

# Integrated urban and transport modelling: the HARMONY Strategic Simulator - Oxfordshire application.

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## Summary

The HARMONY Model Suite is an integrated set of models aimed at capturing the dynamics and mobility patterns of metropolitan areas; it is structured over three different levels: 1) Strategic (long-term) demographic land-use transport models, 2) Tactical (mid-term) people and freight activity-based models and 3) Operational (short-term) multimodal network models. This paper presents the Oxfordshire application of the HARMONY Strategic Simulator: a New Housing Development (2030) scenario. This application involves a demographic forecasting model coupled with a regional economy model, both informing a land-use transport-interaction model and a residential land development model in the HARMONY web-based modelling platform.

**KEYWORDS:** Strategic planning, Urban modelling, Transport modelling, Sustainable mobility, Models integration.

## 1. Introduction

Reducing greenhouse gas emissions and energy consumption are primary goals for urban areas when designing and managing future and present transport infrastructures. Despite technological advancements and new mobility services constituting potential key tools to achieve those goals, the complexity of metropolitan areas and the difficulties in the integration of different developments in different sectors pose many challenges in the implementation of effective, holistic, all-encompassing transport and spatial plans. For this reason, local metropolitan authorities require decision support tools to plan, develop strategies and test scenarios for future infrastructure development or for present-day infrastructure optimal management (Lopane et al., 2022.a).

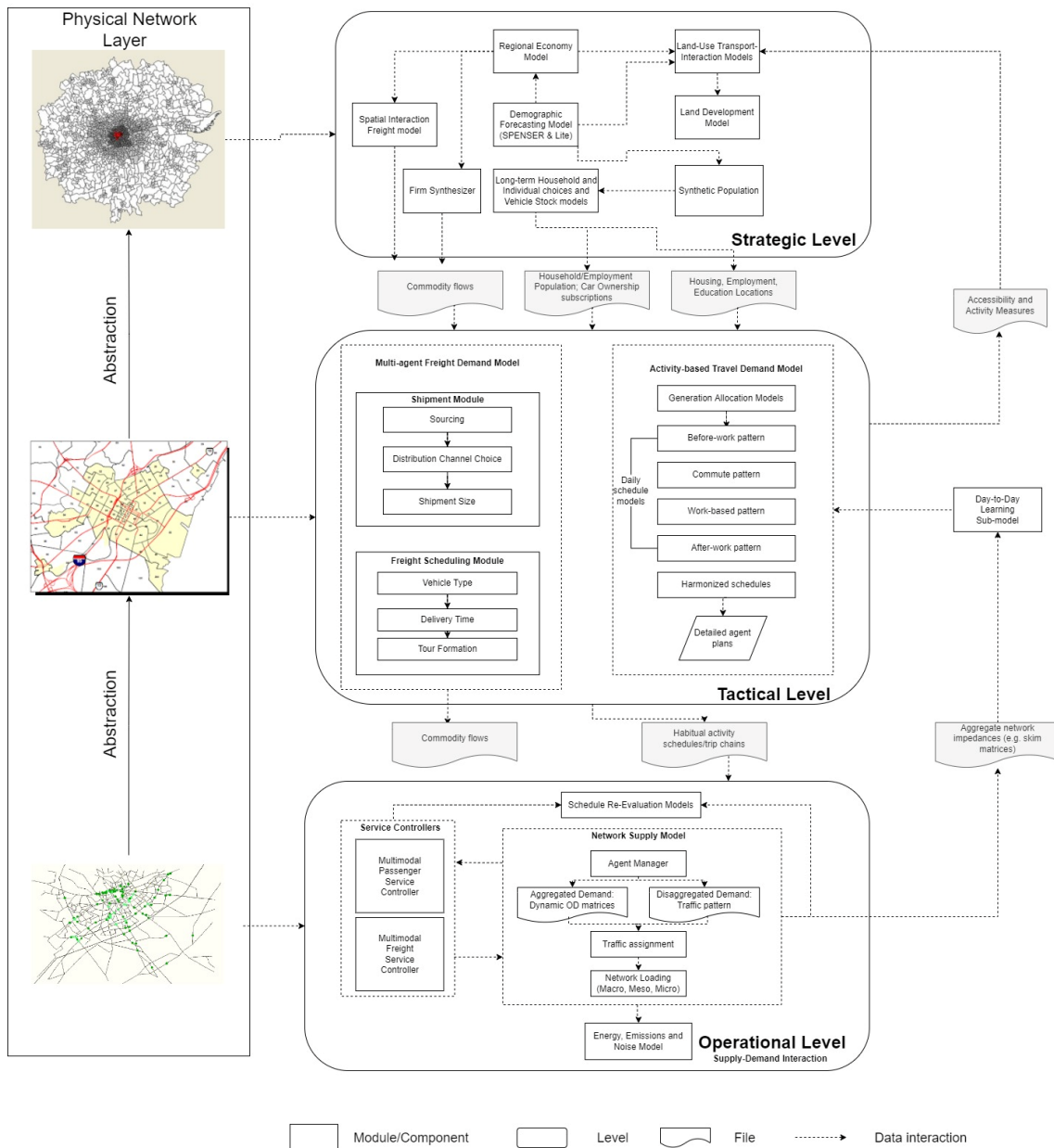
HARMONY is a Horizon 2020 project under the CIVITAS Initiative, whose aim is to provide metropolitan authorities with a multiscale spatial and transport planning framework to foster a sustainable transition towards a low-carbon new mobility era. HARMONY's main objective is to assist metropolitan authorities with evidence-based decision making, by providing a state-of-the-art model suite that quantifies the multidimensional impact of various policies, investments, and mobility concept applications.

