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An Activity- and Agent-based Co-Simulation Framework Integrating ActivitySim and MATSim for the MRDH Region, Netherlands

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Abstract

Existing activity-based and agent-based simulations alone often failed to capture the interaction between individual activity scheduling and detailed urban traffic dynamics. ActivitySim provides a representation of individual activity schedulings but often lacks detailed traffic dynamics, whereas MATSim can capture detailed interactions between travellers and mobility systems but often overlooks several decision-making factors, such as activity scheduling shift, household interactions and land-use influences. To address these limitations, this paper presents an Activity- and Agent-based Co-simulation framework that integrates ActivitySim and MATSim. ActivitySim generates individual activity schedules and location choices, which serve as synthetic travel demand input for MATSim. MATSim then simulates detailed mobility interactions, with its outputs aggregated into zonal level-of-service matrices and fed back to ActivitySim for iterative scheduling adjustments. The feedback loop bridges the strengths of both models and is applied to the MRDH (Rotterdam-The Hague Metropolitan) region in the Netherlands. The initial MRDH model for the base-year reference scenario demonstrates that the proposed co-simulation framework effectively replicates existing mobility patterns, paving the way for fine-grained intervention evaluations like ride-hailing services in the future.

Keywords: Activity-based model; MATSim; ActivitySim; Agent-based Simulation; Rotterdam–The Hague Metropolitan Area

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1. Introduction

In transport planning, the high level of aggregation within conventional trip-based models limits their ability to calculate detailed individual travel behaviours. However, this level of detail is essential for evaluating the effects of emerging mobility services, such as studies on smart mobility solutions. Two advanced modelling approaches have emerged to address these limitations: activity-based modelling (AcBM) and agent-based modelling (AgBM). AcBM

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simulates individual travel demand by modelling their participation in activities, considering lifestyle choices, social interactions, and economic constraints. On the other hand, AgBM shares conceptual overlaps with AcBM but extends the approach by simulating, in a self-learning manner, the interactions between agents and their interactions with the environment [1]. Several toolkits are available for AcBM and AgBM, though many blur the lines between these categories. For instance, ActivitySim is typically classified as activity-based but also includes individual interaction and competition, such as constraints from land use patterns. Conversely, MATSim is generally considered agent-based but also involves modifications to activity schedules, such as mode shifts. However, no existing single tool is comprehensive enough to fully capture the interaction between individual activity scheduling and detailed urban traffic dynamics. Such an interaction is important because mobility systems are inherently interlinked with other systems. Introducing specific interventions in the urban mobility network inevitably impacts land use patterns, individual travel patterns, location choices and household travel interaction. To comprehensively assess the impact of interventions, it is crucial to understand how these factors co-evolve with changes in transportation systems and incorporate them into existing simulation frameworks [2, 3].

One way to address this gap is by integrating existing activity-based and agent-based toolkits. ActivitySim and MATSim are well-suited for this purpose due to their open-source nature, widespread adoption and strong community support. ActivitySim [4] primarily focuses on capturing shifts in individual activity schedulings considering individual and system characteristics. However, it lacks the ability to capture traffic dynamics as explicitly as MATSim [5, 6]. To that end, this paper presents a co-simulation approach that integrates ActivitySim and MATSim, enabling a more comprehensive activity- and agent-based co-simulation framework. The ActivitySim components generate agents' synthetic travel demand considering individual characteristics, land use, location choices, and household travel interactions. The MATSim simulates detailed traffic dynamics and provides aggregated travel information back to ActivitySim in an iterative feedback loop. A case study of the proposed framework is carried out for the MRDH (Rotterdam-The Hague Metropolitan Area) region, the Netherlands. To the best of our knowledge, the generated model would be the first simulation model for the MRDH region on an Activity- and Agent-based level.

2. Related Work

MATSim is an open-source agent-based modelling framework that simulates the mobility behaviours of large numbers of individual agents and their interactions within real-world traffic environments [7]. By the start of the simulation, each agent in MATSim holds daily "plans" to be performed that differ in time, location, and purpose. MATSim simulation is based on the co-evolutionary algorithm constituting several iterations: agents perform respective activities and compete for space-time constraints when travelling in mobility networks. At the end of each iteration, agents apply modifications to travel plans to optimise daily travel performances for utility maximisation. Such an iterative process is repeated until agents in MATSim reach the stochastic user equilibrium.

