21min 45s	5.744km	16km/h	9km/h
22	334	348	16min 2s	16min 2s	3.060km	11km/h	8km/h
23	334	366	24min 59s	24min 59s	7.565km	18km/h	10km/h
24	335	349	21min 3s	21min 3s	4.509km	13km/h	5km/h
25	336	344	9min 33s	17min 34s	2.369km	8km/h	4km/h
26	337	328	6min 41s	12min 4s	0.968km	5km/h	3km/h
27	337	347	14min 24s	17min 44s	3.617km	12km/h	6km/h
28	337	358	16min 36s	16min 36s	3.576km	13km/h	9km/h
29	338	346	5min 38s	12min 2s	1.027km	5km/h	6km/h
30	339	326	6min 43s	12min 16s	1.227km	6km/h	5km/h
31	339	346	7min 28s	7min 28s	1.271km	10km/h	9km/h
32	340	346	7min 46s	9min 10s	1.384km	9km/h	8km/h
33	341	325	8min 45s	14min 59s	2.155km	9km/h	4km/h
34	341	348	8min 42s	8min 42s	1.202km	8km/h	6km/h
35	342	334	8min 54s	11min 9s	2.422km	13km/h	9km/h
36	343	337	6min 25s	6min 25s	1.607km	15km/h	6km/h

