



HARMONY MODEL SUITE: AN INTEGRATED SPATIAL AND MULTIMODAL TRANSPORT PLANNING TOOL TO LEAD A SUSTAINABLE TRANSITION TO A NEW MOBILITY ERA

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Abstract

The importance of integrated spatial and transport planning in regional and urban policy making stems from the fundamentally interdependent relationship of land-use, transport demand and transport supply. The adoption of integrated approaches would offer local authorities the possibility to steer urban development towards simultaneously pursuing economic competitiveness, social cohesion, mobility and environmental sustainability. This is even more important in the current situation where the latest developments in innovative mobility services and technology would significantly influence the passenger and freight transport systems. Against this background, the HARMONY research project envisages developing a new generation of harmonised spatial and multimodal transport planning tools which comprehensively model the dynamics of spatial organisation and changing transport sector, taking into consideration the dynamics that new services and technologies introduce. The ambition is to represent new forms of mobility for freight and people in order to enable metropolitan area authorities to lead the transition to a low carbon new mobility era in a sustainable manner. This paper is intended to provide a general overview of the HARMONY project and a description of the conceptual architecture designed for the development of the integrated modelling system and the interaction among the components.



1. Introduction

Metropolitan areas should be at the heart of any attempt to address the carbon neutrality climate goals, since they are currently responsible for almost over two thirds of greenhouse gas emissions and energy consumption. In an era with major improvements in technology and transport modes, private vehicle ownership and use have been still growing, due also to expanding urban sprawl where distances between functional destinations (workplaces/shops, etc.) have increased. Widespread congestion has become the norm in many cities, reducing people's quality of life through negative externalities, such as pollution or increased travel times.

While public transport systems could provide a satisfactory alternative to private cars, accessible public transport requires large subsidisation and some routes operate with very low ridership making it unsustainable in its current form. Additionally, administrative boundaries do not always cover entire metropolitan areas, resulting in disjointed mobility policies and transportation systems. This often leads to inefficiencies, poor regional connectivity and accessibility and inconsistent fares or schedules within metropolitan areas.

Lately, new disruptive mobility services and technologies present a possible solution. However, public authorities face several challenges when it comes to harmoniously integrating these developments into spatial and transport plans to improve citizens' wellbeing and achieve environmental targets.

With this respect, latest regional spatial and transport system development discussions on the European scale are characterized by polycentric planning with urban-rural co-operation and sustainable, green, multimodal transportation, aiming towards simultaneously pursuing economic competitiveness, social cohesion, travel and environmental sustainability (Rauhut, 2017, Rupprecht et al., 2019). A key requirement for the realization of sustainable metropolitan and urban development is the investigation and application of appropriate spatial and transport planning policies and investments.

The importance of integrated spatial and transport planning in regional and urban policy making stems from the fundamentally interdependent relationship of land-use, transportation demand and transportation supply, which has been extensively investigated from researchers and practitioners of the field (Bertolini, 2017; Levinson and Krizek, 2018; Wegener and Fürst, 1999). Metropolitan, regional and urban planning organizations are, therefore, faced with the challenge of informed or evidence-based decision making with regards to future land use, transport or integrated land-use and transport planning that may ideally contribute to sustainable development.

The objective of this paper is to present the initial conceptual architecture of an integrated spatial and transport planning simulation platform that deals with the aforementioned challenges. The development of this platform is conducted within the H2020 funded project HARMONY. The paper is structured as follows. Section 2 provides an overview of the HARMONY project. Section 3 presents the conceptual architecture of the simulation platform/model suite. Section 4 concludes the paper.



2. Overview on the HARMONY project

HARMONY is a European project funded by the European Commission within the H2020 Framework Research Programme (www.harmony-h2020.eu). 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”. Its consortium gathers 21 members from 9 different European countries, led by the University College of London and working together for three and a half years since June 2019. The consortium includes Technische Universiteit Delft, University of the Aegean, University of Wolverhampton, TRT, MOBY, Aimsun, and Institute of Communication and Computer Systems as key partners of the scientific and theoretical activities.

In the context of expanding urbanisation and evolving transport challenges, HARMONY aims to support public authorities and service providers in transport and spatial planning. More specifically, the project plans to develop an integrated model suite, i.e. a software-agnostic platform bringing together not only transport and spatial planning models but also regional community growth models. Stakeholders from both the public and private sector are 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 electric Autonomous Vehicles (AVs) and drones take 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 will be 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).

