HARMONY

MODELLING TOOLS FOR SUSTAINABLE URBAN MOBILITY PLANS IN THE NEW MOBILITY ERA

Imprint

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Title: Modelling tools for Sustainable Urban Mobility Plans in the new mobility era

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Executive summary

These guidelines are aimed at providing local planning authorities guidance on transport modelling applications in their Sustainable Urban Mobility Plan (SUMP) implementation process. They build on the concept of SUMP, as outlined by the European Commission's Urban Mobility Package[1] and described in detail in the European SUMP Guidelines 2.0 (second edition)[2].

As mentioned in the SUMP Guidelines, *a transport model can be used to generate reliable and consistent input to the SUMP process, specifically in certain planning stages such as scenario development, measure appraisal and selection, and monitoring. Modelling results help to predict the impact of different combinations of policies and measures, taking into account the complex interactions and potential reinforcing or rebound effects, thereby helping to define the most effective integrated packages. Beyond their use to define the baseline scenario, they also enable regular monitoring of changes in the transport system during the implementation phase to assess whether you are on track or if you need to react and adapt your actions*.

These guidelines will help public authority planners and practitioners from various levels of government (from local/city level to regional, national, and European), with a broad variation in their level of expertise in relation to mobility and planning, **to answer to the following questions**:

- What transport models are?
- What transport models can do?
- What are their challenges and limits?
- Is a transport model really needed to draft a SUMP?
- What kind of model should be used?
- What are the development steps of a model? When such steps are to be taken within the SUMP planning cycle?
- What are the roles and responsibilities when developing a transport model to support a SUMP?

Transport models are simplified representations of transport supply, transport demand and their interaction in a given context (e.g., mobility within a city). However, the purpose of building transport models is not to create simple versions of existing conditions: transport models are built to simulate the effect of modifications of such existing conditions.

1 Annex 1 of COM (2013) 91.

2 Rupprecht Consult (editor), Guidelines for Developing and Implementing a Sustainable Urban Mobility Plan, Second Edition, 2019.

Mobility, as well as the wider social, economic, demographic context, is continuously changing. Change makers are background conditions (e.g., demographic trends, economic growth); behavioural adaptations (e.g., preference for sustainable solutions) and policy interventions. Some of these sources of change correspond to modifications of some elements of transport models: input variables or parameters. Therefore, by changing input variables and parameters, alternative conditions can be simulated and the resulting effect on mobility can be estimated. In a nutshell, **transport models allow to do experiments, anticipate the effect of exogenous trends, and assess policy measures**.

However, **transport models cannot do everything**. Their responses are necessarily affected by the explanatory power of the theory underlying algorithms and parameters, by the quality of data, by the amount of time and resources that are devoted to their development. Transport models are not one-fits-for-all solutions providing estimations on everything, but useful tools which should be built and used for the specific purposes they are capable to handle being aware that they cannot invent solid responses out of limited knowledge.

A **transport model is not necessarily the only method to estimate the impact of policy measures and support the development of a SUMP**. Alternative, simpler, methods are realistic options in case of simple context, which are common in smaller towns and cities, where, furthermore, data, time and resources are often limited. **In more complex contexts, without a transport model, only rough and often qualitative indicators can be estimated**. So, in those contexts, the conditions where a model is not applied are also conditions where planning is quite poor. This conclusion does not mean that using a transport model ensures that the plan will be a high quality one. Models are tools and the results depend ultimately on how they are used rather than on their theoretical potential.

Assuming that the application of a transport model is considered the appropriate way to proceed, the following step is **selecting the type of model**. There are different types of transport models, more or less articulated, with different capabilities. One may wonder which type of model is the most appropriate for supporting a SUMP. Again, the answer depends on case by case. Considering some aspects can help to choose.

Are transport models useful tools for developing SUMPs? Yes, they are. Are there some types of transport model more useful than others to support the development of SUMPs? Yes, there are.

The answers to these to questions are undisputable. Nevertheless, they do not bring to a unique recommendation, because **specific circumstances matter**. Building transport models is not a quick and cheap task, it requires expertise and the availability of data. When the mobility context is reasonably simple and the content of the planning is necessarily simple as well, a transport model is not necessarily required. When resources, time, expertise, and data is poor or lacking, developing a transport model is simply unfeasible.

Transport models are not crystal balls opening a sight on the actual future. They are tools based on simplified representations of conditions, options, behaviours. They depend on information and cannot transform poor data into reliable forecasts. Using transport models means doing an effort to get estimations. And estimations inherently include some degree of uncertainty. Notwithstanding, it should be clearly understood that, whenever the planning context is articulated, any alternative to models can only provide coarser, more uncertain estimations than those of models or even only vague qualitative considerations. There is nothing less demanding than models but providing the same, or even better, results of models when the object of the analysis is complex.

Developing a model is a process requiring skills, data, time, and resources. These guidelines provide a closer glance to this process and describe the **five main phases**: design, data collection and elaboration, implementation, calibration, application.

As it comes to **roles and responsibilities**, transport models are developed by experts (**modellers**) holding the required knowledge and experience as well as the necessary specialised software. Nevertheless, especially when the transport model is developed for a local administration to support an urban mobility plan, other actors play a role. One actor is the **local authority**, which ultimately should be the owner of the model and holds the political responsibility for the content of the SUMP. Another actor is the **planner team**, which is the technical arm of the local authority regarding the definition of the content of the SUMP. A third actor consists **of stakeholders**: transport operators (e.g. the providers of urban and non-urban public transport, car-sharing companies, etc.), specific categories of citizens like cyclists, disabled people, retailers and so on. Stakeholders can be involved in the definition of the SUMP in one form or another as they represent interests that can be affected by the plan.

The main actions and elements essential for implementing transport modelling as part of **the phases of the SUMP cycle** are finally introduced. We identify crucial aspects and recommend concrete actions to the general guideline cycle, to encourage urban planners to better integrate transport modelling in their SUMPs.

The document has been drafted within the **Harmony project** (www.harmony-h2020.eu), within the WP8 (Process assessment, SUMPs recommendations and roadmaps) activities, and takes advantage from the project achievements related to the development of the Harmony Model Suite and its application to case studies in Rotterdam (NL), Oxfordshire (UK), Turin (IT), Athens (GR).

1. Introduction

These guidelines are aimed at providing to local planning authorities **guidance on the application of transport models in their Sustainable Urban Mobility Plan (SUMP) implementation process**. They build on the concept of SUMP, as outlined by the European Commission's Urban Mobility Package[1] and described in detail in the European SUMP Guidelines 2.0[2].

As mentioned in the SUMP Guidelines, *a transport model can be used to generate reliable and consistent input to the SUMP process, specifically in certain planning stages such as scenario development, measure appraisal and selection, and monitoring. Modelling results help to predict the impact of different combinations of policies and measures, taking into account the complex interactions and potential reinforcing or rebound effects, thereby helping to define the most effective integrated packages. Beyond their use to define the baseline scenario, they also enable regular monitoring of changes in the transport system during the implementation phase to assess whether you are on track or if you need to react and adapt your actions.*

The primary **target audience** for these guidelines are public authority planners and practitioners from various levels of government (from local/city level to regional, national, and European), with a broad variation in their level of expertise in relation to mobility and planning.

3 Annex 1 of COM (2013) 91.

4 Rupprecht Consult (editor), Guidelines for Developing and Implementing a Sustainable Urban Mobility Plan, Second Edition, 2019.

BOX THE CONCEPT OF SUSTAINABLE URBAN MOBILITY PLANS

Sustainable urban mobility planning is a strategic and integrated approach to deal with the complexity of urban transport. Its core goal is to improve the accessibility and the quality of life of citizens by achieving a shift towards sustainable mobility. SUMP advocates fact-based decision-making guided by a long-term vision for sustainable mobility. It requires a thorough assessment of the current situation and future needs and trends, a common vision with strategic objectives, and an integrated set of regulatory, promotional, financial, technical, and infrastructural measures. Implementing these measures to deliver the objectives should also be accompanied by reliable monitoring and evaluation.

In contrast to traditional planning approaches, SUMP particularly emphasises the involvement and cooperation of different levels of government with diverse groups of citizens, stakeholders, and private stakeholders. It also emphasises the coordination of policies between sectors (transport, land use, environment, economic development, social policy, health, safety, energy, etc.).

The revision of the TEN-T Regulation[5] requires that 424 major cities ("cities") on the TEN-T network have sustainable urban mobility plans by 2025, in order to align their mobility developments on the TEN-T network. The SUMPs will contain measures such as the promotion of zero-emission mobility and the greening of the urban fleet.

The document has been drafted within the Harmony project (website: www.harmony-h2020.eu), within the WP8 (Process assessment, SUMPs recommendations and roadmaps) activities, and takes advantage from the project achievements related to the development of the **Harmony Model Suite** and its application to case studies in Rotterdam (NL), Oxfordshire (UK), Turin (IT), Athens (GR).

5 https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=COM%3A2021%3A812%3AFIN

BOX THE HARMONY PROJECT

HARMONY is a (CIVITAS) European project funded by the European Commission within the H2020 Framework Research Programme. Its name stands for "Holistic Approach for Providing Spatial & Transport Planning Tools and Evidence to Metropolitan and Regional Authorities to Lead a Sustainable Transition to a New Mobility Era".

In the context of expanding urbanisation and evolving transport challenges, HARMONY aimed to support public authorities and service providers in transport and spatial planning. The project developed an integrated model suite, i.e. a software-agnostic platform bringing together transport and spatial planning models. Stakeholders from both the public and private sector have been actively engaged in both regional and cross-metropolitan co-creation labs to share their requirements with regards to integration of traditional and new transport modes and services, utilization of new technologies and sustainable regional developments. At the same time, demonstrations with last mile delivery robots, Autonomous Vehicles (AVs) and drones took place in selected metropolitan areas to understand in real-life their requirements providing insights for their simulation within the model suite.

More specifically, the **HARMONY Model Suite (HARMONY MS)** aims to assess the multidimensional impacts of the new mobility concepts and technologies, integrating land-use models (strategic/long-term), people and freight activity-based models (tactical/mid-term), and multimodal network (operational/short-term) models allowing for vertical planning.

The concept of HARMONY is to assist metropolitan areas by providing a state-of-the-art model suite that quantifies the multidimensional impact of various concepts, soft and hard policies on citizens' quality of life, sustainability, economic growth, while identifying the most appropriate solutions and recommending ways to exploit advances in mobility concepts to achieve their goals.

HARMONY's concepts have been applied in six EU metropolitan areas on six TEN-T corridors: Rotterdam (NL), Oxfordshire (UK), Turin (IT), Athens (GR), Trikala (GR), Upper Silesian-Zaglebie Metropolis (PL).

2. What Transport Models are

A model is a simplified representation of some aspects of the real world, like a map is a simplified representation of a geographical area. A model does not capture all details and provides a limited in scope and approximated description of the reality.

However, such a description is manageable, it can be used to analyse the current situation and assess potential alternatives. As an example, dummies used for crash tests can be considered models reproducing individuals; their structure is a good approximation of physical features of human beings when the interest is on the effect of crashes on person's body. Using dummies, the safety of vehicles and driving habits can be measured and the impacts of modifications on the structure of vehicles can be tested. Maps and dummies are physical objects, while models can be virtual: meteorologists use models to describe weather conditions and provide forecasts.

A transport model is a stylised representation of the interaction between mobility demand – i.e. individuals and goods which want/need to move between two locations – and mobility supply[6] – i.e. the infrastructures and the services - that individuals and goods can use for their movements – in a certain spatial context.

Any transport model consists of four basic elements: a description of the spatial context; a description of transport supply; a description of transport demand; a description of the behaviour of demand and supply when they interact to each other. Depending on the type of model, these four elements are described in different forms and at different levels of detail.

2.1. A classification of Transport Models

One main dichotomy is between **microscopic models** and **macroscopic models**. In microscopic models, parameters and mathematical functions are used to describe the behaviour of single individuals or vehicles. Macroscopic models work with segments representing aggregations of individuals or vehicles (e.g., trips by purpose between two zones). Macroscopic models can be further distinguished in two categories. Most of macroscopic models are **network models**, i.e. they include a more or less detailed description of the transport networks (e.g. roads, railways). Other macroscopic models can be not focused on the spatial dimension but rather on functional aspects of the interaction between mobility demand and supply. They can be defined as **strategic models**.

Microscopic models provide a more detailed picture of demand and supply. Therefore, they are suited for studying traffic flows in small study areas (e.g., specific crossroads or part of a city) described in great detail.

6 The terms "demand" and "supply" recall economics. Indeed, a significant part of the theory behind the modelling of mobility has been developed building on economic concepts (e.g. utility).

Macroscopic models are less detailed on this respect and are applied at different geographical scales: the study area of macroscopic transport models can range from a city to a metropolitan area, to a region, to a whole country or more countries (e.g., the whole Europe).

In microscopic and network models, the study area is divided into zones and transport demand is represented in terms of movements between zones. In strategic models the study area can be considered as a whole, or it can be segmented into functional rather than geographical zones (e.g., downtown and outskirts, or urban areas and rural areas). Microscopic and network models include an explicit description of transport networks (i.e., roads, railways, etc.), which in microscopic models is very detailed. A stylised description of transport services (routes, frequency) can also be part of a model. On the other hand, in strategic models transport supply is simply represented by parameters like cost and speed of alternative modes of transport.

It can be readily seen that the three categories of models are quite different to each other. They are suitable for different objectives. The most useful model can be one or another depending on the specific study. Later in this guide, we'll discuss the selection of the appropriate model with reference to the requirements of SUMPs.