Figure 18. Results Analysis in PTV VISUM: Requested demand with details



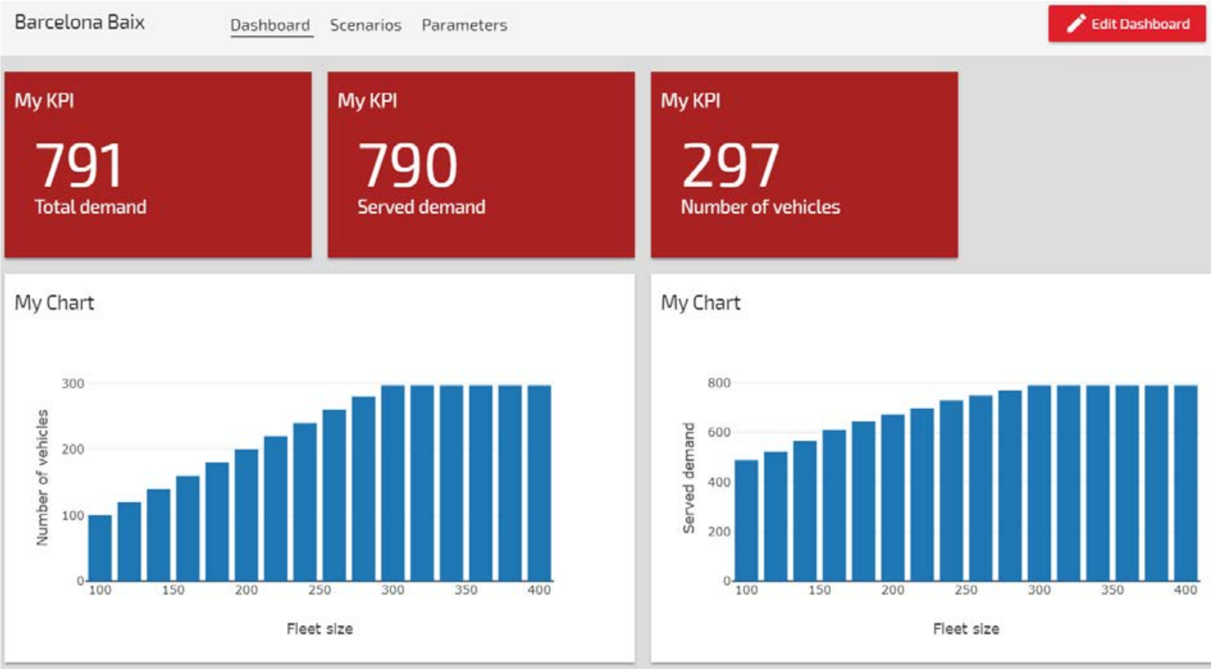
DSeg / Path set: Path set 1: Selectio

Count 34	SetNo	No	omZone	oZoneN	Vol
1	1	1	0	0	1.000
2	1	2	0	0	1.000
3	1	3	0	0	1.000
4	1	4	0	0	1.000
5	1	5	0	0	1.000
6	1	6	0	0	1.000
7	1	7	0	0	1.000
8	1	8	0	0	1.000
9	1	9	0	0	1.000
10	1	10	0	0	1.000
11	1	11	0	0	1.000
12	1	12	0	0	1.000
13	1	13	0	0	1.000
14	1	14	0	0	1.000
15	1	15	0	0	1.000
16	1	16	0	0	1.000
17	1	17	0	0	1.000
18	1	18	0	0	1.000
19	1	19	0	0	1.000
20	1	20	0	0	1.000
21	1	21	0	0	1.000
22	1	22	0	0	1.000
23	1	23	0	0	1.000
24	1	24	0	0	1.000
25	1	25	0	0	1.000
26	1	26	0	0	1.000
27	1	27	0	0	1.000
28	1	28	0	0	1.000
29	1	29	0	0	1.000
30	1	30	0	0	1.000
31	1	31	0	0	1.000
32	1	32	0	0	1.000
33	1	33	0	0	1.000
34	1	34	0	0	1.000

Figure 19. Results Analysis in PTV VISUM: Vehicle Route during the journey with stop points

<u>Scenario 2: Barcelona Airport Area</u>

The second example is also an experiment to determine the fleet size for a service of Vehicle Sharing around the airport and L9, the special metro line which arrives to the airport. In this case, many experiments varying the fleet size has been done to see if it is able to serve the requests for the service. In Figure 20, the KPIs and the graphs for this scenario are shown, where the ideal fleet size depending on the percentage of the served requests can be set.



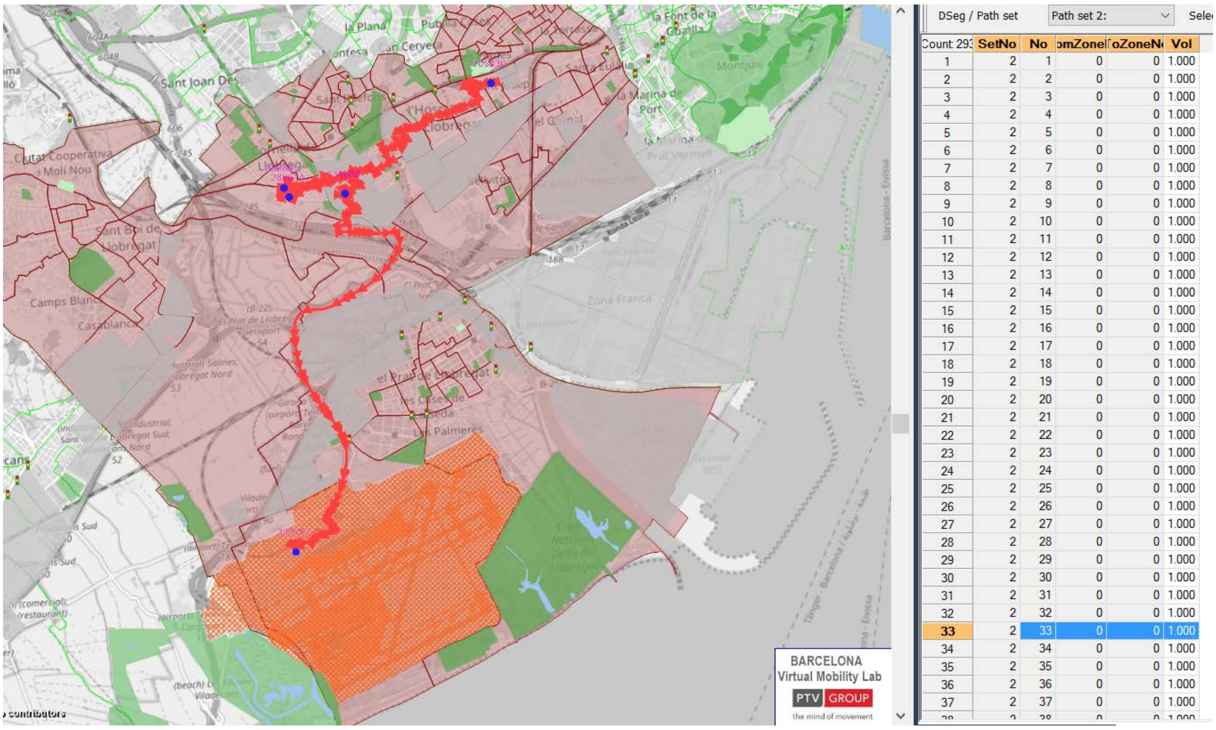
My KPI
791
Total demand

My KPI
790
Served demand

My KPI
297
Number of vehicles

Figure 20. PTV MaaS Modeller KPI's and graphs' dashboard

As in the first example, one can download the scenario to PTV VISUM and check further results such the ones shown in Figure 21.