3. The conceptual architecture of HARMONY Model Suite

Among the main objectives of the HARMONY project lies the investigation, modelling and evaluation of new disruptive mobility services and technologies for both passenger and freight mobility. New mobility services and technologies introduce an added level of modelling complexity in transport demand and supply models. Such a complexity springs from the need to realistically emulate their organizational, behavioural and operational characteristics. In addition, new technologies like AVs and drones or personalized multimodal app-based mobility services - e.g. ride



hailing, Mobility-as-a-Service (MaaS) - can only be represented using disaggregated demand/supply modelling approaches (microsimulation) based on the activity-based modelling paradigm (Jittrapirom et al., 2017). As such, demand model frameworks in activity-based models should be extended with new behaviourally realistic model structures for monomodal and multimodal app-based mobility services, considering also latent traits that account for sociodemographic changes and technological advancements (Kamargianni et al., 2019). At the same time, the operational dynamics that new services and technologies introduce need to be integrated into large-scale simulation models (Kamargianni et al., 2019; Basu et al., 2018), enabling the assessment of energy and emissions levels. Operational models that replicate within-day supply-demand interactions need to account for the complex operational characteristics of existing and new usually private-sector-led mobility services like shared, on-demand services, Mobility-as-a-Service, autonomy and air mobility.

Finally, integrated model systems require a large amount of diverse data used for building, estimating, calibrating and validating the model system itself (e.g. household survey data, land use data, demographic information, transport network data and other urban form indicators). Due to potential data availability challenges that integrated models inherently come with, there is a need for a data collection and model development plan/strategy to ensure consistent data developments and standards.

Existing limitations and challenges for integrated model development described above have guided the conceptualization of the HARMONY MS, which is envisioned as a multi-scale, software-agnostic, integrated model system (mainly based on the activity-based approach). The HARMONY MS aims at enabling end-users such as planners, decision makers, researchers and transport operators/providers to couple/link independent models and analyse a portfolio of regional and urban interventions for both passenger and freight mobility, including policies and capital investments, land-use configurations, economic and sociodemographic assumptions, travel demand management strategies and new mobility service concepts.

The main focus of this paper is the description of the conceptual architecture of the HARMONY model suite, which consistently integrates new and existing sub-models with a multi-scale approach, consisting in the Strategic Level (Long-term), the Tactical Level (Mid-Term) and the Operational Level (Short-term). Depending on the examined scenario, each level of the HARMONY MS could be applied either integrated or in isolation, given adequate availability of exogenous data inputs.

- The *Strategic Level* is mainly composed of regional economic, demographic forecasting, land-use, spatial freight interaction and long-term mobility choice models. It operates on a long-term horizon (e.g. year-to-year) and is mainly responsible for generating i) disaggregate household and firm population and the locations for different types of activities, ii) aggregate commodity flows between employment sectors and iii) long-term mobility choices of households and individuals (agents).
- The *Tactical Level* is made of a fully agent-based passenger and freight demand model, representing passenger and freight agents' choices on a day-to-day level. The output from the sub-models is represented by: i) disaggregated demand in the form of agents' daily activity schedules (trip-

- chains), and ii) disaggregated demand in the form of truck tours and their corresponding trips.
- The *Operational Level* represents the transport supply and demand interactions at high granularity (e.g. second to second, minute to minute). It can be characterised as a multimodal network supply model system that is responsible for loading the demand into different types of networks, while simultaneously capturing travellers' route choices and dynamic schedule re-evaluation choices due to varying 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