To achieve this goal, the HARMONY Model Suite (MS) (**Figure 1**) is an integrated set of models aimed at capturing the dynamics and mobility patterns of metropolitan areas; it is structured over three different levels: 1) Strategic (long-term) demographic land-use transport models, 2) Tactical (mid-term) people and freight activity-based models and 3) Operational (short-term) multimodal network models. The structure of the framework is modular and allows the employment of all or only a selection of components: according to data availability and the scope of the analysed case study, different models can be selected and different scenarios can be set up to provide a wide portfolio of results and outputs to evaluate the impacts of developments, interventions or policies and to inform strategic planning.

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## HARMONY MS Conceptual Architecture



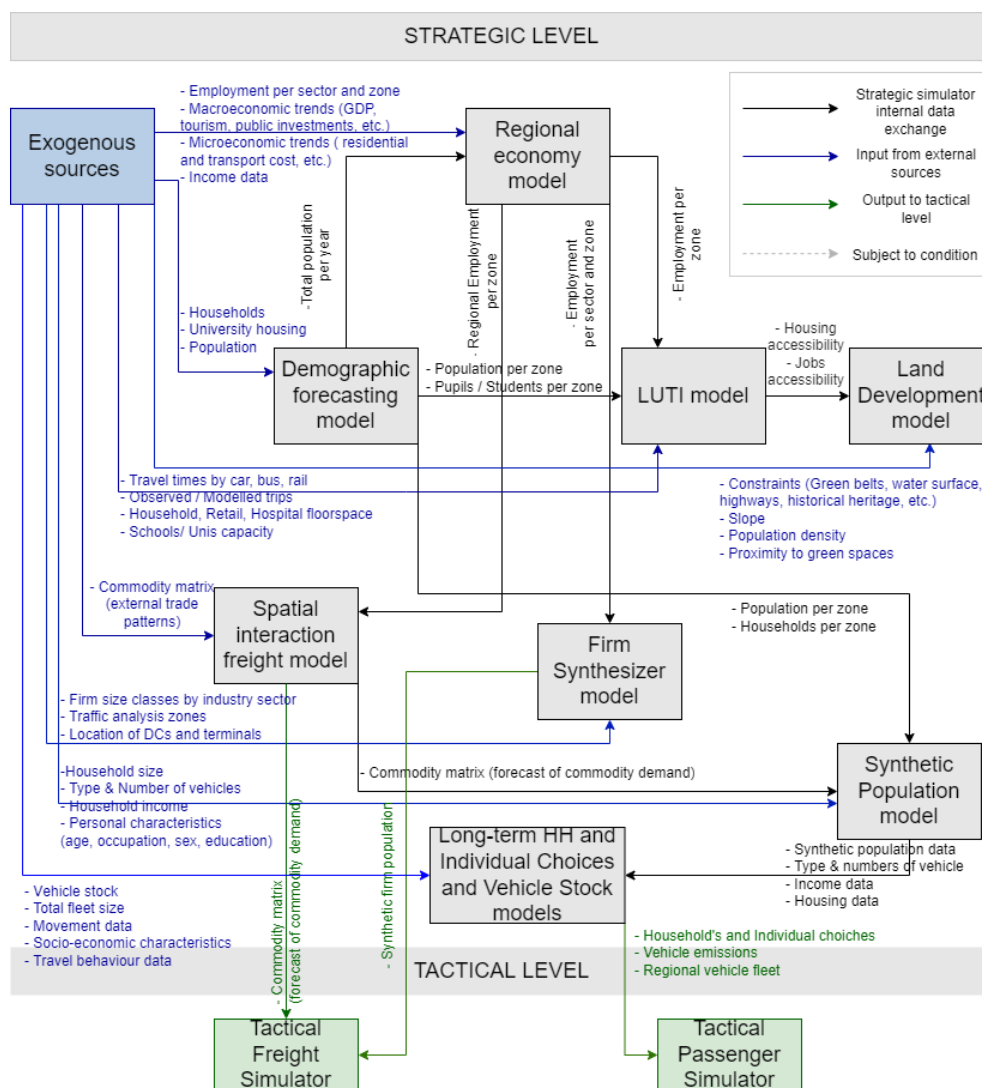
**Figure 1** The HARMONY Model Suite Framework structured over three levels: Strategic, Tactical and Operational (figure from Lopane et al., 2022.a).

## 2. The Strategic Simulator

The Strategic Simulator is the most upstream component of the HARMONY MS, the one with the highest level of abstraction and the longest time frame (multiple years) (Kamargianni et al., 2021). The Strategic level provides spatially referenced quantification of individuals, households and firms at different levels of segmentation and geographical scope (regionally or using a zoning system based on: homogeneity of socio-economic characteristics, natural and political boundaries, principal highways, previous studies using origin-destination data) as well as demand and supply of retail, work, educational, health activities and aggregate commodity flows between employment sectors. These