TABLE 1 MAIN TRANSPORT MODEL TYPES

Element	Microscopic	Macroscopic - Network	Macroscopic - Strategic
Study area	Usually, a small area divided in a limited number of zones	Variable, from an urban area to groups of countries. Number and size of zones depending on the dimension of the study area.	A specific geographical area of any size or a generic area type (e.g. a metropolitan area, a region, a country). Zones can be defined or not. When defined can be in functional terms (e.g. downtown, outskirts, suburbs) rather than in geographical terms.
Supply	A network representing the available transport infrastructure in the study area (e.g. roads) in great detail (e.g. single lanes with exact width, exact traffic lights sequence, etc.).	A network representing the available transport infrastructures in the study area with a detail level inversely proportional to the size of the study area. Transport services can be described in terms of routes, timetable or frequency	No spatial representation of supply (i.e. no networks). Functional parameters like cost, speed, frequency, etc. are used

Element	Microscopic	Macroscopic - Network	Macroscopic - Strategic
Demand	Single vehicles or individuals moving within or through the modelled network described in terms of origins, destination, and time of departure	Number of vehicles or individuals moving between origins and destinations in a specific period (e.g. peak hour, working day). Different groups can be defined according to elements like trip purpose or vehicle type. Agent-based models using single individuals are currently an emerging option, with still limited applications.	Number of vehicles or individuals moving within the study area in a specific period (e.g. peak hour, working day). Different groups can be defined according to elements like trip purpose or vehicle type.
Supply/ Demand interaction	Dynamic assignment of individuals or vehicles on the network. Pre-defined algorithms available in dedicated software to describe agents' behaviour regarding e.g. turning, lane shift	In simpler models, pre-defined algorithms to compute route choice for each origin-destination pair, considering congestion effects. In models where the number of trips or vehicles by mode of transport for each origin-destination pair is endogenously estimated, algorithms usually based on some utility maximisation. Agent-based models using single individuals following heuristic rules are currently an emerging option, with still limited applications.	*Ad-hoc* algorithms designed to simulate the choices of interest (e.g. mode choice). Often these algorithms are adaptations of those used in network models, based on some utility maximisation.

In any model, demand behaviour and interaction between demand and supply are described by means of numerical parameters and mathematical functions.

These elements provide a simplified and computable definition of rules used to choose e.g., between alternative modes of transport or between alternative routes and to reconsider choices when condition changes (e.g., when a road is closed or when the public transport fare is changed). The **functional scope of macroscopic models**, i.e., what types of behaviour they deal with, is the ground for another important classification of transport models.

The simplest macroscopic models are **Assignment models** focused on one mode of transport (generally road mode, which can be detailed according to vehicle types, e.g., cars and trucks). These models use a fixed demand (number of trips between zones) to simulate route choices, i.e.: the calculation of path(s) to move from one origin to one destination along the transport network.

Demand models are instead focused on the estimation of mobility in terms of trips or tours[7] between zones. Usually demand models deal with the generation of movements (how many trips will depart from one zone), with the distribution of movements generated in one zone among alternative destinations and with the choice of the transport mode. In some cases, the choice of the time of the day for movements is also included.

Many macroscopic models fall in the category of **Four-stages models**. These are basically the combination of demand models and assignment models. So, the scope of four-stages[8] model is the same as for demand models plus route choice. It can be noticed that four-stages models do not necessarily need to deal with all steps.

For instance, these models can work with exogenous trips between zones and manage only mode and route choice.

A further element of analysis is added in **Land Use and Transport models (LUTI)**. The location of households and activities is a main driver of mobility: the more a zone is populated the more trips will start from there; the more activities are located in one zone, the more trips will have destination there, and so on. However, the linkage works in the opposite direction (from transport to land use) too: the more accessible a zone is (e.g., because there is a metro station) the more individuals and activities will consider locating there. LUTI models manage the impact of transport on aspects like location choices and floorspace cost.

TABLE 2 MAXIMUM FUNCTIONAL SCOPE OF DIFFERENT MACROSCOPIC TRANSPORT MODEL TYPES

Modelling steps	Assignment	Demand	Four-stages	Land Use and Transport (LUTI)
Route Choice				
Mode Choice				
Time of the day choice				
Destination choice				
Trip/Tour generation				
Individuals and activities location				

7 Trips are the movements between an origin and a destination for a specific purpose. Tours are sequences of trips, where the first one is generally home-based and the last one is a return to home.

8 The denomination "four-stages" (or "four steps") refers to the sequence generation-distribution-modal split-assignment. The modelling of the choice of the time of the day is an additional, less common, step.

A four-stages model covers all aspects addressed by a demand model or by an assignment model. A LUTI model covers all aspects dealt with by a four-stages model. One might wonder why all these different model types exist if one of them can handle everything. One reason is that more power implies more complexity. A LUTI model is clearly more informative than an assignment model, but at the same time it is much more complex to build and use.

Another reason is that a wider scope is often associated to a coarser detail (e.g. a smaller study area or a lower number of zones) to keep the size of the model within manageable limits. Depending on the purpose, a simpler model can be preferable to a sophisticated one. We'll discuss the selection of models in the following.

From another perspective, transport models can be categorised according to the main element which their mathematical part is built on. Traditional transport models are **Trip-based**. The functions they adopt are used to estimate the total number of trips generated, the number of trips between two zones, the number of trips by mode of transport and so on.

This approach works, but thinking of how mobility is part of the real life of individuals, it can be recognised that decisions about trips are generally interweaved with decisions about activities. Mobility demand derives from demand for activities (work, shopping, leisure, etc.) for which individuals need to change location. Modelling mobility as part of activities is more realistic. Furthermore, deriving demand from activity allows to consider the constraints existing within households (e.g. if in one household there is just one car and this car is used by one household member, for the other members driving car is not an available option). This approach is adopted by **Activity-based models**[9].

We have already mentioned the difference between microscopic and macroscopic models. Microscopic models were initially developed (and are now commonly used) as Network models. More recently, microscopic models have been extended to demand models as application of **Agent-based** modelling[10]. Agent-based models work with single agents (e.g. individuals) and do not use predefined parameters or equations to derive decisions. They rather define basic rules guiding single individuals when interacting with other individuals and external conditions. The aggregated result is the outcome of the interactions.

The theoretical and methodological rationale of Activity-based models and Agent-based model is founded and appealing. These approaches promise to extend the scope and the realism of transport models. In the future one can expect that these models assume the role of mainstream modelling application.

Nevertheless, for the time being, they are complex, data hungry and only limitedly operational to represent widely available alternative to build transport models supporting SUMPs. For this reason, they will not be specifically treated in the following of this guide.

9 See for instance: https://tfresource.org/topics/Activity_based_models.html

10 See for instance: https://www.fhwa.dot.gov/publications/research/ear/13054/13054.pdf

BOX THE HARMONY MODEL SUITE

The HARMONY Model Suite (HMS)[11] is a web-based platform entirely developed within the HARMONY project with the main purpose to assist transport modelers and planners in their activities. HMS allows the combination of different transport models – at different abstraction levels including strategic, tactical, and operational – and provides an intuitive way of running the combined models and comparing their results.

The HMS has been developed to satisfy the objectives related to the goals of different target users:

- **Transport planners**. These users are interested in defining the parameters for their policies quickly and intuitively, to run scenarios and examine their results in a flexible way. To this end, planners need, first, to be guided by the platform itself on which model(s) to use for the required transport analysis at hand. They also require additional guidance on how to parametrize the relevant model(s) – i.e., which numeric values to set for different parameters (and what is the meaning of a parameter or value they choose), which files to provide as input to the model(s), and which data files and performance indicators to expect as output. The availability of the model(s)´ outputs in both raw formats (e.g., generated files) and as a set of key performance indicators (KPIs) graphically depicted in different diagrams or formats is also a highly significant requirement of this user category. Finally, transport planners require intuitive output comparison features for different scenarios.
- **Transport modellers**. These users need to be able to combine, in a flexible and intuitive way, different models and create integrated models (that can in turn be used also by transport planners). They need to be provided with a way to specify such a combination – in particular, with a way to describe both the control flow (i.e., the running sequence) and the data flow (i.e., which outputs from the previously run models will be used as inputs (if any) to the subsequent models). Finally, they need to be supported by the platform in specifying the inputs and outputs of each individual model – which is a prerequisite for the combination of models.

On top of the above end-user roles, there are two technical roles in the development and operation of the platform:

- **Component Developers**. They need to be guided in extending the platform with individual transport models. To this end, component developers need to have clear and detailed instructions on how to structure and prepare their models (i.e., executable code) so that they can be integrated into the platform and, as a result, made available to transport modelers and planners.

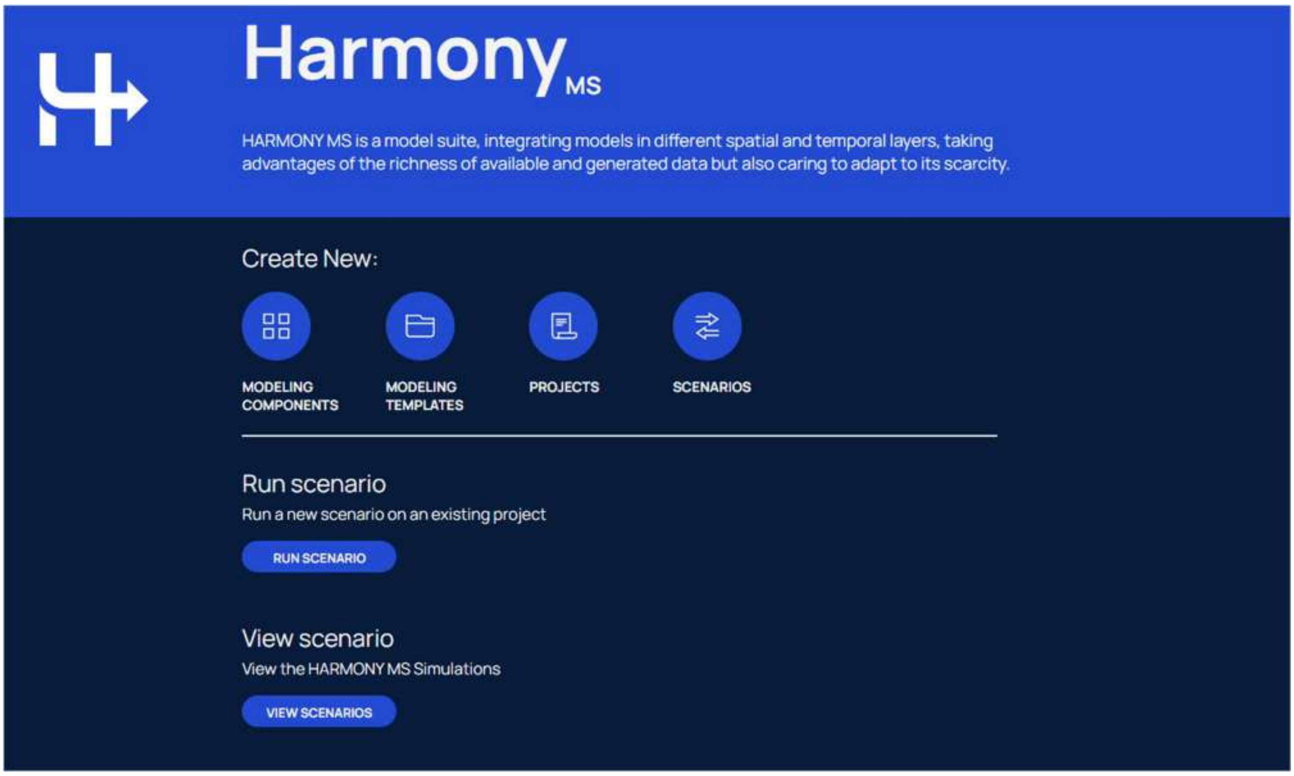
11 https://harmony-h2020.eu/model-suite

- **HMS Maintainers**. They need to have the necessary access rights and guidelines to be able to (1) integrate the models provided by the component developers (i.e., make the necessary changes in the platform's codebase so that the new models are recognized and used), (2) extend the platform by providing more features to its end-users, and (3) deploy the platform in different infrastructure providers (e.g., virtual/physical servers). Overall, maintainers need clear and comprehensive documentation to achieve the above.

The HARMONY Model Suite operates on **three integrated levels of modelling**, namely:

- **Strategic Level** for regional economic, demographic forecasting, land-use, spatial freight interaction and long-term mobility choice models. This level covers a long-term horizon (year-to-year, every 5 years) and is responsible for generating: a) disaggregate household and firm population and their locations for different types of activities such as employment, housing, and education; b) aggregate commodity flows between employment sectors; c) long-term mobility choices of individuals (agents) including car-ownership or subscriptions to different mobility services.
- **Tactical Level** for a fully agent-based passenger and freight demand model. It consists of two sub-models which can model agents' choices on a day-to-day level. The activity-based passenger demand modelling framework considers individuals, households, and the interaction of individuals within the same household, focusing specifically on capturing their activity choices throughout the day and the corresponding travel decisions. The multi-agent freight demand simulator simulates individual firms and shipments and the logistic decision-making choices of freight stakeholders. This level produced disaggregated demand in the form of daily activity schedules (trip-chains) and freight vehicle tours (i.e., trucks, vans, freight bikes, etc.).
- **Operational Level** for transport supply and demand interactions at high granularity. It can be characterised as a multimodal network assignment model system that is responsible for simulating the demand on transport networks, while simultaneously capturing travellers' route choices and dynamic schedule re-evaluation choices due to supply conditions. It also includes dedicated modules that emulate disruptive new mobility service operations and their interactions with agents (e.g., traveller, vehicles) of the system. This level generates, among others, traffic volumes and impedance measures of the form of skim matrices (e.g. travel time, cost distance) per mode and Traffic Analysis Zone.

FIGURE 1 LANDING PAGE OF THE HARMONY MS



3. What Transport Models can do

Transport models are simplified representations of transport supply, transport demand and their interaction in a given context (e.g., mobility within a city). However, the purpose of building transport models is not to create simple versions of existing conditions. **Transport models are built to simulate the effect of modifications of such existing conditions**.

Mobility, as well as the wider social, economic, demographic context, is continuously changing. Change makers are background conditions (e.g. demographic trends, economic growth), behavioural adaptations (e.g. preference for sustainable solutions) and policy interventions. Some of these sources of change correspond to modifications of some elements of transport models: input variables or parameters. Therefore, by changing input variables and parameters, alternative conditions can be simulated and the resulting effect on mobility can be estimated.

In a nutshell, **transport models allow to do experiments, anticipate the effect of exogenous trends, and assess policy measures**.

The variables and parameters that can be used to implement modifications depend on the structure of each specific model. An indicative list of the **main drivers available in the different types of transport model** is summarised in Table 3.