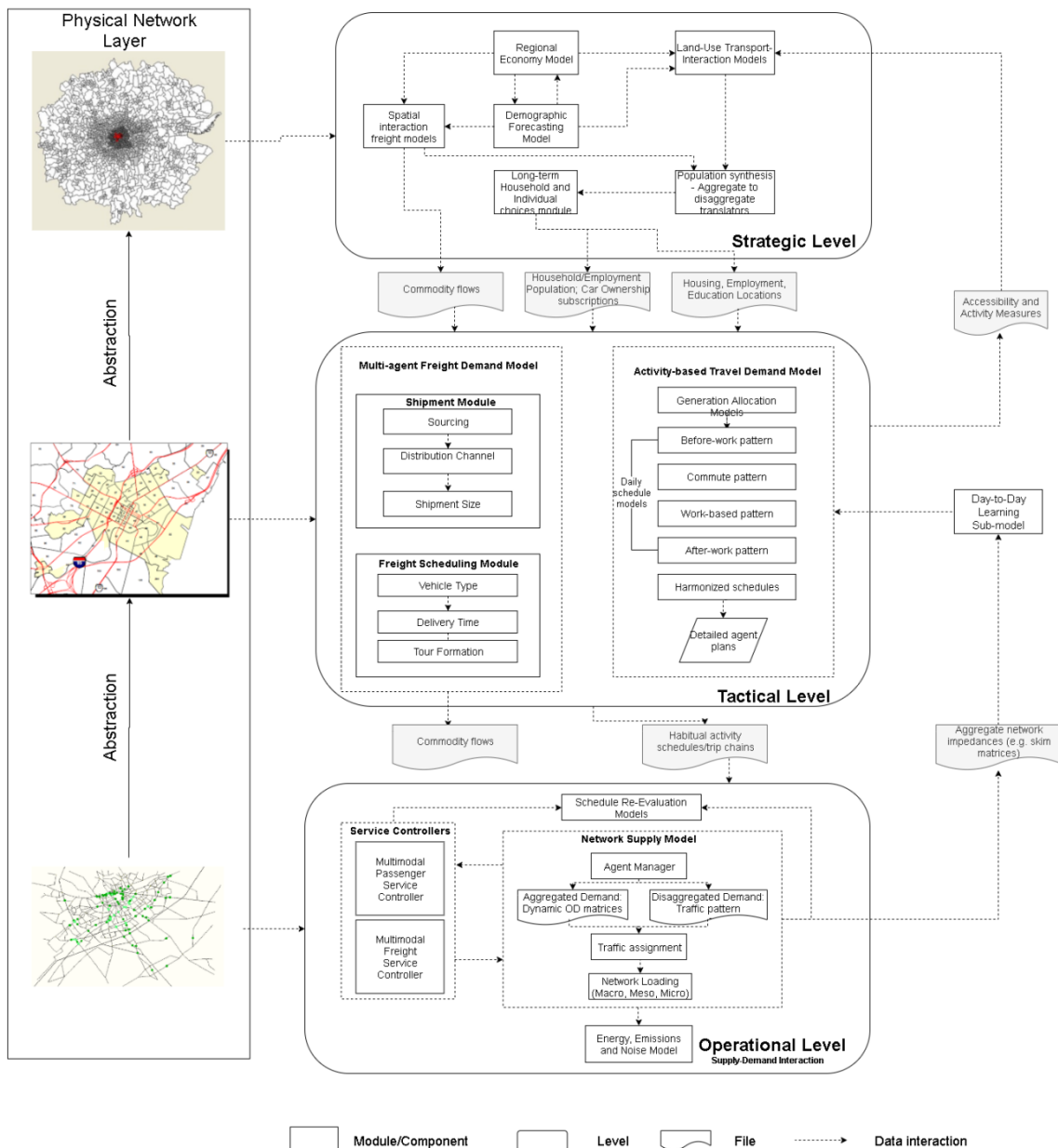


Figure 1 - The HARMONY MS Conceptual Architecture



A crucial consideration for developing integrated land-use and activity-based transport model systems, is the system's ability to converge to a stable solution. Analysis of detailed geographical, spatial, modal or demographic segments requires higher level of convergence in order to ensure that the differences between alternatives are attributable to the intervention being tested, and not due to "noise" resulting from the model system configurations (Castiglione et al., 2015). Therefore, to be used in an application context, the model system needs to produce consistent outputs when seeded with similar input. Due to the existence of three autonomous but also interdependent levels within the HARMONY MS, equilibrated or stable solutions need to exist both within and between the levels by processes of iterative feedback.

First, an equilibrated solution needs to exist between the various models of the Strategic Level. More specifically, spatial interaction models represent the demand for land in the residential and other activity sectors and land supply or development models the supply for it. With supply being the attractor for the spatial interaction models and demand being the attractor for supply through accessibility, equilibrium can be ensured via local iterations between them. Furthermore, network supply/assignment model convergence constitutes a crucial precondition on the way to achieve overall model system convergence. Depending on the nature of the traffic assignment model, static or dynamic user equilibria need to be achieved via well established procedures from the literature.

Having secured within level stable solutions, it is also equally important to achieve an overall system convergence via inter-level iterative feedbacks. Land use and transport demand model integration, i.e. Strategic-Tactical integration, should not assume to be in perfect equilibrium, because land use changes tend to "lag behind" transport system changes (Moeckel et al., 2018). To account for this, activity-based accessibility measures for households, firms and individuals generated from the Tactical Level are provided as input to the Strategic Level, and thus capturing the impact of travel impedances in housing, employment and education location decisions.