DSeg / Path set   Path set 2:   Sele

Count: 293	SetNo	No	omZoneN	oZoneN	Vol
1	2	1	0	0	1.000
2	2	2	0	0	1.000
3	2	3	0	0	1.000
4	2	4	0	0	1.000
5	2	5	0	0	1.000
6	2	6	0	0	1.000
7	2	7	0	0	1.000
8	2	8	0	0	1.000
9	2	9	0	0	1.000
10	2	10	0	0	1.000
11	2	11	0	0	1.000
12	2	12	0	0	1.000
13	2	13	0	0	1.000
14	2	14	0	0	1.000
15	2	15	0	0	1.000
16	2	16	0	0	1.000
17	2	17	0	0	1.000
18	2	18	0	0	1.000
19	2	19	0	0	1.000
20	2	20	0	0	1.000
21	2	21	0	0	1.000
22	2	22	0	0	1.000
23	2	23	0	0	1.000
24	2	24	0	0	1.000
25	2	25	0	0	1.000
26	2	26	0	0	1.000
27	2	27	0	0	1.000
28	2	28	0	0	1.000
29	2	29	0	0	1.000
30	2	30	0	0	1.000
31	2	31	0	0	1.000
32	2	32	0	0	1.000
33	2	33	0	0	1.000
34	2	34	0	0	1.000
35	2	35	0	0	1.000
36	2	36	0	0	1.000
37	2	37	0	0	1.000

Figure 21. Results Analysis in PTV VISUM: Vehicle Route during the journey with stop points

6. Concluding remarks

The main thesis supported in this report is that the future urban mobility will not only depend of the ICT and the automotive technology evolution, a key factor shaping our societies but not the only one, other non-technological factors will also play relevant roles, technology will then become a necessary but not sufficient component of that future mobility. This report has explored some of these sufficient components, and their interrelationships with technology. Land use, urban forms, and their relationships with transport infrastructure are also determinant on where, how and when citizens move to accede to the locations where social activities happen. Accessibility to activities becomes then the driving force of why and when people moves, technology usually provides the support on how to move, when physical journeys are necessary, or how to accede to the activities without physically moving, since current technological advances make it possible. This is inducing societal changes, namely in the way individual motorized mobility is perceived, prompting what is being considered a paradigm shift, from car ownership to vehicle usage, materialized in the new emergent mobility concepts and business models known as "Mobility as a Service" (MaaS). This report also addresses crucial questions of which is the way in which these emerging mobility services will work better in the benefit of citizens? How they should cooperate with public transport services? Will they free public space, how much, how should it be used? Etc. The report hold the thesis that proper answers to these questions can be provided by suitable new transport planning tools. The Virtual Mobility Map is just an example of such tools, whose engine is a Visum model of a city, supporting new utilities purposely designed to address these questions. To probe this assertion it discusses a use case of implementation of the Virtual Mobility Lab in Barcelona, and integrates it with one of the new tools, the PTV MaaS Modeller, to implement and evaluate specific instances of MaaS.

7. Additional remarks

The first part of this report is based on the material used in my presentations as Academic Director, in CARNET Partners meetings and CARNET Urban Mobility Challenges symposiums, held in 2015 and 2016.

The second part uses material from two internal CARNET reports:

Borrador para una propuesta del proyecto modelo de simulacion de tráfico de la ciudad de barcelona (Virtual Mobility Lab BCN): objetivos a corto y medio plazo. J. Barceló, Academic Director of CARNET (28.08.2016)

Proyecto Virtual Mobility Lab BCN: a common tool to support CARNET mobility projects, J. Barceló, Academic Director of CARNET (19.06.2016)

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