aggregate predictors are then linked downstream to long-term mobility choices of individuals (agents) including car-ownership or subscriptions to different mobility services which serve to bind together the Strategic and Tactical Levels. **Figure 1** helps understanding how the Strategic level interacts with the Tactical and Operational levels and the quality of the information exchanged between different levels (and different time and spatial scales).

The Strategic Simulator of the HARMONY MS consists of the integration (and calibration) of all the strategic level models (**Figure 2**). These models consist of: i) a demographic forecasting model that defines the overall size of the city systems generating the total population disaggregated into age-sex cohorts. ii) A regional economy model that generates future employment and structures the demand for physical travel. iii) A Land-Use Transport-Interaction 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 Land Development model that predicts land suitability and desirability, v) A Firm Synthesizer that generates a synthetic population for firm agents, which are input for the tactical simulators, for freight and passenger demand. vi) A spatial-interaction freight model for strategic planning to capture freight generation, trade and outsourcing logistics, vii) A synthetic population model as translator for the disaggregation and distribution of aggregate variables to the population of households and firms. viii) 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.



**Figure 2** The HARMONY Strategic Simulator Framework (figure from Lopane et al., 2022.a).

### 3. Applications

The HARMONY models have been applied to different European metropolitan areas: the Turin Functional Urban Area (Italy), the Attica Region (i.e. the metropolitan area of Athens - Greece), Oxfordshire (UK), and Rotterdam (the Netherlands). This paper focuses on the Oxfordshire application, outlining the main applied models and results.