TABLE 3 MAIN INPUT DRIVERS FOR TESTING ALTERNATIVE CONDITIONS USING TRANSPORT MODELS

Driver	Microscopic[12]	Macroscopic				
		Assignment	Demand	Four-stages	LUTI	Strategic
Roads/intersections design	X					
New roads	X	X		X	X	
Total or partial (e.g. one way) closure of roads or zones (e.g. pedestrian areas)	X	X		X	X	
Reserved lanes	X	X		X	X	X
Speed limits	X	X		X	X	X
Modification of Public Transport service (new lines, frequency, stops)		X	X	X	X	X

12 Agent-Based models not included: as mentioned above, this class of models is still not widely available.

Driver	Microscopic[12]	Macroscopic				
		Assignment	Demand	Four-stages	LUTI	Strategic
Public transport fare system (e.g. integrated fares)						
Parking areas						
Parking fees						
Road charging						
Introduction of new transport solutions (e.g. new metro line, shared bike)						
New residential areas						
New/Moved city functions (e.g. hospital, shopping village, logistics platform)						
Energy price change						
Composition of road vehicles fleets (cars, buses) change						

At the opposite side of input drivers, there are **model outputs**. Again, the list of outputs and especially the level of detail (segments, zones) is different for each specific model, however, in general terms, each type of model can provide different kinds of outputs as summarised in Table 4.

Several drivers and outputs are available in different types of models, but not necessarily at the same level of detail. Microscopic models are the only ones allowing to test changes to the geometry of roads or intersections, in specific portions of the network and to analyse the dynamics of specific road sections or intersections. They can be used to test the introduction of reserved lanes or the closure of one road to analyse local impacts on traffic.

These same input drivers can be applied in macroscopic network models in a less detailed way but on a wider area (e.g. analysing contextual modifications in different parts of a urban network) to observe more aggregated outputs (e.g. the level of congestion on road sections or total travel time on the network).

TABLE 4 MAIN OUTPUTS PROVIDED BY TRANSPORT MODELS

Driver	Microscopic[13]	Macroscopic				
		Assignment	Demand	Four-stages	LUTI	Strategic
Dynamic of traffic on roads sections/intersections	X					
Vehicles per hour on roads sections/intersections	X	X		X	X	
Travel speed on road sections (level of congestion)	X	X		X	X	
Travel time between zones		X	X	X	X	
Accessibility of zones		X	X	X	X	
Boarding/alighting on public transport per zone		X	X	X	X	
Public transport passenger on route sections		X		X	X	
Modal split based on the number of trips			X	X	X	X
Modal split based on the number of passenger-km			X	X	X	X
Overall travel time for mobility in the study area			X	X	X	X
Overall travel expenditure for mobility in the study area			X	X	X	X
Public transport revenues			X	X	X	X
Individuals/Activities per zone					X	
Floorspace rent per zone					X	
Transport energy consumption	X	X	X	X	X	X
Transport emissions	X	X	X	X	X	X

13 Agent-Based models not included: as mentioned above, this class of models is still not widely available.

Changes of the features of public transport services can be analysed through Assignment models (i.e. with fixed demand) if the target of the analysis is comparing alternative configurations of routes in terms of travel times between zones or allocation of passengers at different stops. However, interventions on the public transport are usually expected to influence the size of its demand. Therefore, four-stages (or LUTI) models are generally more appropriate and provide a wider set of outputs, including the effect on modal split (i.e. number of trips or passenger-km by mode). Strategic models are an option to analyse modifications of public transport when these modifications can be translated into aggregated inputs (e.g. average cost or time per trip) and aggregated outputs are sufficient. Basically, while in network models one can change routes, frequency of services, specific fares and get results at zone and zone-to-zone level, in strategic model one can only change an average speed or cost and get results for the study area as a whole: coarser and faster.

Similarly, **road charging or parking fees** can be simulated by means of an assignment model if the interest lies only in route choice and with a strategic model if the purpose of the analysis is doing a fast screening of the effect of these measures. In four-stages model or LUTI models road charges and parking fees can be implemented at link/zone level and spatially detailed results can be obtained.

Microscopic and assignment models are not helpful to test **transport modes such as shared bikes or shared cars**. For this type of measures, four-stages or LUTI models are needed or, for a simpler analysis, a strategic model where modal split is represented in aggregated terms.

Four-stages models are needed whenever the inputs have a **spatial dimension**, like for instance new residential areas or the move of some relevant function from one zone to another. Strategic models are hardly useful for these cases. A LUTI model can extend the analysis of territorial modifications providing specific outputs like the relocation of households or activities or the floorspace rent.

Environmental effects, like energy consumption and emissions can be provided by all models but of course with a different level of detail. Microscopic models measure emissions only in the portion of area under analysis. Assignment models measure emissions on the whole study area as well as link by link but only for road mode(s). Strategic models measure emissions on the whole study area and for all modes but based on coarse inputs (e.g. average speeds). Four-stages and LUTI models can provide emissions for the whole study area considering link-based speeds and for all modes of transport.

4. Challenges and limits of Transport Models

Transport models are useful tools for supporting mobility planning, however one should be aware that, as any other tool, they are not limitless. A transport model cannot provide any response.

Some aspects of mobility are not computable for **theoretical or practical reasons**. For instance, transport models cannot deal with the impact of advertising or awareness campaigns. It is conceivable including in a model a parameter reflecting beliefs or prejudices and using this parameter to consider the effect of their modifications. However, the size of these modifications should be quantified outside of the model.

Even remaining within the variables, parameters, interactions falling in the domain of transport models, there are various limits and challenges to be aware of.

A very common limitation for transport models is data. A popular formula says "garbage in, garbage out". It might not be garbage, but if a model is fed with poor data, its results can hardly be reliable. Unfortunately, data in the mobility area is often lacking, or of limited quality. A significant example is the **spatial pattern of movements**. Origin-destination trips are a cornerstone for network models. Assignment models use exogenous origin-destination trips as starting point; four-stages models estimate origin-destination trips but would need observed data to validate the estimations. However, origin-destination trips are almost invariably unknown. It is not surprising: tracking all individual trips with some kind of geo-referencing is just impossible. Even today, in the early stage of the **big data** era, a full coverage of personal mobility is unfeasible for technical reasons plus privacy issues. Actually, experts in data mining have started to estimate origin-destination trips building on big data but we are still talking of estimates not of observations. By the way, big data consists of traces that almost anyone leaves behind using a car or a smartphone or an electronic ticket, but these traces are not in the public domain. So, exploiting big data for developing a transport model can be expensive. This is just one example; transport models need several data items and, in many cases, the required information is unknown or only partially known or hardly accessible (e.g., transport operators are more and more reluctant to share their own data on ticketing).

Another limitation of many transport models is the balance between realism and operability. Eventually, mobility is the outcome of the interaction of a number of individual decisions. Human beings are complex entities whose behaviour cannot be explained by a fistful of simple rules. On the other hand, models need exactly a limited number of rules to be operational. Therefore, most of transport models are based on algorithms derived from very simplified representations of how individuals choose among alternatives. Of course, simplified representations provide rough pictures or the reality. It is not by chance that the development of any transport model must pass through a phase called "calibration" (see below). This phase is needed to tell the model how to fix the gap between the results it would produce on the ground of its behavioural parameters and algorithms and the real world observations. More sophisticated models, with less naïve mechanism exist, especially in the academic context. For instance, as mentioned above, recently **agent-based models** have started to be proposed. But these improvements in terms of realism come at the price of more data to be collected, as well as more time and resources required for implementing modelling structures, which are often beyond the range of pre-defined methods made available by the most common commercial software packages.

Transport models generally deals with **a specific aspect of personal behaviour, i.e. mobility decisions, taking the rest as exogenous conditions**. This approach works for marginal modifications; structural changes are much more difficult to accommodate. For instance, personal mobility is generated in transport models according to specific parameters linking personal features (e.g. age, employment status, car ownership) with transport habits for different trip purposes. These generation models are quite robust but do not address the reasons why individuals make trips. Emerging trends like smart working can be considered in these models but only exogenously. Models cannot estimate endogenously if and when smart working or home shopping will develop.

The same applies to mode choice. Transport models use parameters linking personal features and characteristics of alternative modes. Environmental consciousness leading to prefer active modes even if slower and less comfortable can be handled but only in exogenous form; transport models are unable to predict endogenously that the attractiveness of cars can decline because a growing share of people is worrying for the global warming. **In a nutshell, transport models, like many models, have a limited capability of handling trend breaks. They can be arranged to estimate the impacts of breaks analysing "what if" scenarios but cannot forecast breaks.**

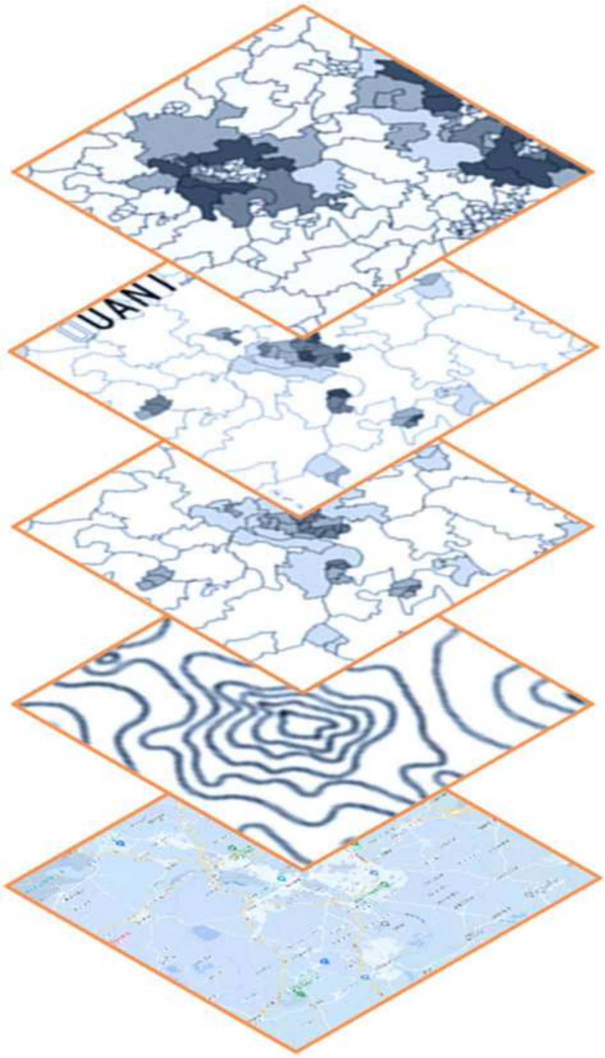
On a similar vein, **innovative mobility solutions like shared modes or MaaS or autonomous vehicles are a challenge for transport models**, because they introduce more structural changes than just the addition of an alternative mode of transport. New transport modes are a common content of scenarios investigated through transport models. However, new transport modes mean that in the mode split phase of the model there is one more option for travelling at a certain cost and a certain time. Shared modes or MaaS or autonomous vehicles are more than this.

Modelling these solutions is not just a matter of choosing one mode or another for a single trip, but of choosing how to manage the whole mobility needs of one individual or one household. Similarly, policy measures targeted at affecting the wider mobility habits rather than single trips – i.e. **tradable mobility permits**[14] – are also challenging. As seen, modelling approaches dealing with mobility in the wider context of individual activity and household constraints exist (e.g. Activity Based models) but they are far less established than the traditional models mentioned above and their requirements in terms of data are huge.

14 Tradable mobility permits have been proposed to handle distributional issues associate e.g. to road charging. See for instance Raux, 2004 (https://halshs.archives-ouvertes.fr/halshs-00067895/document).

Another challenge for transport models does not come from theory but merely from the **inherent variability of mobility over time**. Microscopic models are dynamic models that are used to simulate periods of several minutes of hours. Macroscopic dynamic assignment models also exist. However, the largest part of transport models is built to represent a specific time slice, often peak time or a whole day. At the same time, models are often used to generate indicators for wider periods. For instance, an urban transport model designed to represent the two morning-peak hours can be used to estimate yearly time spent travelling or yearly travel expenditure or yearly public transport revenues to feed cost-benefit analyses and compare against investments for new infrastructures.

The results of the model are extrapolated considering which part of the daily activity occurs in morning-peak and how many days there are in one year. It is easy to understand that the conditions of morning-peak are not the same as the off-peak conditions. Similarly, the conditions in working days are not the same as the conditions in the weekends. Especially in some contexts, there can also be significant differences between winter and summer, because of meteorological conditions or the number of tourists. Thus, extrapolating yearly results from a peak time model is a very crude approximation. A better option would be creating a model for each condition: a model for morning-peak time of a working day in winter, a model for the morning-peak time of weekend day in summer and so on. The challenge here is clearly that instead of one model there would a number of models. A multiple of the effort and resources (and data) would be needed.



In summary, transport models are helpful tools, but they cannot do everything. Their responses are necessarily affected by the explanatory power of the theory underlying algorithms and parameters, by the quality of data, by the amount of time and resources that are devoted to their development.

Any transport model is a sort of compromise between the desirable scope and the feasible effort. For this reason, **transport models are almost invariably tailored to specific circumstances**. A model designed and implemented to address some policy questions is not necessarily suitable to analyse a different set of measures and projects. When a transport model is built to support a mobility plan it should be designed carefully to ensure that all the measures envisaged in the plan (among those falling with the domain of transport modelling) can be reasonably represented. Then, this model can be updated and used over time to test modifications of the same measures or their impact on a different pattern of trips and so on. Testing completely new policy options, not originally included in the scope of the model is another story. Some of them might be simulated in the model as it is; others might be accommodated in the model only upon revisions of its structure and this would not be necessarily fast and cheap.

Transport models are not one-fits-for-all solutions providing estimations on everything, but useful tools which should be built and used for the specific purposes they are capable to handle being aware that they cannot invent solid responses out of limited knowledge.

5. Transport Models for SUMPs: If and What

With a hopefully clearer idea of what transport models are, what they can do and what limits they have, there is a better ground to address two fundamental questions.

First: is a transport model really needed to support your SUMP? If the answer to this first question is positive, the second question is then: what kind of model should be used?

5.1. Transport Models vs alternative methodologies

Addressing the first question means asking whether there are alternative methodologies which can work as good as transport models. Actually, there is not a wide range of alternative methodologies to support mobility planning.

The simplest approach could be using a **qualitative or semi-qualitative analysis**, based e.g. on the observed impact of some measures in other contexts as reported in literature. A meta-analysis of results could fall in this method. A more structured and quantitative approach could be applying some aggregated parameter, like demand elasticities[15], to generate **parametric estimations** (e.g. expected impact of a revision of public transport fares). A third method could be organising a **survey** to ask citizens about behavioural changes that would result when some measures are applied. A survey could investigate if a new configuration of public transport could attract users, if dedicated lanes could support the use of bicycle, if parking regulation can affect the spatial pattern of car trips and so on. As mobility plans usually include several measures, investigating all of them by means of a survey can be challenging and results can hardly be very specific, but they can be closer to the context than those based on other experience or on generic parameters drawn from literature. At the same time, in comparison to these other alternative methods, more effort would be needed.