One challenge associated with MATSim's implementation is that the demand data describing detailed activity schedulings of all individuals within the study area is usually unavailable to modellers. Several recent attempts have developed data synthesis pipelines that generate synthetic travel demand to replicate attributes and travellers' activity chaining. Nevertheless, most current synthetic travel demand generation pipelines rely on statistical matching [8, 9], which means matching agents' attributes from the synthetic population (e.g., age, gender, income) with similar attributes in reference datasets, such as household travel surveys. The matched agents then inherit mobility patterns directly from the reference population, resulting in the synthetic population's mobility patterns being primarily replicated from the reference data. Additionally, since the number of respondents in the reference data is usually limited, the statistical matching process relies on limited combinations of attributes to ensure that every individual within the synthetic population could find respective matched samples in the reference data. Consequently, the generated synthetic travel demand mostly lacks behavioural richness and variability compared to real-world travel behaviours.

After MATSim scenarios are generated, they are primarily used to test various "what-if" scenarios under different mobility interventions. However, one primary assumption within most MATSim studies is that agents' travel behaviours will remain largely unchanged, except for route choice, activity departure time, and mode shifts. This could potentially be problematic due to the complexity of urban mobility systems, where a shift in one factor can influence many other perspectives. The potential shifts include changes in agents' activity schedulings and sequences, activity location choices, parking destination choices, and travel interactions between household members. There is some research trying to take some of these factors into account in MATSim, such as the parking [10] and discretionary activities choice extensions [11]. Still, incorporating these extensions into a single MATSim simulation will require advanced MATSim knowledge and increase the already time-consuming MATSim computational time. Even when integrated, the existing functions still cannot capture all relevant factors for a more comprehensive simulation assessment of the proposed interventions.

AcBM is another methodology commonly used in transport planning to simulate how people decide to participate in activities based on behavioural theory [12]. Specifically, based on empirical data and individual typologies, AcBM adopts probabilistic approaches and behavioural categorisation to replicate how individuals with different characteristics make activity decisions. Consequently, compared to statistical matching, AcBM is ”emulating” the activity schedulings from reference data rather than simply reproducing them [13]. However, one limitation of the current AcBM is that traffic dynamics are still calculated at the zonal level, which restricts the models' analysis capability for research questions that require finer granularity, such as for ride-pooling and car-sharing.

Due to the complementary characteristics, it is clear that existing toolkits hold vast potential to be integrated into an activity- and agent-based co-simulation framework, where two models are composed together to run simultaneously and exchange data to capture the interaction between individual activity scheduling and detailed urban traffic dynamic [14]. The AcBM offers a more realistic representation of individual travel behaviours by incorporating multiple factors. In contrast, AgBM offers a more granular analysis of travellers' interactions and traffic assignments. [15] developed a simulation framework integrating MATSim with FEATHERS. However, such an integrated framework has never been applied to policy studies to assess its usefulness. Besides, the closed source of FEATHERS limits the framework's accessibility. A co-simulation framework using both open-source software could significantly broaden the applicability of such a co-simulation framework for policy analysis. MATSim (AgBM) and ActivitySim (AcBM) could potentially be adopted due to their widespread use in respective communities. Nevertheless, an integrated framework bundling these two is not yet available to the best of our knowledge.

3. Activity- and Agent-based Co-Simulation Framework Integrating ActivitySim and MATSim

This research aims to present an activity- and agent-based co-simulation framework facilitating a two-way interaction between MATSim and ActivitySim. Figure 1 illustrates the proposed framework, where blue blocks represent real-world data, the hard orange and green represent modules within ActivitySim and MATSim, whereas the light version of the same colours stands for the output generated by the respective software. The co-simulation process is based on an iterative approach. Firstly, ActivitySim generates a detailed daily activity schedule for each individual from the synthetic population based on their socio-demographical characteristics and the features and constraints of the transportation system (such as accessibility and point-of-interest availability). Then, the generated activity-travel patterns are individually converted into MATSim agents' plans for the detailed agent-based mesoscopic traffic simulation. MATSim output, representing detailed mobility patterns, is aggregated into zonal level-of-service matrices and then inputted into ActivitySim to adjust agents' daily activity participation and scheduling. This two-way interaction continues until there are no significant changes in the zonal level-of-service matrices between the input into ActivitySim and the corresponding MATSim output within the same iteration. The following sections will present a detailed demonstration of each step involved using the case study of the MRDH region in the Netherlands.