Referring to **Figure 2**, the models applied for Oxfordshire consist of: i) the demographic forecasting model (DFM), ii) the regional economy model (REM), iii) the Land-Use Transport-Interaction model (LUTI), and iv) the Land Development Model (LDM).

In Oxfordshire, the DFM consists on an adaptation to the HARMONY MS of the Synthetic Population Estimation and Scenario Projection Model (SPENSER) (Lomax et al., 2020), which produces population and household projections at a high spatial resolution, using the UKCensusAPI and UKPopulation Python libraries. Both packages help to generate the sum of total population, population projections containing the residential population per sex, age, ethnicity and ONS code for geographical area, and household projections containing the households divided by build type, tenure, composition, occupants and Output Area.

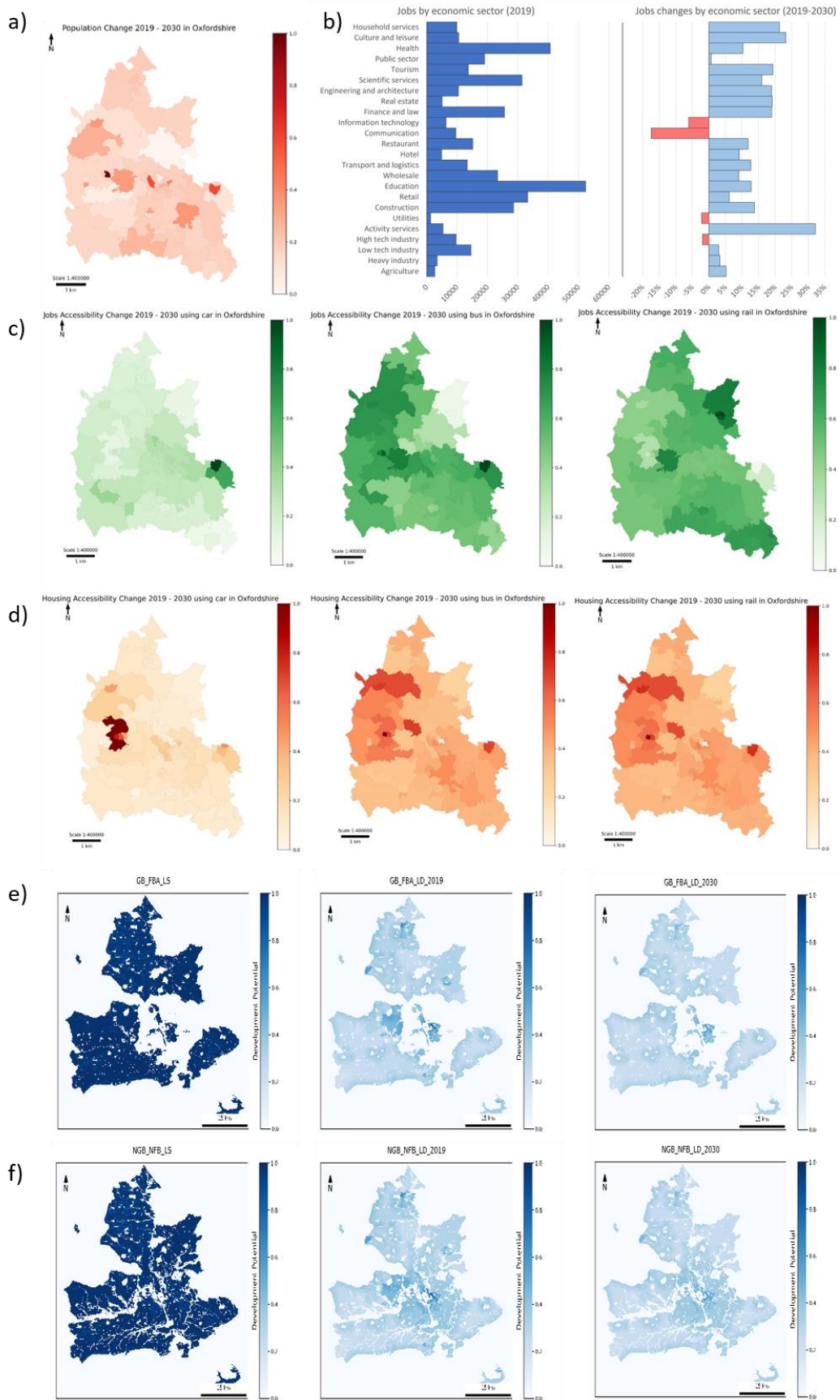
The REM takes population data from the Demographic Forecasting Model (DFM), but also public investments, National Gross Domestic Product (GDP), tourism and Income data as inputs and produces employment projections by economic sector per year, supplying the Land-Use Transport-Interaction (LUTI) model with total employment data per zone.