These three approaches are clearly different from a transport model, but it can be useful to specify the differences.

Table 5 provides a **summary comparison between transport models, qualitative analysis, parametric estimation and surveys** according to some relevant criteria. Of course, a more appropriate comparison should be made considering a specific type of analysis a specific type of parametric estimation, a specific survey and a specific model used for a given purpose (e.g. estimations of the modifications induced on some KPIs by some exogenous changes). Since we cannot consider all the potential alternatives, the comparison should be interpreted in terms of typical applications of the different methods. It might be that in one specific case the application of one method would deserve a different judgement according one or another criterion, but in most of the cases the description in the table holds.

15 Elasticity is a measure of how much one variable (e.g. demand for one mode of transport) changes in response to a change another variable (e.g. the cost for using that mode of transport).

TABLE 5 COMPARISON OF ALTERNATIVE METHODOLOGIES

Criterion	Qualitative analysis	Parametric estimation	Survey	Transport models
Number of output indicators	Only a few indicators	Limited number of indicators	Limited number of indicators	Several indicators
Degree of approximation	Non-quantitative or anyway very rough responses	Quite rough responses	Quite rough responses	Better approximated responses
Level of detail	No details available	Only few details available	Some details can be available depending on sample size and questionnaire	Spatial and functional details depending on model features.
Data needs	Limited	Limited	Limited	More or less considerable depending on model features
Internal consistency of results	No	No	Partial	Yes
Flexibility	Inversely linked to the use of some evidence: the less purely qualitative the less flexible	Flexible	Limited flexibility	Limited flexibility
Expertise and experience needed	No mathematical or technical skills required	Basic mathematical or technical skills required	Survey administering skills required	Specific mathematical and technical skills required
Resource/time needed	Limited	Limited	Significant (especially resource)	Large

The table makes explicit the intuitive consideration that **transport models are more reliable, powerful and detailed tools than other approaches while, on the other hand, they are more demanding in terms of data, expertise, time and resources**. It is not impossible to setup a qualitative analysis for several different indicators, but it is not the most common situation (and, in that case, the time and resources needed for these approaches would not be as limited as mentioned in the table). In case more indicators are considered in qualitative and parametric estimation, they would be treated separately, so the internal consistency is poorer than from transport models, where all indicators come from the same calculations. Surveys can provide more details and, with appropriate techniques, consider the interaction between different elements and so ensure internally consistent results. However, more detailed and consistent results would imply more effort, more resources and more time as well as adequate expertise.

On the other side, it is not impossible to setup a strategic model which is not very data hungry and does not require much work of experienced specialists to populate, calibrate ad apply, but again it is not the most common situation (and, in that case, the degree of approximation, the level of detail and the internal consistency would not be as good as mentioned in the table).

So, **transport models are not the only resource available to support mobility planning, there are alternative methodologies that can be considered to reduce the effort and the need of data and technical expertise. It should be however clear that estimating the impact of transport measures outside of transport models can provide only very limited and crude responses**. It is like comparing two stones keeping each one in one hand. One can say which is the heaviest one, provided that there is enough difference, but weight can only be guessed. If one needs to know the weight, a scale is needed.

5.2. Is a transport model really needed to support your SUMP?

Deciding whether a transport model is required or not to support the definition of a SUMP depends on the specific circumstances. Here below, a list of key questions that should be asked and answered is presented. The discussion of these questions can guide in taking a decision.

Is my mobility context complex?

Mobility planning makes sense where movements of individuals and goods generate some undesired effects, especially at the local level (congestion, pollution, reduce safety and liveability, etc.). Unfortunately, this often happens but the intensity of these effects and/or the complexity of their specific causes vary from case to case. In larger cities, both mobility patterns and transport supply are usually complex, with many interactions and network effects. In smaller towns mobility is generally much simpler, maybe entirely based on private modes of transport.

Complex contexts usually require more complex planning: several measures of different kinds properly integrated in order to address a wider number of goals with a range of indicators to be monitored. Planning in simpler context can often be reasonably simpler as well, focused on a limited number of interventions to reach a few key targets which can be easily monitored. **In the complex cases, a transport model is the most powerful tool to support planning. In the simpler cases a model can well be unnecessary**.

Do I need to define the intensity/ extensions of measures included in the SUMP in detail?

The next question is if details are relevant. Normally they are because several measures can be applied in different forms, and it is important to decide the most appropriate ones. Infrastructures can be built in some places and not in others; charges can be applied in a range of levels; regulation can be applied to some groups of vehicles and so on. **Whenever this is the**

case, a transport model is the best support for the planning process. However, there might be cases where some constraints limit the choice set. For instance, it can be undisputed that one infrastructure (e.g. a bridge, a ring road) is a required intervention or it can be that the territorial and land use features of the urban area clearly indicate where traffic calming can or need to be applied or where public transport services should be more accessible. One should always be cautious to consider that there are obvious solutions, but especially in simpler mobility contexts, like smaller towns, this can actually be true. **In those cases, a transport model can be superfluous**.

Do I need to estimate the impact of the SUMP?

This question is linked to the previous ones. Why one measure should be preferred to another or why one measure should be applied in a certain way? Because the measure or that way to apply the measure is the most effective or efficient one. Therefore, the selection of measures and of their level or extensions implies an estimation of the effect of alternatives. From a more generic perspective, a mobility plan asks efforts to the administration (for developing, implementing, and monitoring the plan) and to the citizens. It provides services but sets constraints or charges. It is therefore reasonable to expect that an estimation of the benefits of this effort is made.

A transport model is the most powerful tool to estimating the impacts of a SUMP, or at least of part of its content. However, there can be cases where the interest is only whether the plan would have effect on one specific aspect (e.g. congestion in some parts of the city) and the content of the plan implies that some effect is certainly obtained (e.g. building a ring road would necessarily alleviate congestion) and estimating in advance exactly how much is not considered essential. These cases are not very frequent in larger cities but can be in smaller towns. **If it can be fair accepting to assess the success of a plan based on semi-qualitative expectations (e.g. more than before, less than before) something less elaborated than a model can be sufficient**.

Do I need to consider the interaction between different measures?

Of course, this question comes out only if there is an interest to analyse the contribution of the different measures and if these measures are not totally or largely independent to each other. **This is the most common case and transport models are basically the only method allowing to address it.**

The interaction between different measures is usually relevant because the effect of different intervention is often non-additive. Reserved lanes for public transport – and the consequent improvement of speed and reliability of the service – can attract new demand. Reserved lanes for bikes – and the consequent improvement of safety for cyclists – can induce more people to use bike. Building both reserved lanes for public transport and reserved lanes for bikes will hardly have the same results in the terms of increase of demand for the two modes, because part of the potential additional demand comes from the same individuals. If both alternatives are improved, they will choose one or another. At the same time, building two networks of reserved lanes instead of one would have a deeper impact on the capacity of roads available to cars, making private transport less attractive.

In simpler circumstances, a plan can consist of some measures which can reasonably be seen as independent to each other. **In those cases, their interaction can be irrelevant, and the estimation of their impact does not necessarily need a model**.

Do I have access to the outcome of previous experience of mobility planning in comparable urban areas?

As we mentioned above, one option for estimating the outcome of a mobility plan is making reference to the impacts of measures that would be part of the plan as reported in literature. One of the main problems with this approach is that local conditions matter. A measure applied in one city does not necessarily produce the same effects in another city. The starting situation of local mobility, the level of congestion, the competitiveness of public transport, topography and even weather conditions can make a significant difference. Furthermore, a mobility plan is made of more measures, and we have seen above how the interaction between measures can be significant.

So, **if for some specific interventions, literature can provide indications (e.g. through a meta-analysis of various applications to identify factors influencing the effectiveness), for multifaceted plans it is quite unlikely that one can find representative enough experience to provide reliable estimations of the expected effects**.

The number of SUMPs is increasing and, as new evidence is accumulated with reference to different urban contexts, **indicative ideas of what can be expected could be drawn from a review of existing experiences in simple contexts. Elsewhere, estimations tailored on the specific local conditions can hardly be generated without a transport model**.

Can I assume that there will be need to support urban mobility planning in the future?

Sustainable urban mobility planning is an iterative process. Mobility planning does not necessarily start and, above all, does not necessarily end with the production of a given SUMP. On the one hand, the SUMP itself will need periodical updates. On the other hand, other interventions – regulation, service provision, infrastructural modifications – can be considered in front of specific circumstances. Therefore, the availability of a tool for estimating impacts of mobility measures in the future can be useful.

If a transport model is built to support a SUMP, it remains available for analysing the same kind of measures in future circumstances. Models, like plans, need periodical updates and maintenance, but this is not equivalent to re-start from scratch. **So, since mobility planning is expected to continue over time, there are reasons to build a transport model.** At the same time, in simpler contexts updating a plan will always consist of applying a limited set of specific interventions. **In those contexts, lessons from past measures, if properly observed, can well serve as indications for revisions and extensions without the use of a model**.

How rich is the available data on population, economy, territory, transport sector for the urban area?

Any quantitative analysis needs data, transport models need more data than simpler methods. The availability of data related to the urban area is an important condition to develop a good transport model. Public administrations usually collect and generate several types of data for various purposes; therefore, it is quite unlikely that no data exists.

The data will not be as complete, detailed, up-to-date as wished but some data usually is there and other data can be collected on purpose during the development of the model. **The richer the already available dataset is, the easier building a transport model will be**. If, for any reason, territorial data is lacking, building a model could be complex or very expensive.

Do I have access to internal or external expertise in transport modelling?

Transport models require a specific expertise. They are developed using some specific software, therefore someone able to use that software is needed. Then, developing a model consists of various steps, which will be examined below, each one requiring experience and technical knowledge to be carried out properly. Once the model is built, expertise is not strictly required. For some models a user interface can be developed to allow non-expert users to interact with the tool (e.g. making tests and reading results). For other models, non-expert users can learn some simple functionality to manage pre-defined operations (again: making tests and reading results). However, one thing is learning how to change an input, start a model simulation, access a specific output and another thing is knowing if and how the model can be used for a new analysis or how the model can be updated over time. For these tasks, expertise is needed.

Modelling skills can be available within the body in charge for developing a SUMP (the local Administration). **In many cases, however, these skills are initially not existing or are too limited for managing the development of a transport model in-house.** In such cases, external providers are needed. There can be this expertise in universities of the area or private companies can be engaged.

Experts in transport modelling are not as widely available as lawyers or other common specialists, so it could be that in city or even in the region there are no or limited options. Until a few decades ago this could have been an obstacle, but nowadays accessing the required expertise, even if based outside a specific geographical area, is not problematic at all. Furthermore, most of the activities for developing a plan can be carried out even if the experts work in another place. So, **the availability of the required skills is a precondition to develop a transport model to support a SUMP, but it is very unlikely that this availability is a barrier**.

Do I have financial resources to develop the SUMP?

Developing a SUMP requires resources. The development of a transport model is one of the activities for which resources are needed. It is an activity inherently expensive, because the overall process (described in the next section) requires that some experts work nearly full time for several weeks and months, depending on the size of the city and the complexity of the issues at stake. Additionally, there is the cost of the software and of data collection. The cost of a transport model depends on its type, its size and detail (see below) but even the simpler model cannot be setup nearly for free.

Therefore, the availability of resources is a requirement. **If only limited resources are available, developing a transport model can be difficult**. Since the cost of implementing a model is not strictly proportional to the size of the study area (a model for a 10,000 inhabitants town does not cost only 1% of a model for a 1,000,000 inhabitants city), because some tasks are basically the same or are only marginally simpler, a model can easily be too expensive for smaller towns. So, unless the mobility context is anyway particularly complex, building a transport model could be not the best choice. Resources can remain a problem also for medium and large cities. However, it should be clear that, given the discussion of the previous questions, if in more complex contexts only limited resources are available, the problem goes beyond the model: developing a good quality SUMP in itself is challenging.

Do I have time to develop the SUMP?

This question is strictly linked to previous one. The resources required to develop a transport model partly depend on fixed costs – like the software – but the most relevant share is the work of the required experts. This work needs to develop along a sufficient time. Completing all the required steps in a short timeline is impossible or becomes feasible only tolerating a large degree of approximation in the functioning and in the results of the model. Again, the time needed to arrange a transport model depends on the type of model and on the required size and detail, but even the simpler model needs at least several weeks. Furthermore, if the model is expected to support the planning process, once it is ready an interaction between planners and modellers starts. Planners ask to test some measures, modellers implement the measures, run the model, extract, and present results. Based on the results, planners can wish to test some modifications and so on.

In brief, it is not just the development of a transport model requiring time, but more in general the development of a SUMP supported by a model. **Pretending to elaborate a SUMP in short time is hardly compatible with a model but. More in general, it is hardly compatible with a robust plan**.

A synthesis of the discussion above is that a transport model is not necessarily the only method to estimate the impact of policy measures and support the development of a SUMP. **Alternative, simpler, methods are realistic options in case of simple context, which are common in smaller towns and cities, where, furthermore, data, time and resources are often limited. In more complex contexts, without a transport model, only rough and often qualitative indicators can be estimated. So, in those contexts, the conditions where a model is not applied are also conditions where planning is quite poor**.

This conclusion does not mean that using a transport model ensures that the plan will be a high quality one. **Models are tools and the results depend ultimately on how they are used rather than on their theoretical potential**.

5.3. What kind of model should be used?

Assuming that the application of a transport model is considered the appropriate way to proceed, the following step is selecting the type of model. As we have seen above, there are different types of transport models, more or less articulated, with different capabilities. One may wonder which type of model is the most appropriate for supporting a SUMP. Again, the answer depends on case by case. Considering some aspects can help to choose. Like above, the main aspects can be discussed with the help of some questions.

Do (some of the) measures potentially part of the SUMP have a significant spatial dimension?

Mobility is by definition movement across space; so, the spatial dimension is hardly insignificant in mobility planning. Nevertheless, there could be cases where this dimension does not play a primary role. Some measures can have a general geographical scope; for instance, the ban for some vehicle technologies or integrated ticketing are generally extended over the whole urban area. It can also be the case that some measures are spatially defined but their application is planned in several locations and the interest is in understanding their overall impact. For instance, reserved lanes will necessarily be on specific roads, but if the plan is to build a network of reserved lanes across the whole urban area, one can assume that public transport speed or bike safety are improved basically everywhere and wonder about the total impact.