3.1. ActivitySim Simulation & Conversion into MATSim Synthetic Travel Demand Based on Iterative Feedback Loops

To initiate the co-simulation process, an ActivitySim model must first be established. ActivitySim requires four basic data inputs: synthetic population representing the detailed demographic profile of individuals within the study area, land use data demonstrating the ”attractiveness” of each Traffic Analysis Zone (TAZ) for different activity purposes, network data containing the level-of-service matrices reflecting the generalised cost travelling between TAZs, and parameters of utility functions estimated from survey data revealing travellers' daily activities. Based on the input data, the model predicts the locations for long-term activities such as work and school for the synthetic population, along with their primary activity objectives. Subsequently, it determines the number of obligatory (work and school) and optional (e.g., shopping, dining out) tours. Each tour will then have its start time, duration, destination, and mode of transport determined. Following this, the model decides on various aspects of the tour, including the number of

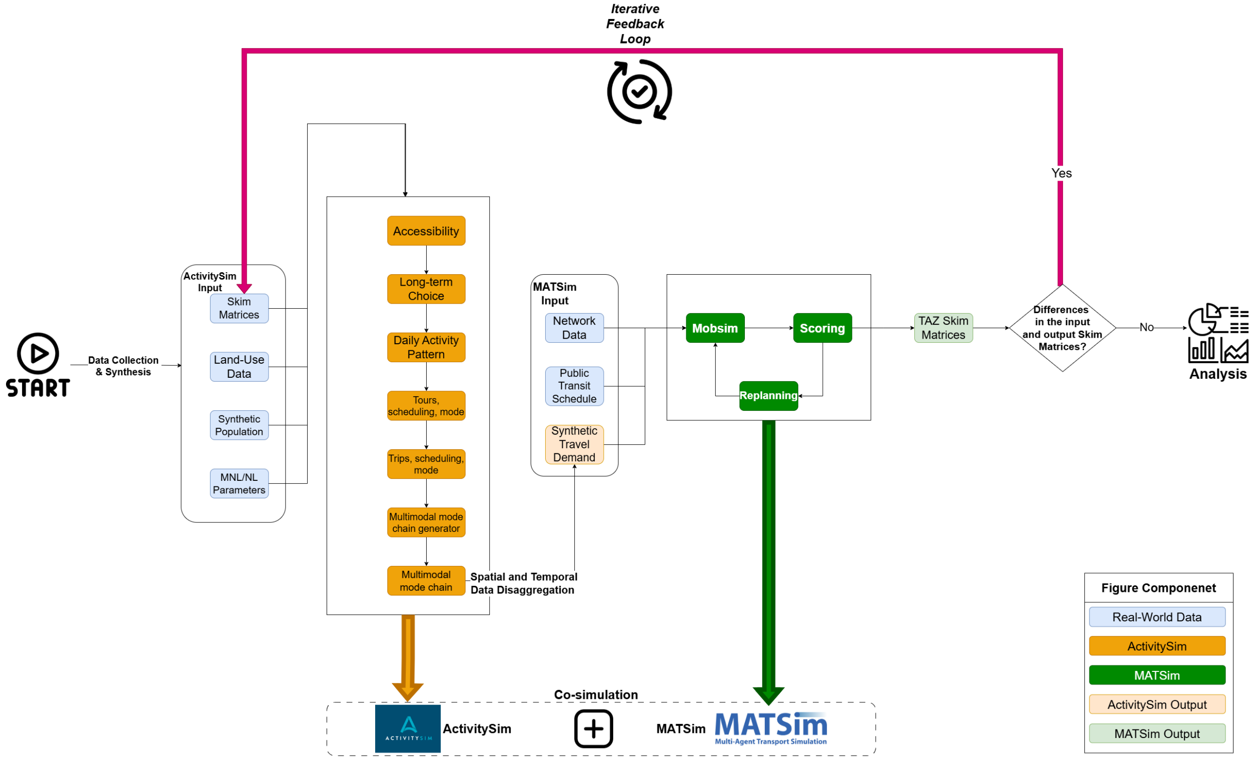

Fig. 1. Activity- and Agent-based Simulation Framework Integrating ActivitySim and MATSim with Iterative Feedback Loops

stops, trip destination, trip duration, and travel mode. For our case study of the MRDH region, an ActivitySim model is customised as detailed in [12], and this model will serve as the starting point for our co-simulation framework.

The output of ActivitySim contains the socio-demographical attributes of individuals within the MRDH region, plus their daily activity schedulings. The output data contains the primary information required for MATSim's synthetic travel demand. However, agents' activity departure times, durations, and locations produced by ActivitySim are represented in hourly and TAZ-level resolutions. Additional processing is required to disaggregate these temporal (in seconds) and spatial (in coordinates) information for integration into MATSim. TAZs in the original ActivitySim MRDH scenario are already quite refined, where the Netherlands is divided into 7011 zones, and the areas of zones within the MRDH regions are much smaller compared to the rest of the country. Consequently, random coordinates within the respective TAZs are chosen as activities' locations for this study. Similarly, for the temporal resolution of activities, for the first trip an individual undertakes within a day, we assign a random minute within the hour provided, representing the end time of the first activity. For the subsequent activities, as ActivitySim only provides the total duration of the entire tour rather than specific activities linked by trips, we estimate the duration of each activity based on the time difference between the departure times of consecutive activities, including