HARMONY aims to apply the integrated model system (or part of it) in four metropolitan areas and evaluate the impact of different modelling exercises and spatial or transport planning scenarios: Oxfordshire (UK), Rotterdam (NL), Turin (IT) and Athens (GR). The application and evaluation of modelling use-cases will enable HARMONY to generate evidence-based recommendations with regards to Sustainable Urban Mobility Plans and indications of how new spatial and transport planning policies and investments can contribute to sustainable developments within the HARMONY metropolitan areas, and potentially, to other metropolitan areas on European scale.

3.1 The Strategic Level

The Strategic level is the most upstream component of the HARMONY MS, the one with the highest level of abstraction and the longest timeframe. The ultimate goal of the Strategic simulator is the application to the metropolitan areas to explore and

quantify the impact of economic growth, spatial redesign and other strategic co-created scenarios. The models included at this level consist of:

- i) a *demographic forecasting model* that generates the population disaggregated into age-sex cohorts, modelling both standard demographic processes (e.g. ageing) and other processes impacting on household status or membership (e.g. marriage).
- ii) A *regional economy model* that generates future employment by economic sector (including services, health and educational activities), and therefore its influence on income level and on the demand for physical travel.
- iii) A *Land Use Transport Interaction (LUTI) model* that takes inputs from the aggregate economic and demographic forecasting models, allocating these activities to small zones using spatial interaction approaches consistent with the transport activity models at the tactical level.
- iv) A *spatial interaction freight model* for strategic planning to capture freight generation, trade and outsourcing logistics, considering both regional freight demand (directly related to regional economic development) and interregional / international movements.
- v) A *synthetic population model* as translator for the disaggregation and distribution of aggregate variables to the population of households and firms.
- vi) A *Long-term Household and Individual Choices module* that enriches the synthesised population with long-term household- and individual-level mobility choices, while adding a new level of responsiveness in the socio-economic modelling process. Examples are vehicle ownership, mobility service subscription, etc.

In general, the Regional Economy model estimates regional employment by industrial sector, based on the competitiveness of the region compared to other regions. This information provides regional controls for demographic forecasting model and the Spatial Interaction freight model. The Demographic forecasting model makes predictions on population evolution over time, which in turn, define the demographic explanatory variables used by the Land Use Transport Interaction model (as well as a potential feedback to the regional Economy model). Land-use model generate information on population and activity location at spatial level. This information is processed and disaggregated by the synthetic population model, together with the input from the Long-term Household and Individual Choices module, in order to provide the passenger agent-based model at tactical level with the required information in a consistent manner. On the freight side, information from the Regional Economy model are processed to estimate commodity matrices, to be used as input for both the synthetic population model and the freight simulator at tactical level.

The process also requires feedbacks to steer the overall suite at this level to an equilibrium: more iterations may be required if certain constraints are not met. These constraints are use case- and scenario-dependent; for example, the Regional Economy model takes population projections as an input from exogenous sources and based on this data produces employment and income data that are passed to



the Demographic Forecasting model. Based on this input, the Demographic Forecasting model, in turn, produces a more refined prediction for future population growth. If the difference between this new population and the one considered in the Regional Economy model is greater than a certain threshold (margin of error), an extra iteration of the two models is necessary. This is repeated until a relative convergence is reached.

3.2 The Tactical Level

The Tactical Level is a fully econometric, agent-based demand model, operating on a day-to-day level. It takes input from the models at the Strategic Level (i.e. household and firm locations, socio-demographic characteristics, vehicle ownership, commodity production/consumption, fleet compositions) and estimates high-level decisions of both passenger and freight agents.

From a freight perspective, the Tactical Level includes models that capture the organization of freight distribution processes. It aims at establishing a comprehensive multi-agent simulation of the logistic decision making behind urban freight transport demand, representing individual firms and individual freight shipments. In freight transportation, most logistic decision-making takes place at the level of shipments: therefore, the framework includes an explicit simulation of shipments. Since freight transportation demand involves a large variety of decision-makers, choices are simulated at level of individual firms. This gives more advanced possibilities to simulate behavioural decision-making, and account for costs, and constraints that are in many cases agent specific.

More specifically, the Tactical Freight Simulator (TFS) is a multi-agent simulation model of urban freight transport demand. In freight transport decisions are made in two levels. The lower levels involve the decisions made on shipment level which are explicitly modelled in the TFS. A manifold number of factors influence the decisions made on freight transport markets (Marcucci et al., 2017). Thus, choices are simulated on the level of individual firms in a way that accounts for behavioural decision-making, and for costs, and constraints that are in many cases, agent specific.