In these cases, strategic models can work. Instead, **whenever some of the measures potentially included in a SUMP are spatially located, strategic models do not help, and one needs a network mode**l. It is definitely uncommon, but **if a plan is made essentially of several very detailed interventions on crossroads, roundabouts, traffic lights timing and similar measures, a microscopic model could be an appropriate tool**.

Do I just need to compare measures in terms of effectiveness/efficiency, or I need to estimate some other KPIs?

A transport model helps to simulate the effect of one or more measures that can be part of a mobility plan. Measuring the effect can have different meanings. A simple meaning is taking two or more alternative measures and estimating which one is expected to produce the most significant effect considering a specific target. For instance, one might be interested to estimate which measures reduces car usage more significantly. This comparison of effectiveness in broad terms can be obtained even with strategic models.

If the estimation of the effectiveness is associated to the expected cost of measures, aggregated models can be helpful also for efficiency analysis. If the application of the model is expected to provide the elements to compute some KPIs, it might be that a strategic model is not detailed enough. For instance, if one Key Performance Indicator is the accessibility or the level of congestion, the strategic model can hardly help.

Do I need to estimate impacts of the SUMP in aggregated terms, or I'm interested in spatially detailed impact?

When addressing the question above, one particular aspect will often emerge, i.e. whether the estimations should concern the urban area as a whole or they should be produced for different zones of the area. It is partly the same difference mentioned above but with a difference: here the focus is on the need for spatially detailed estimations. It could be even just one only indicator (e.g. the number of car trips or the number of passengers on public transport services) but defined for more zones.

Of course, it is more likely that spatial detail is required together a set of KPIs. In any case, **if the estimation of impacts by zone is required, the choice should be for network models**.

Should the model support the analysis of all measures potentially part of the SUMP?

In several cases the answer to this question will be "yes", but it is fully conceivable not completely unrealistic that planning measures are concentrated on private mobility, pursuing sustainability by means of technology and the distribution of trips across space and time. Should this be the case, assignment models might be enough to estimate the impact of a SUMP.

More commonly, mobility planning will involve different modes of transport. Therefore, a multimodal model will be needed.

Do I need to consider the network effect of measures?

For assessing if a transport model was needed, we asked whether the interaction between measures was relevant or not. Here, another sort of interaction is considered. Network effects are those deriving because of the spatial pattern of mobility. A modification on a specific road (e.g. changing speed limit or convert it into a one way road or reducing capacity to reserve space for a dedicated bike lane) changes transport conditions for several origin-destination pairs. Trips between these origin-destination pairs use other roads as well or start to use different roads as effect of the intervention. Therefore, there will be indirect effects even in other parts of the network where no modifications have been applied.

If the content of a mobility plan includes measures that can generate this kind of effects – in most of the cases it is so – then **a network model is preferable as strategic models cannot deal with network effects**. We say "preferable" rather than "required" because other considerations can lead towards the choice of simpler models. The use of a tool unable to capture network effects would be a limit of the analysis, and it is not recommended, but if a detailed network model is unaffordable and the choice is between a strategic model and no model, the former can anyway be better than the latter.

Am I interested in the impact of the SUMP on land use?

Mobility plans are targeted at improving sustainability in the mobility sector. Their impacts are assessed considering transport indicators as well as measures of transport impacts, like air pollution or noise or safety. On the other hand, because of the linkage between transport and land use, the modifications on urban mobility can generate effects on land use. For instance, modifying the accessibility of some areas (either providing transport services or banning private modes) will change not only liveability but floorspace rent as well.

Especially when significant infrastructural interventions are considered, the land use effects can be significant, and the local authorities can be interested in estimating them. In that case, the most appropriate option is to build a Land Use and Transport (LUTI) model.

Do I plan to use the model only to support the SUMP or I expect other potential uses in the future?

When considering the opportunity of using a model to support mobility planning, we mentioned that, once a model is build, it remains available (provided that it is properly maintained) and can be used for different future applications. Similarly, when different transport models are compared, it is worth considering other potential applications than the support of a specific mobility plan. For instance, a network model can be used even to test local modifications and interventions, outside of any articulated plan.

When a model is built, it can be maintained and kept up-to-date with a reasonable effort, while it cannot be converted to a more complex model. A strategic model cannot become a network model. An assignment model can be the base for a four-stages model, but the work required for the conversion is not much less expensive than building a new model from scratch. Therefore, it can be wise to opt for a more sophisticated model even if the analysis required to support a mobility plan can be managed by a simpler one.

How many financial resources have I to develop the SUMP?

Developing transport models needs some resources. More complex models are more expensive. The **cheapest option is the adaptation to the urban area of an existing strategic model**. When this option is available, the cost can be of some thousand euros. Of course, as discussed above, a model of this kind would be very limited in terms of detail and would provide only very approximated estimations without spatial detail.

A strategic model built on purpose, customised on a specific urban area and on a set of policy measures to be analysed would require tens of thousands of euros. Compared to a network model for a medium town, the lower costs of a strategic model would result from a simpler and faster calibration phase (at the price of less precise and spatially detailed outcomes) and from the use of common software rather than a dedicated package.

For cities and large metropolitan areas, the cost of a **network model**, namely a four-stages model, would be significantly higher because of the complexity in the calibration phase as well as data collection.

Finally, a **land-use and transport model would be the most expensive option** (of the magnitude of several tens of thousands of euros, again the size of the urban area would matter) as everything would be bigger and more complex. The availability of resources is therefore a critical aspect, also considering that developing a model is not the only activity required for the preparation of a SUMP.

How much time do I have to develop the SUMP?

This question goes hand in hand with the previous one. Developing and applying a model needs time and, of course, the more complex is the model, the more time is needed. The **adaptation of a pre-existing strategic model** can be completed in some weeks (most of the time being for data collection and elaboration and for the application of the model to analyse policy options). For building an on-purpose strategic model the time required is of a few months, as the design, coding, debugging phases cannot overlap.

A **four-stage network model** requires several months because of the finer level of detail and of the calibration phase. This latter phase is usually time consuming and inherently uncertain. There is also a sort of **trade-off between the data collection and elaboration phase and the calibration task**: the more data and of the better their quality the easier the calibration. So, spending time to create a good database is time-consuming but can save time later. Vice-versa, saving time in the preparation of the data can easily be paid in terms of a problematic calibration.

Finally, a **LUTI model** is the most time-consuming as it is the most complex especially in the calibration phase. It is unlikely that a LUTI model can be developed in less than 1 year and usually the time needed is longer.

5.4. Summary: the most appropriate transport model (if any)

Are transport models useful tools for developing SUMPs? Yes, they are. Are there some types of transport model more useful than others to support the development of SUMPs? Yes, there are.

The answers to these to questions are undisputable. Nevertheless, they do not bring to a unique recommendation, because specific circumstances matter. **Building transport models is not a quick and cheap task, it requires expertise and the availability of data. When the mobility context is reasonably simple and the content of the planning is necessarily simple as well, a transport model is not necessarily required. When resources, time, expertise, and data is poor or lacking, developing a transport model is simply unfeasible**.

Transport models are not crystal balls opening a sight on the actual future. They are tools based on simplified representations of conditions, options, behaviours. They depend on information and cannot transform poor data into reliable forecasts. Using transport models means doing an effort to get estimations. And estimations inherently include some degree of uncertainty. Notwithstanding, it should be clearly understood that, whenever the planning context is articulated, any alternative to models can only provide coarser, more uncertain estimations than those of models or even only vague qualitative considerations. **There is nothing less demanding than models but providing the same, or even better, results of models when the object of the analysis is complex**.

In smaller towns and cities, choosing alternative methods can be a fully reasonable choice. Elsewhere, if conditions are considered not appropriate to develop any model, this means that the content of a SUMP can be supported only by very generic justifications; a real comparison between alternatives cannot be made; an analysis of the cost of the measures against their effects is unfeasible. So bad conditions that any model is unaffordable are, however, quite uncommon. Applications of **existing strategic models**, such as the Urban Transport Roadmaps tool (http://www.urban-transport-roadmaps.eu), can be organised with limited resources, even with limited data available. They can provide only aggregated estimations, but at least allow to compare alternatives using a consistent analysis framework.

BOX URBAN TRANSPORT ROADMAPS TOOL

Urban Transport Roadmaps (urban-transport-roadmaps.eu/), developed on behalf of the European Commission DG Move, is a free on-line tool to help developing the first scenarios of a SUMP. With its simplified approach the tool serves as a first step for people with non-specialist knowledge and allows to:

- explore and identify appropriate sustainable transport policy measures;
- quantify the transport, environmental and economic impacts of these measures;
- consider an implementation pathway (roadmap) for the policy scenario.

The tool is available in 10 European languages.

Developing a strategic model on purpose could also be a reasonable alternative to reduce complexity (lower time, more limited resources) but one should think very carefully if this option is really the most preferable one. Actually, **developing a network model instead does not imply a much larger effort, while the level of detail and the re-usability of a network model are significantly higher**.

In many circumstances, if it is accepted that the development of a SUMP (or of another transport planning instrument) requires the possibility to estimate the potential of alternative measures or combinations of measures, considering their interaction and network effects, considering the spatial dimension in terms of implementation and outcomes, **a four-stages network model** or **an activity-based model** are the most appropriate solution. A Land-use and transport model would be even better.

Network assignment models and **microscopic models** are realistic to analyse only specific measures, because their scope is hardly sufficient to cover the whole content of SUMPs. Normally, sustainable mobility planning deals with all modes of transport – to incentivise or disincentivise them. Models focused on road transport only do not provide enough drivers to analyse measures. Part of the content of a mobility plan could well be analysed by means of assignment models, but four-stages network model manage assignment, so they can be used. Local authorities can often plan localised interventions whose design can benefit of simulations made by means of microscopic model.

So, a model of this kind would not be useless in the toolbox available to support mobility planning, but it would not be sufficient alone.

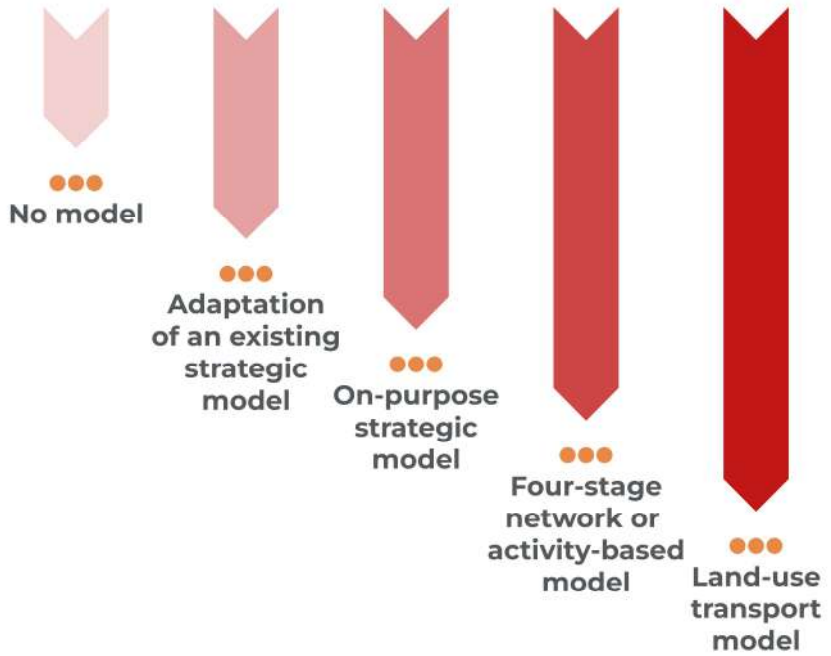
Figure 2 summarises the most appropriate choice regarding the use of a transport model to support the development of SUMPs according to the relevant conditions discussed above.

Whatever the choice is, it is vital that investment and expectations are commensurate. Accepting that a network model or even a LUTI model is needed means accepting to invest enough time, resources, data collection effort, training effort to develop and then use the model properly.

Pretending that a network model is ready and applied in a few months or pretending the demonstration that the model is fully reliable providing only limited data would be contradictory.

FIGURE 2 CHOICE ABOUT TRANSPORT MODEL DEPENDING ON SPECIFIC CONDITIONS

Interest in testing alternative measures	Limited	Yes	Yes	Yes	Yes
Interest in estimating various KPIs	Limited	Yes	Yes	Yes	Yes
Interest in spatial details of measures	No	Limited	Limited	Yes	Yes
Interest in spatial detail of estimations	No	Limited	Limited	Yes	Yes
Interest in network effect of measures	No	No	No	Yes	Yes
Interest in land use effects	No	No	No/Limited	No	Yes
Data availability	Poor	Limited	Average	Good	Wide
Resources availability	Poor	Limited	Average	Good	Wide
Time availability	Poor	Limited	Average	Good	Wide



6. Developing a Transport Model in practice

Debating about whether a transport model is a useful support for elaborating a SUMP and, in that case, what kind of models should be used, we have mentioned that developing a model is a process requiring skills, data, time and resources. A closer glance to this process can be useful to interpret what have mentioned above and, at the same time, it can provide a basis for presenting the roles of different actors involved in the preparation of a mobility plan when a model is developed. The development of a transport model includes five main phases: design, data collection and elaboration, implementation, calibration, application.

FIGURE 3 TRANSPORT MODEL DEVELOPMENT PHASES

6.1. Model design

The design phase is the starting point for developing a model. In this phase, the features of the model are defined. The elements to be designed depend on the model type, but most of them are common to any kind of model.

One element is the **spatial scope** or **study area**. In broad terms this is given: if the model is for the urban area X, the spatial scope includes the urban area X. However, for designing a model a more detailed definition is required. First, the urban area can correspond to one municipality or to a wider area (e.g. a Functional Urban Area[16]). Especially in the former case, the model scope may be extended beyond the boundaries of the urban area in order to better represent the mobility entering or leaving it. The definition of the external limits of the study depends on considerations on the expected mobility patterns, on the administrative boundaries, on data availability and so on. Second, unless the model is an aggregated one, the model spatial scope needs to be segmented in **zones**. The definition of the zones – how many, their shape – depends again on various aspects. Of course, a more

16 https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Glossary:Functional_urban_area

detailed zoning allows a more spatially detailed analysis. On the other hand, however, a very detailed zoning system requires very detailed data (which may easily be not existing). Furthermore, many zones make the implementation phase more demanding.