LUTI models can evaluate the impact of significant changes in land-use and transportation. In Oxfordshire, a new housing development plan will result in the building of 33.263 new dwellings by 2030. Based on the census population and on population projections provided by the DFM, two different scenarios were developed, one for the reference year (2019) and one for the projection year (2030) including a journey to work sub-model, a journey to retail centres sub-model, a journey to schools sub-model, and a journey to hospitals sub-model (Lopane et al., 2022.b).

Finally, the Land Development model uses as constraint layers the administrative boundaries of Oxfordshire, surface water, conservation areas, parks, areas of outstanding natural beauty, highways, flood zones, sites of special scientific interest and natural reserves. Slope, population density and  $\geq 2.5$ km distance from green spaces of Oxfordshire are considered as negative attractors, while job and housing accessibility for 2019 and 2030 for all the considered modes of transport (car, bus, rail) as positive attractors. Based on these inputs and in accordance with LUTI model 4 scenarios for Oxfordshire were built (**Table 1**).

**Table 1** LDM Scenarios

Scenario	Years	Green belt dev. allowed	High flood risk areas dev. allowed
1	2019, 2030	No	Yes
2	2019, 2030	No	No
3	2019, 2030	Yes	Yes
4	2019, 2030	Yes	No



**Figure 3** Strategic Simulator sample results. a) DFM: population change; b) REM: employment by sector; c) LUTI: job accessibility by mode of transport; d) LUTI: housing accessibility by mode of transport; e) LDM: land suitability and desirability scenario 1; f) LDM scenario 4.

#### 4. Conclusions

The added value of such a framework consists in overcoming the knowledge gap of a single modeller/planner/decision-maker when it comes to the development of different urban models: the HARMONY MS allows, for instance, transport engineers to run their models in combination with demographic forecasting or land-use models that might be outside their expertise, or, conversely, allow urban planners to combine long-term economy forecasts to agent-based last-mile analyses for freight and passengers in a single software-agnostic platform.

The HARMONY MS is a web-based platform that will allow urban and transport planners to set up templates and scenarios combining different components (i.e. models) from different levels (strategic, tactical and operational) to explore what-if scenarios and evaluate the impacts of policies, infrastructure developments and/or long- and short-term changes in the socio-economic texture of cities (e.g. changes in employment distributions, demographic patterns, flows of people and freight etc.). The online documentation, will allow modellers from different countries, regions and cities to upload/develop models of different metropolitan areas, or, alternatively, to integrate the HARMONY MS with custom models and run them in combination with the HARMONY components.

#### 5. Acknowledgements

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#### Biographies

**Fulvio D. Lopane** got his PhD in spatial optimisation for sustainable infrastructure services at Newcastle University, and currently he is an Associate Lecturer in Spatial Data Science at the Bartlett Centre for Advanced Spatial Analysis (CASA) at University College London. His research interests are complex systems and sustainable infrastructure development.

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**Michael Batty** is an urban planner, geographer and spatial data scientist, and Bartlett Professor of Planning in The Bartlett at University College London. He is Chairman of the Centre for Advanced Spatial Analysis (CASA). His research and the work of CASA is focused on computer models of city systems.