To develop the conceptual framework of the TFS the markets, the agents and their choices and decisions need to be defined. To accurately conceptualise the logistics process the consumers and producers of goods are distinguished. The flows of shipments start from the production firms and are delivered to the consumers. These flows can either be direct or via one or more logistics nodes (distribution centres or transshipment terminals). Specifically, the decisions modelled in the TFS are vehicle choice, distribution channel choice, shipment size choice, tour formation and time of day choices. Producers and in case of outsourced transport, Logistics Service Providers (LSPs) define the size of shipments and the choice of distribution channels. Carriers and LSPs with own account transport form the tours and chose the type of vehicle. Finally, consumers set the time-of-day delivery requirements. On the other hand, the supply of transport is covered by carriers, LSPs and shippers with own account transport. Although local authorities provide the transport infrastructure, they are not represented directly in the TFS but their policies and behaviours are part of the scenarios tested by the TFS.



From a passenger perspective, the Tactical Level is based on a hierarchical series of interconnected behavioural/discrete choice models that estimate and capture the daily activity schedules (travel plans) for each agent. The tactical passenger simulator is based on the well-established SimAGENT model (Goulias et al., 2011). It is divided into two main model categories: the generation-allocation models and the daily schedule models. The first category includes models that are necessary for the daily schedule estimation. For example, an individual's decision to go to work is defined upon a binary choice model (Yes/No) with socio-demographic (and other) variables which are considered exogenous input variables. Similar models define non-work based main tours or a child's decision to go to school. The second category includes models that result in the derivation of daily schedules of individuals. These models are split into 4 sub-categories: a) worker models; b) non-worker models; c) student models and d) joint decision models. In a general form these models include mode choice models, activity location models, activity duration models, travel distance, stop location, home stay duration and others.

The model specification allows for the in-depth exploration of traveller behaviour, including the joint decisions of the household. For instance, a set of behavioural models is developed that will span across strategic and tactical decisions of a household on vehicle ownership and service subscription, including new forms of mobility such as AVs and services such as MaaS. The growing omnipresence of data (most of which is user generated), shifting trends, emerging needs of commuters, novel work patterns (e.g. remote working) and the introduction of new forms of mobility are all factors to be incorporated in Activity Based Models. The design of the Passenger Simulator aims to address the above challenge and allow for the architecture of the HARMONY Model Suite to host innovative add-ons or adjusted models to enable further exploration of these developments.

3.3 The Operational Level

HARMONY's operational simulator is an integrated dynamic demand and supply simulator, operating on a short-term horizon (with-in day simulations). Its main purpose is the evaluation of the transport network's performance, under different loading conditions (demand) and variable infrastructure and mobility services configurations (supply). It receives, as input, demand as daily activity schedules (for passengers) and round tours (for freight) from the tactical simulator and transforms them into routes of different types of vehicles that can represent the demand to be simulated. It is composed of dynamic travel demand modules that model and estimate travellers' dynamic routing and re-routing decisions, potential modal shifts and activities re-scheduling according to a range of events that might occur such as congestion, disruptions, accidents, etc. Such events are detected by a nowcasting module that is integrated, where possible, with real data sources for better representation of the supply. The dynamic demand models interact with a multimodal network model (be it meso- or microscopic) that emulates disaggregate vehicle movements and traffic conditions.

As part of transport supply, HARMONY's operational simulator aims to offer a number of controllers that emulate the daily operations performed by mobility and logistics operators towards managing and optimizing the services and meet the daily



demand (e.g. routing, scheduling, vehicle reallocation, etc.). In particular, modules for both passenger and freight mobility will be considered and these will indicatively include on demand services using autonomous vehicles, MaaS and crowd-shipping. The operational simulator will be developed based on a modular approach, with each module having the necessary interfaces for internal and external interoperability. Furthermore, each module will be developed using an agent/event-based approach and collectively will form controllers for the management of passenger, freight and air transport services.

Finally, a suite of existing open source energy, emissions and noise models complement the simulators and generate scenario performance data related to air quality, pollution dispersion and noise levels.

4. Conclusions

This paper presents an overview of the HARMONY MS and of its components, which is being developed to serve as a harmonised spatial and multimodal transport planning tool to analyse regional and urban policies and interventions for both passenger and freight mobility. An overview of the model suite methodological outline and the illustration of the interaction among the sub-models are provided.

The HARMONY model suite is structured on three different levels: i) Strategic (long-term) demographic land-use transport models, ii) Tactical (mid-term) people and freight activity-based models and iii) Operational (short-term) multimodal network models. Each level is made of different components interacting together, relying on their consistent integration approach and a structured convergence strategy. The platform is envisioned as a multi-scale, software-agnostic, integrated activity-based model system.

More details on the development of the model components and the results of their applications for the HARMONY metropolitan areas will be disseminated in future literature, as the model implementation process develops.

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