Another element of the model is the description of the **demand** side. The description of demand is made of different components. Personal mobility consists of trips made by individuals for different travel purposes. It is often useful distinguishing several trip categories as each category can be different for one reason or another (e.g. the pattern of trips, the preference for faster modes of transport, the average fare paid on public transport). As trips are generated by individuals and different population groups have different mobility habits, it can be advisable to consider various population groups if the trip generation phase is explicitly modelled.

The description of the **supply** side can be even more articulated than demand. The road network is usually a major component of transport supply. Being models a simplified representation of the real world, they often do not consider all the existing roads in the study area (the larger the study area the most likely that a selection of roads is made). The modelled road network needs to be defined to be consistent with the detail of the zoning system. For multimodal models, other networks are part of the supply description. The urban rail network or the routes of public transport services could be described. Transport services can be modelled in a more or less sophisticated way up to a full definition of routes, stops and timetables. Choosing the appropriate level of detail is one task for the design phase. Part of the supply description could also be the representation of intermodal connections.

When demand interact with supply, one consequence is that various **transport modes** are used to make trips. The definition of the transport modes is another task in the design phase. Some modes, like walking can be defined explicitly or not. Some transport modes can be defined as independent alternatives or as part of a wider option. For instance, one model could define public transport as a unique mode while another model could define bus, tram and metro as separate modes. There are pros and cons in both solutions; the choice of the most appropriate one should be based on different aspects, especially on the expected use of the models and on the expected indicators. Again, inter-modality can require the design of some specific solution. Combinations of modes are often modelled as one main mode and potential "feeder" modes, but the available combinations need to be defined also considering how demand and supply are described.

Last but not least, the **algorithms** of the model need to be designed or, at least, selected. Specialised software packages offer a range of available algorithms to deal with the various modelling stages (generation, distribution, modal split, assignment). In some cases, however, there might be reasons to define a "customised" version of one algorithm (provided that the software allows it).

The features of the model define its methodological scope. The variables defined and the segmentations used identify what can be used to represent policy interventions. Mobility measures (those that are within the scope of a transport model) need to be translated into the modification of some model variable or parameter. The structure of the model should include an appropriate variable or parameter for implementing any measure of interest. For instance, if the SUMP can include the realisation of a network of reserved bike lanes, the model should include explicitly the mode "bicycle" among the alternatives and there could be a way to tell the model that bike lanes are available. It is therefore very important that the design of the model is made after an early and comprehensive discussion with the planners.

6.2. Data collection and elaboration

Whatever model needs data. Even a simple model needs some information and more complex models need more information. Transport models require two main categories of data. The first category includes the value of the **variables** used by the model as exogenous input because are not endogenously computed.

For instance, it is very likely that a transport model dealing with the generation of trips needs population data. At the same time a transport model does not compute population endogenously (at least for the first simulated year) because the number of inhabitants in the study area (and even in each zone, unless the model is a Land Use and Transport one) depends on demography and on other drivers which are outside of a transport model scope. Therefore, population should be provided as an external input. The same applies to other variables, like the location of relevant trips attractors or the number of jobs. Many features of transport supply – like the number of lanes of roads or the frequency of transport services are exogenous information as well, but they are coded when transport supply is implemented.

The second category of data needed by a transport model consists of the **parameters** used during the calculations. Parameters are of various kinds. Transport costs for each mode of transport and each demand segment are usually described in the model by means of parameters. The average number of trips generated by an individual in one day or one year for a given purpose is another parameter. The importance attached to each element used to measure the utility of alternative transport modes (e.g. travel cost, travel time) is incorporated in parameters.

The number and variety of external data – variables as well as parameters – depend on the type and complexity of the model. Strategic models do not necessarily use less exogenous elements. It could be easily the other way round because strategic models can take externally variables that in a network model are endogenously computed (e.g. travel speed).

A peculiar feature of most of the data required by a transport model is that it is generally not available in the format requested by the model. Sometimes it is not available at all. Population is generally published in some statistics database or report. However, the published data could not provide the required level of detail. Municipalities divided into several zones within the model might not publish population data for those zones (the definition of the zoning system should consider administrative areas like census zones as well as the available statistics, but not always the model requirements are fully consistent with the existing data sources). Also, the model might need population segmented according to elements like employment status or car availability, but this detail is hardly available in demographic data.

Data collection consists of exploring several known or potential sources, send requests to administrative bodies or transport operators or economic associations to ask for unpublished information. For some kind of model elements, especially some parameters, the estimation can be based on direct surveys organised on purpose. For instance, parameters used in the utility function to measure the relative importance attached to each element can be estimated by means of Stated Preference surveys[17]. Collecting data by means of direct sample surveys can be an effective strategy. On the other hand, it can be expensive and requires specific skills and experience.

The data collected will then need to be processed in order to derive the inputs required by the model in terms of definition and in terms of format. Processing the data means applying simple conversions or aggregations as well as defining more complex methods to transform the original collected data. For instance, the model can require population by zone according to car availability, but the collected data includes only population by age in a certain number of districts (each one containing several model zones) and the total number of a cars registered in the administrative division which the urban area under study belongs to. In that case, procedures to make use of the existing data should be defined and applied.

Therefore, the data collection and elaboration phase is often demanding as well as time consuming. One will hardly overestimate the time and the resources needed to produce the data used by a transport model.

6.3. Model implementation

The implementation of the model consists of two main activities. One is the coding of the model components defined in the design phase. The other one is populating the model with all exogenous values for variables and parameters. The latter activity can be carried out only when the data collection and elaboration phase has provided the required inputs.

The coding of the **model components** means using the functionalities of the chosen software package to translate the theoretical elements into operating entities. In principle, the complexity of this phase should not be undervalued. Software packages are built to maximise the efficiency of calculations and to provide a consistent framework where accommodating the various elements needed in a model. These requirements can lead to use an internal "language" or codes or structures which are not necessarily the most intuitive ones. Furthermore, the most sophisticated software often provides alternative ways to implement the same element. These ways are generally not exactly equivalent. One can be simpler but more rigid than another.

17 Stated Preference is a methodology based on hypothetical scenarios where alternative conditions (e.g. two different transport modes) are presented to a sample of individuals in terms of a common context and a set of attributes. By means of various techniques, individual preferences regarding the alternatives are collected and can be used to estimate the importance attached to each attribute.

Therefore, implementing the model components often implies to find the appropriate solution, considering different requirements: compliance with the theoretical definition, ease of implementation, flexibility for future use and updates and so on.

The implementation of some specific components can be inherently time-consuming even if conceptually easy. For instance, the implementation of the networks does not offer alternative solutions to choose from. Software packages embed functionalities to automatically import shapefiles and other data (e.g. timetables), but the mere result of automatic procedures is seldom sufficient.

For instance, the density of the network imported can be excessive for the detail of the zones and a certain number of links should be removed paying attention to preserve the connectivity of the network. Also, the implementation of the networks includes the definition of a set of virtual links representing the connections of each zone to each network. The correct implementation of these virtual links is very important, and a manual work can hardly be avoided.

The population of models with the exogenous **data** is generally much less complex. The complexity is almost entirely in the production phase. The implementation of the data can anyway imply some work when there are many data items and maybe some items consist of large files. While from a user perspective, data tables in format like .csv or MS Excel can be the most convenient solution, from the software perspective (i.e. to optimise and minimise the operations to read and write data) pre-importing data in some internal format can be preferable. The appropriate compromise between usability and efficiency should be found.

6.4. Model calibration

When a model is implemented and populated with all the exogenous data, it is still not ready to provide results. Most complex models, especially where specific calculation steps are coded, often need a debugging phase to identify trivial errors preventing the model to be executed. Even simpler, aggregated model can be affected by these errors, e.g. some typos in an exogenous data table or some settings forgotten.

But the most important and demanding task is calibration. This phase consists of tuning specific parameters to drive the model towards correct results and reactions. As already pointed out, transport models are necessarily very simplified representations of the real world, e.g. of how a number of heterogeneous individuals, with different preferences, constraints, options, choose among alternatives. Transport models are not like physics models, which (at least in the macroscopic domain) provide precise and complete descriptions of specific aspects. Provided that the input data is known, their estimation will always be exact without the need for *ad hoc* adaptations.

Transport models are different because their equations, variables and parameters do not provide an exhaustive description but only an approximated version of the reality. The gravitational attraction between two bodies depends only on their mass and on their distance according to a known relationship. The choice of one mode instead of another depends on several aspects, which cannot be entirely identified, measured, and translated into model inputs and parameters. Therefore, even assuming that all the input data and parameters included in the model are fully correct (but we observed above that in many cases data is only estimated), when the model is applied to the current conditions, it will not output the observed transport demand: vehicles on roads, passengers on public transport, trips attracted in a certain area, etc.

The calibration is the phase where dedicated parameters are tuned to teach the model how generating results closer to the observed demand. Basically, during the calibration, the model receives additional information to improve the realism of its results.

This phase is the most crucial one during the development process. Its complexity depends on the nature of the model, on the quality of the input data as well as on the variety and reliability of comparison data. The calibration of strategic models is often not too demanding because equations are usually not very complex, and the comparison of results is made against quite aggregated data. For network models, calibration is usually more complex and time-consuming. For some aspects of the calibration, automated procedures can be defined and applied but this is not always feasible. The calibration is generally easier when the input data of the model is of good quality. Producing good input data requires time but can save time in the calibration phase.

Data and calibration are linked from another point of view. The calibration is made comparing model results against observed statistics (e.g. vehicles on roads). The richer and the more detailed is the set of comparison data, the more complex is the calibration, but the more robust will be the result. When the data on the observed conditions available for the calibration consists only of a few very aggregated figures, it can be relatively easy driving the model towards those figures, but within the more detailed results can remain unnoticed inconsistencies which may undermine the reliability of the model when it is applied.

The ending part of the calibration phase is often termed as “**validation**”. Validation is basically the same as calibration but using a different set of observed results. For instance, during the calibration phase, modelled loads on road links are compared to a set of traffic counts. Validation is again a comparison of modelled loads against counts but for a different set of sections, not used during the calibration phase.

The rationale behind validation is showing that the model, once calibrated, is capable to reproduce results not already used to setup its parameters. While validation is recommended, in practical terms it is not always applied because of the lack of data. As mentioned above, observed data at the appropriate level of detail is often hard to find. When there is only a limited set of numbers as term of comparison, they are necessarily used for the calibration phase and nothing else remains for the validation.

The calibration of a transport model is basically craftwork. There are few objective rules; expertise and experience of modellers are very important. It is a phase intrinsically very difficult to plan. What we said about the production of data is even more true for the calibration: it is very hard overestimating the time needed for completing the process.

6.5. Model application

The application of the model is the final phase of its development. In principle, the development of the model ends when the model is calibrated. However, considering the wider process of producing a mobility plan, the application of the model is worth to be mentioned.

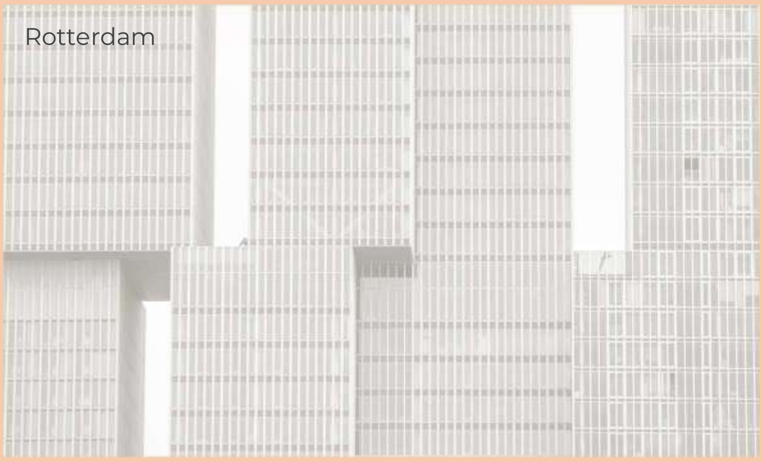
The purpose of a transport model is to estimate the effect of modifications of the current conditions. These conditions can be background conditions (e.g. the population trend or the cost of energy) but the most relevant ones are those related to the policy measures. Using the model, the impact of one or another measure or of their combination can be estimated. The model can therefore be exploited to explore various options for combining different measures (and/or different levels for some measures, e.g. parking fares). Using the model for this exploratory work can be time consuming. Unless a strategic model with simple inputs is used, arranging simulations, executing the model, extracting and analysing the results require time. So, there is usually a limit to the feasible number of preliminary simulations, but the application of the model can help for defining the content of a mobility plan.

Assuming that the content of the plan is defined, or a few alternative versions of the plan are under consideration, the application of the model consists in the simulation of each alternative as a separate policy scenario. Usually, a reference (or baseline or "do-nothing") scenario is simulated to serve as term of comparison. As many measures of mobility plans need some time to be made operational (e.g. building new infrastructures) the simulations make reference to a certain number of future time thresholds.

The model will produce several indicators to assess the effectiveness of the plan. In more detailed models, it will be possible to zoom in specific zones to observe more detailed results.

BOX THE HARMONY MODEL SUITE: EXAMPLES OF USE CASES APPLICATION

The **HARMONY MS** has been used to test several modelling **use-cases**, simulation scenarios, and results that were produced through the HMS in four of the project's pilot areas, namely Rotterdam (NL), Oxfordshire (UK), Turin (IT) and Athens (GR). The simulation scenarios were chosen for each city that pertain to the three interdependent levels, namely the strategic level, tactical level and operational level. The simulation scenarios along with the generated results for each city have been used to demonstrate the various functionalities for each of the three levels, the required input data, key performance indices, and how to interpret the results. Most importantly, it allows to underline how the HMS can be used by researchers, practitioners, and planners to better design their cities and make the urban mobility landscape more efficient, equitable and sustainable.



As first example, the application of the **HARMONY tactical freight simulator** to a case study for **zero emission zones in Rotterdam** is reported.

As part of a broader vision for emission-free city logistics, the city of Rotterdam plans to introduce a zero-emission zone in combination with urban consolidation centres (UCCs) at the outskirt of the city to generate a shift to zero-emission vehicles. For the design of this zero-emission zone many research questions arise that require a systematic analysis of the impacts of the transition scenarios on the freight demand patterns, the use and market shares of new (zero-emission) vehicles, and the impacts of truck flow and emissions. As a case study heterogenous transition scenarios have been implemented for each logistic segment into the Tactical Freight Simulator and the system wide impacts have been analysed. The model is multi-agent, empirical and shipment based and simulates long-term tactical choices (distribution channel choice, shipment size and vehicle type choice, sourcing) and short-term tactical choices (tour formation, delivery times).

Results shows that the impact of UCCs is not trivial: we can see a small increase in vehicle kilometres travelled (VKT) overall: +0.25% which can be attributed to the rerouting of shipments through the UCCs. Calculations confirm that emissions are reduced dramatically, by 90%, inside the Zero Emission Zone. At the city scale this corresponds to a reduction of almost 10%, as most freight related traffic is generated by the port and involves long haul HGV transport that do not enter the city centre. At a regional level the reduction of impacts is very small. More measures are needed if more ambitious reductions in emissions are to be achieved.

In **Oxfordshire**, the **HARMONY MS Strategic Simulator** has been used to assess the impact of a **new housing development**. The local plan of Oxfordshire foresees the building of 8,000 new homes by 2026 and 33.263 new dwellings in total by 2031. The Strategic Model Suite for Oxfordshire case study is a suite of aggregate and disaggregate regional economic, demographic forecasting, land-use transport-interaction and land development models for spatial planning.

To evaluate the impact of a new housing development in Oxfordshire, four Strategic models (DFM, REM, LUTI and LDM) have been applied. The results present that Oxfordshire's population is expected to rise to 832,300 (+21%) and the number of jobs to 432,000 (+11%) in 2030. Thus, new dwellings and transport infrastructure will be built to support new population and job positions. LUTI results reflect new mobility patterns by 2030 and show how the housing and jobs accessibility will be formed around the new housing locations. They also indicate which of these locations are more suitable to build on and which of them are more preferable, i.e. where higher demand and prices are expected.

The LUTI model shows flows of people travelling with car much more intense than the ones travelling with bus, both concentrated in the major roads of the city centre. In 2030, the flows of the two transport modes are predicted to increase in the western, eastern and some parts of the northern ring roads, while the flows in the local roads inside the town centres will decrease. With respect to population, Witney faces the greatest population change from 2019 to 2030, while Thame and some parts of the city of Oxford follows. Chipping Norton, Benson and Didcot also show a notable change.

To understand how a new housing development will change the area, the accessibility around job and housing locations are evaluated. The scores of the jobs' accessibility stays relatively the same in 2019 and 2030. For both car and bus the biggest difference of 4.5% occurs in the city of Thames. Additionally, a difference of around 3% (for bus) occurs in the regions near the cities of Witney and Chipping Norton. For the rail network the highest value of 2% is found only in the city of Bicester, while for bus network the city of Bicester and its surrounding area presents the highest negative change (-4.5%).

These results confirm that the HARMONY model suite constitutes a powerful tool that can support policy – making, spatial and transport planning and can be used to explore the impact of different scenarios. New housing development is one of them, but the methodology of this tool can be utilized in the future to test and access multiple scenarios in Oxfordshire, like the new high-speed railway from London to Birmingham, post-pandemic, post-Brexit and climate crisis periods.

The HARMONY MS has been applied in **Turin** to simulate the impacts of **urban vehicles access regulation**, implementing a combination of measures in order to support mode shift from private cars as well as the diffusion of cleaner vehicles. In fact, Turin municipality pursues the goal of rebalancing the demand for transport between collective and individual modes, with the objectives of road congestion reduction, mode shift and air pollutant and GHG emissions reduction. The area of analysis in HARMONY is the Turin Urban Functional area, which includes the municipality of Turin and 87 municipalities within the province of Turin.

The application has been implemented on top of reference assumptions on land use developments and new public transport infrastructures, in place at the year 2030 as reported in the SUMP of the Turin Metropolitan area, published in July 2021. On one hand, there are transport infrastructure projects aiming to improve public transport services at urban and inter-urban level (metro and tram lines as well as metropolitan railway network); on the other hand, some land use development projects related to university, health and public administration office are considered for their relevance also at metropolitan scale.

Concerning Urban Vehicles Access Regulation, the following measures are considered at the projection year 2030: the temporal extension of application of Limited Traffic Zone in the central area of Turin municipality, traffic calming areas implemented extensively in Turin municipality, as well as in the neighbouring municipalities[18], the application of a Low Emission Zone in the area including several municipalities, assuming that only vehicles complying with Low emission standard (minimum Euro 6, as well as hybrid and electric vehicles) can travel within the area. The municipalities involved are the same considered in the Air pollutant emission winter Emergency Plan[19] already in place in the North Italian regions.

The modelling application has been tested focusing on the **tactical and operational levels of the HARMONY MS,** linked with some models of the **strategic level**. As a result of the implementation of urban access regulation measures, two impacts are simulated: (i) car demand related to vehicles not complying with LEZ requirements and travelling to / through the LEZ is forced to change mode, (ii) car demand of vehicles complying with the LEZ is reacting to the implementation of ZTL and traffic calming areas, i.e. changing travel path. The modal shares show a decrease in car demand by about -8% in both peak and off-peak hour and an increase especially for bus (5% in peak hour and 6% off-peak). Rail (including metro and tram) and bike modes are also increasing their mode share in the range of 1%. In terms of CO2 emissions, a reduction with respect to the base year is observed, mainly due to the car vehicle fleet composition projections (where conventional vehicles decrease their relevance in the stock) but also explained by the mode shift from car to the other modes.

18 Settimo Torinese, Venaria Reale, Collegno, Rivoli, Grugliasco, Orbassano, Moncalieri, Nichelino.

19 http://www.arpa.piemonte.it/approfondimenti/temi-ambientali/aria/aria/semaforo-qualita-dellaria-pm10

7. Roles and responsibilities when developing a Transport Model to support a SUMP

Transport models are developed by experts holding the required knowledge and experience as well as the necessary specialised software. Nevertheless, especially when the transport model is developed for a local administration to support an urban mobility plan, other actors play a role.

One actor is the **local authority**, which ultimately should be the owner of the model and holds the political responsibility for the content of the SUMP. Another actor is the **planner team**, which is the technical arm of the local authority regarding the definition of the content of the SUMP. A third actor consists of **stakeholders**. There can be different types of stakeholders; some can be transport operators (e.g. the providers of urban and non-urban public transport, car-sharing companies, etc.), others can be associations of specific categories of citizens like cyclists, disabled people, retailers and so on. Stakeholders can be involved in the definition of the SUMP in one form or another as they represent interests that can be affected by the plan.

As different actors are involved in the planning process, they are necessarily involved also in the development of a transport model conceived to support the plan. The first role of the local authorities is **to start the project for developing a model**. So, preliminarily to modelling work, the local authorities should prepare the ground. Since in most of the cases external expertise is needed, the starting point is to define the requirements for the model and mobilise the required resources. The requirements for the model should consider the specific needs of the local area as well as guidelines issued by national authorities or other entities. At the same time, in this phase it is of utmost importance that realistic requirements are set, and adequate resources are made available. Local authorities should also be prepared to interact with the modellers and to facilitate the interaction of modellers with planners and stakeholders.

When the modelling work starts, the role of local authorities is mainly to guarantee a **smooth dialogue with modellers**, remaining consistent to the initial agreements, avoiding as much as possible to add requirements or to change the objectives when the work has already started. The modellers need to involve the local authorities and the planners during the design phase, because the requirements for the model – the type of measures it is expected to simulate and the type and detail of indicators it is expected to provide – are a fundamental input. Ideally, they should be specified already in the Terms of Reference, but in the initial phase there is room for clarifications and adaptations. Once this phase is completed, modifications to the structure of the model are much less feasible, especially if deadlines should remain the same. For this reason, a good interaction involving should be guaranteed with a joint effort.

Stakeholders should also be involved in the initial phase as they might raise useful suggestions. However, stakeholders are often sensitive to very specific aspects which can easily be too detailed to be handled within a transport model. So, they should be made aware of the methodological scope of the model.

During the **data collection and elaboration phase as well as during the implementation phase**, modellers should work almost independently. The cooperation of other actors should be provided for the data collections, making available any relevant information. Transport operators are often reluctant to disclose data on their demand; moral suasion the local authorities can exert on them can be helpful.

During the **calibration phase**, local authorities and modellers should keep open a dialogue to agree on when the calibration of the model can be considered completed. As already mentioned, the calibration phase is complex and is very difficult to plan. A reasonable level of calibration is required to ensure that model estimations are sufficiently reliable. On the other hand, the calibration work cannot last too much time both because the elaboration of the SUMP has its own deadlines and because there is a fixed number of resources available. In the most favourable cases, especially when the Terms of Reference envisaged a realistic time and budget, the calibration is achieved within the expected time, but the scenario where a fully calibrated model is not ready at the planned deadline cannot be excluded. In this scenario, the role of the modellers is to be transparent, and the role of local authorities is to be flexible.

When the **model is ready for the application**, the temptation is to test everything. However, this is practically impossible. Without a reasoned plan for the modelling tests, the risk is that much work is done without achieving clear results. For this reason, local authorities and planners should discuss internally and with the modellers to agree on a realistic set of preliminary tests. Planners should be responsible for providing modellers with the modelling inputs in a format consistent with the model structure (shared between modellers and planners in the design phase).

Stakeholders might also want to see the results of the tests and contribute to the definition of the plan. It is important that the local authorities establish clear rules on how the stakeholders can contribute and directly manage their involvement, filtering the interaction with modellers to ensure that external suggestions are consistent with the simulation plan.

TABLE 6 DISTRIBUTION OF ROLES WHEN DEVELOPING A TRANSPORT MODEL TO SUPPORT A SUMP

Phase	Local authorities	Planners	Stakeholders	Modellers
Preliminary phase	- Prepare clear, comprehensive, and realistic Terms of Reference - Mobilise adequate financial resources - Identify a point of contact for planners and modellers - Plan for training internal staff on using relevant software			
Model design	- Answer timely any question raised by modellers - Facilitate interaction between planners and modellers - Provide timely feedback when the model description is submitted	- Be available to discuss with modellers about the content of mobility plan - Be aware that some planning measures can be outside the model scope	- Be available to discuss with planners and modellers - Be aware that some planning measures can be outside the model scope	- Discuss with planners about the expected content of the mobility plan - Design the model considering requirements, data availability, time availability for implementation and calibration - Produce internal technical notes addressing all details - Produce a clear and comprehensive description of the model for the local authorities and the planners - Provide the planners with the list of model variables and parameters that can be used to simulate measures

Phase	Local authorities	Planners	Stakeholders	Modellers
Data collection and elaboration	- Help modellers with contacts with stakeholders	- Provide relevant data already collected	- Provide data requested if available	- Collect data from existing data sources - Ask stakeholders about potentially useful data - Carry out surveys if part of the agreed data collection phase - Elaborate data
Model implementation		- Be available to discuss with modellers		- Implement the model
Model calibration	- Be aware that formal deadlines and good calibration can conflict to each other. Agree with modellers about the best compromise - Provide timely feedback on the list of comparisons against observed data to prove the validity of the model. When the list is agreed do not ask comparisons against different data. - Do not argue on calibration on the basis of data not previously shared with modellers			- Provide timely the local authorities with the list of feasible comparisons against observed data to prove the validity of the model. - Calibrate the model as best as possible with a reasonable time. Agree with local authorities about the best compromise

Phase	Local authorities	Planners	Stakeholders	Modellers
Model application	- Agree with planners and modellers a reasonable number of modelling tests - Agree with planners and modellers about the content of modelling tests - Be available to discuss with planners and modellers the results of modelling tests - Define rules and manage the involvement of stakeholders	- Agree with local authorities and modellers a reasonable number of modelling tests - Agree with local authorities and modellers about the content of modelling tests - Provide timely inputs about the implementation of measures - Be available to discuss with local authorities and modellers the results of modelling tests	- Provide contributions to the definition of the measures according to the rules stated by the local authorities	- Agree with local authorities and planners a reasonable number of modelling tests - Agree with local authorities and planners about the content of modelling tests - Implement modelling tests and prepare results - Discuss with local authorities and planners the results of modelling tests

8. Considering transport modelling in the SUMP steps

In the following, the main actions and elements essential for implementing transport modelling as part of the phases of the SUMP cycle are introduced. We identify crucial aspects and recommend concrete actions to the general guideline cycle, to encourage urban planners to better integrate transport modelling in their Sustainable Urban Mobility Plans.

More specifically, this chapter addresses the **4 different phases of the planning process mentioned in the European SUMP guidelines**[20].

FIGURE 4 THE 12 STEPS OF SUSTAINABLE URBAN MOBILITY PLANNING (2ND EDITION)

Source: Guidelines for developing and implementing a Sustainable Urban Mobility Plan, Second Edition, 2019

20 Rupprecht Consult (editor), Guidelines for Developing and Implementing a Sustainable Urban Mobility Plan, Second Edition, 2019.

8.1. Phase 1: Preparation and analysis

In the **first phase of a SUMP**, several steps are recommended in the above-mentioned SUMP cycle to prepare the process, ranging from the set-up of working structures and planning frameworks, to the analysis of the mobility situation – all this supporting a common goal, which should be a modal shift towards sustainable mobility.

The decision on the need and feasibility to implement a transport model supporting the planning process, and the assessment of available resources (human and financial) should be taken at the very beginning of the process.

Subsequently, the working structure being established should include transport modellers, either part of the administration or procured externally (see **step 01)**.

Then, **step 02** (determining the planning framework) and **step 0.3** (analysis of the mobility situation) will pave the way for the scoping of the model. Importantly, **step 3.2 recommends analysing problems and opportunities for all modes**, and this is key in the definition of the model's requirements.

Availability and sharing of the data are crucial for well-informed planning and decision-making procedures. This is particularly the case for transport modelling, which cooperates with data owners like public and private transport operators. To that end, working with open data and architectures as well as standard interfaces is recommended.

After a wider consultation and analysis of problems and opportunities, the city and stakeholders should then build a common vision, including incentives, risk, and profit sharing, ensuring that every stakeholder can benefit.

FIGURE 5 SUMP PHASE 1, "PREPARATION AND ANALYSIS"

Source: Guidelines for developing and implementing a Sustainable Urban Mobility Plan, Second Edition, 2019

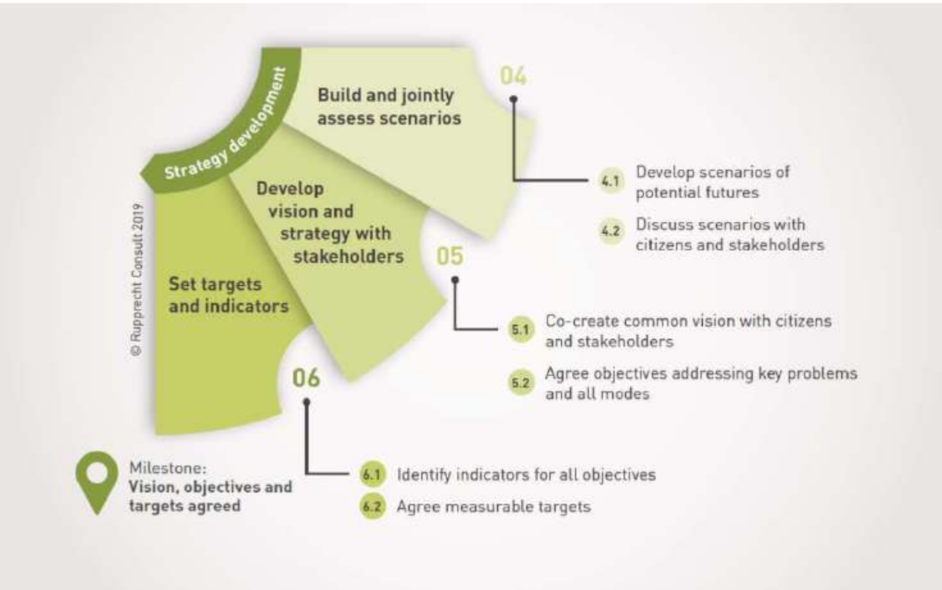
8.2. Phase 2: Strategy development

In the **second phase of a SUMP**, a certain number of actions is recommended to prepare the process, particularly in relation to building and jointly assessing future scenarios, developing a common vision and objectives with stakeholders, as well as setting targets and indicators.

It is in this phase that key elements for transport modelling are set – more specifically in **step 4.1,** which consists of **developing scenarios of potential futures.** Within a model, future scenarios for population growth, land use, transport networks and mobility behaviour can be developed to assess the impact of these changes. This enables urban planners to determine for instance whether a new motorway lane is needed, how the public transportation network should be expanded to best meet demand, where new bus terminals or logistics hubs should be located, or how people's mobility behaviour will change with new mobility services such as autonomous vehicles.

In that phase of the SUMP process, it is also paramount to create an evaluation framework with key performance indicators (KPIs) and measurable targets, to be able to measure the impact of the SUMP on travel behaviour against local transport policy goals. Transport modelling can also play a supporting role in monitoring progress and adjusting measures (see step 7.4).

FIGURE 6 SUMP PHASE 2, "STRATEGY DEVELOPMENT"



Source: Guidelines for developing and implementing a Sustainable Urban Mobility Plan, Second Edition, 2019

8.3. Phase 3: Measure planning

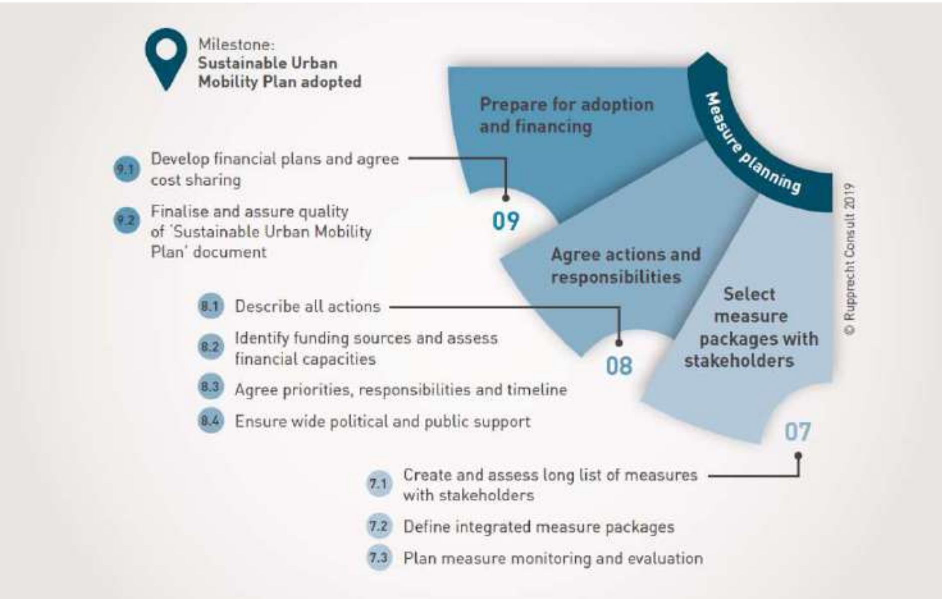
In the **third phase of a SUMP**, the following actions are recommended to prepare the process: select measures packages with stakeholders, agree actions and responsibilities, but also develop financial plans and assure the quality of the SUMP. It is in this planning phase where transport modelling plays a major role in helping to

define integrated measure packages and plan measure monitoring and evaluation (steps 7.2 and 7.3). Following the definition of actions and responsibilities, transport models can help to shape and build packages of measures. Simulations of mobility or traffic are capable to go beyond the representation of the current state on the roads. The major application of transport models is to predict the effects of introducing measures, and can therefore help to shape packages of measures, e.g. identify what interventions may be required and cluster them strategically.

Modelling tools set up data and information for updating cities' SUMPs and provide detailed analyses and verification of effects on mobility management. They are also simulation tools to convince residents of cities to proposed SUMP and other solutions. Modelling outputs can also include economic appraisal and business case development, forecasts of aggregate travel costs and benefits, input to externalities modelling (such as quantum of emissions), etc. For instance, transport models can produce an assessment of scenarios involving pricing policies (e.g. fuel, tolls, parking charges), transport infrastructure provision and service improvements.

In addition to forecasting, transport models enable the generation of quantitative measures to provide key indicators in the business case assessment and economic appraisal. A transport model structure includes the required outputs, such as network performance indicators including vehicle-hours and kilometres of travel, passenger-hours and kilometres, congestion indicators and tonnages of emissions, etc.

FIGURE 7 SUMP PHASE 3, "MEASURE PLANNING"



Source: Guidelines for developing and implementing a Sustainable Urban Mobility Plan, Second Edition, 2019

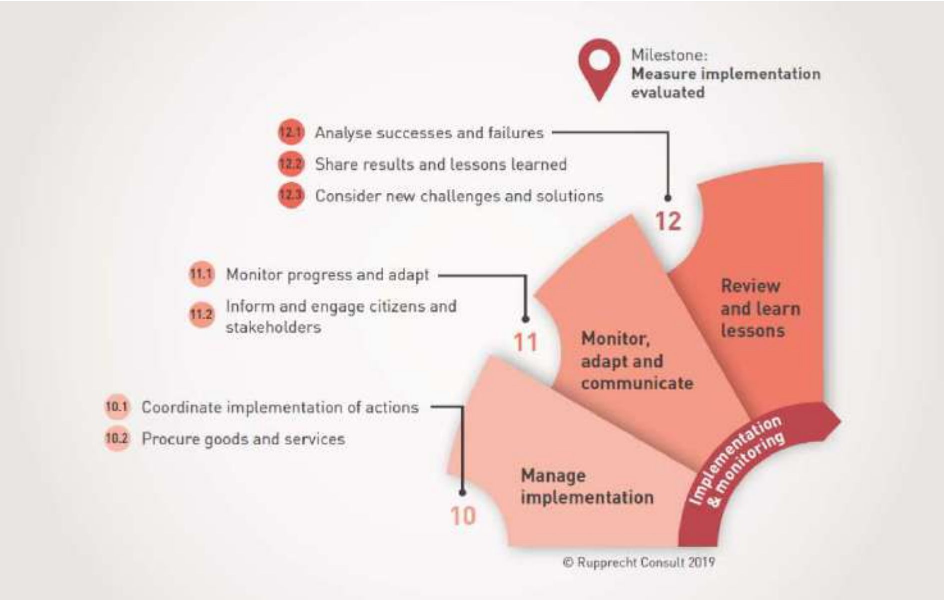
8.4. Phase 4: Implementation and monitoring

In the **fourth and last phase of the SUMP cycle**, transport modelling can be useful in relation to **step 11.1**, that is to say with **monitoring progress and adapting**.

Transport modelling establishes a solid mobility monitoring mechanism for SUMPs. It formulates the indicators that will be integrated and monitored and allows for verification as well as demonstration of implementation results. Modelling can support cities with monitoring impacts of a SUMP implementation, as part of an ex-post evaluation. The purpose of ex-post evaluations is to learn and develop knowledge for future plans or projects. In doing so, models can help to analyse what has happened since the launch of the Sustainable Urban Mobility Plan and support an update of the SUMP – or part of it – in the future.

Modelling indeed assesses the realised benefits of a SUMP or a given measure, e.g. by analysing the efficiency of transport infrastructure investments, and is an important part of understanding the efficiency of SUMP measures. Hence, it is a central part of urban planning.

FIGURE 8 SUMP PHASE 4, "IMPLEMENTATION AND MONITORING"



Source: Guidelines for developing and implementing a Sustainable Urban Mobility Plan, Second Edition, 2019

Annex: Short glossary of commonly used transport modelling terms

This glossary explains the meaning of terms commonly used referring to transport models. A clear understanding of these terms is helpful to interpret model results and to define expectations from the model. Terms are presented in alphabetic order rather than in any logical order.

Activity. An occupation enjoyed in a specific location in a specific period of time. For instance, "working" or "resting at home" are activities. Since many activities can be performed only in specific places, personal mobility is a condition for individuals to perform activities.

Assignment. The phase where a transport model uses appropriate algorithms to estimate what route(s) is/are used by movements between two zones and, therefore, how many vehicles or passengers can be expected on each link in the modelled period of time.

Attractor. A quantitative measure of the importance of one zone as destination for a specific trip purpose.

Calibration. The phase where some parameters are tuned to drive a transport model towards a realistic representation of the observed mobility.

Distribution. The phase where a transport model uses appropriate algorithms to estimate how many movements generated in one zone have destination in each zone.

Feeder mode. A mode of transport used for a minor part of a multimodal chain (for instance, bicycle can be used as feeder mode of train to reach station from home).

Generation. The phase where a transport model uses appropriate algorithms to estimate how many movements are generated in one zone.

Link. The stylised representation of one section of the network (a road or part of a road, a segment of a metro line and so on) connecting two nodes.

Link capacity. The theoretical number of vehicles that can use a link in a given period of time (usually one hour for road link capacity). Generally, roads capacity is expressed in terms of passenger cars units equivalent.

Link load. The observed number of vehicles using a link in a given period of time.

Main mode. The mode of transport used for the largest part of a multimodal chain (for instance, train is the main mode for a multimodal chain where the feeder mode to reach station from home is bicycle).

Modal split. The distribution of mobility demand (trips or passengers-km) across alternative modes of transport. Usually, modal split is expressed as market share (modal share) for each mode.

Mode of transport. A private or public transport system that can be used to move between two zones.

Multimodal chain. A sequence of modes of transport used to make a trip between the origin and the destination.

Network. The stylised representation, in terms of nodes and links, of the infrastructure(s) (e.g. roads, railways) which individuals and vehicles can use to move between different locations.

Node. The stylised representation of one point of the network. A node can represent a specific location (e.g. a tram stop a crossroad) or can be just used to provide a more realistic representation of the topology of the network.

Origin-Destination matrix. A table reporting the number of movements between all zone pairs in a specific period of time (e.g. peak time or one day).

Passenger-km. Aggregated measure of mobility in a given area, obtained as product of the number of trips and the distance covered. This measure is often used as it is more informative than the simple number of trips.

Policy scenario. A set of assumptions regarding the future state of exogenous variables of the model (e.g. configuration of the network, user prices) where some modifications are considered in comparison to the Reference Scenario in order to represent one or more policy interventions. The effectiveness of these interventions is assessed comparing model outcomes under these assumptions and the same outcomes under the assumptions of the Reference Scenario.

Reference scenario. A set of assumptions regarding the future state of exogenous variables of the model which are considered the most likely ones or the case when no policy interventions are applied or just an appropriate term of comparison to assess the effect of the content of the Policy scenario(s).

Route. A sequence of nodes and links used to complete a trip between two zones.

Skim matrices. Tables produced by a transport model reporting measures of travel distance, traversal cost, travel time by mode of transport between each zone pair.

Study area. The part of the territory under analysis, for which the model receives inputs and is expected to produce outputs.

Tour. A ordered sequence of trips. The origin of the first trip corresponds to the destination of the last trip (e.g., the sequence of trips: "home to work" – "work to shop" – "shop to home" is a tour). Trips composing a tour can occur at different times of the modelled period (e.g., "home to work" in the morning while "work to shop" and "shop to home" in late afternoon). Between trips of a tour, a kind of activity is engaged.

Transit line. A description of a specific transport service (e.g, a bus service) in terms of route (departure node, final node, intermediate stops), time between stops, departure and arrival times or headway.

Trip. A movement between one origin and one destination made for one specific purpose and using a specific mode of transport.

Trip purpose. The reason why a specific trip is made, e.g., commuting to workplace, commuting to school, shopping, escorting, return to home. The trip purpose is strictly associated (but not equivalent) to activity. For instance, purpose "commuting" is associated to activity "work"; purpose "return to home" can be associated to different activities like "resting at home" or "housekeeping".

Trip rate. The average number of trips made for a specific purpose by an individual belonging to a specific population group in a given period of time (e.g., one day, one year).

Utility function. A mathematical expression used within the model to compute the utility (actually, often, disutility) associated to a specific alternative (a mode of transport, a destination). The utility function combines various elements like travel cost and travel time.

Validation. The phase where the results of the model are compared against observed data to check that the model, after its calibration, is capable to provide a realistic picture of the mobility in the study area.

Value of travel time. A monetary equivalent of time spent travelling (or, more precisely, a monetary equivalent of the individual utility deriving from saving a certain amount of time spent travelling).

Vehicle-km. Aggregated measure of mobility in a given area, obtained as product of the number of vehicles and the distance covered.

Zone. A portion of the study area for which the model considers the mobility originated and attracted (and the mobility within the area).