the travel time in between (mainly to avoid when the travel time is significant and influence the estimated duration of subsequent activities). The duration is further adjusted by assigning a random minute number within the hour range of the estimated value. By iterating through all individuals' travel schedules generated by ActivitySim, we transform the refined data with detailed spatial and temporal information into MATSim format of synthetic travel demand (so-called ”plan.xml”).

3.2. *MATSim Simulation and Travel Behaviour Adaptation*

With the established synthetic travel demand, the MATSim simulation for the MRDH region is set up incorporating the local mobility network (from OpenStreetMap) and public transport schedules (from the GTFS data) [16]. As mentioned in Section 2, MATSim is based on the co-evolutionary algorithm where a specific proportion of agents modify their travel behaviours during each iteration. The choices contain re-routing, departure time adaption and mode choices. One key challenge associated with the proposed co-simulation framework is ensuring that MATSim does not override the decision that contradicts the empirical knowledge embedded in the ActivitySim simulation. Regarding the co-simulation framework, [15] suggests only enabling route choice in the AgBM, whereas the departure time and mode choice adaptation should only be introduced when their action scope is sufficiently confined.

For this research, route choice in MATSim is enabled as the travel time estimation of ActivitySim is based on the aggregated TAZ level. MATSim can complement this by specifying detailed routes agents undertake during the trips. For the activity departure time, as the temporal resolution provided by ActivitySim is on the hourly basis, MATSim can further adjust the randomly assigned departure minute from Section 3.1 based on actual mobility patterns and mobility conditions. To enable realistic adaptation while preserving the integrity of ActivitySim's output, the mutation range of MATSim departure time adaptation is confined to 30 minutes. For the mode choice, the network level-of-service matrices from ActivitySim input already provide impedances showing travel time, distance, cost or a combination of generalised costs for each TAZ pair. These values are similar to the disutilities that agents perceived when travelling in MATSim. Therefore, the mode choice innovation is switched off in this research to prevent agents from making mode choices in MATSim that violate the established decision in ActivitySim. With the proposed replanning strategy, MATSim will be run in several iterations based on the real-world utility parameters in the MRDH region [6]. We also deploy the alternative specific constant calibration tool in [17] to automate the model calibration process, ensuring the alignment of mode and mode-distance share between the simulation and reality.

3.3. Interaction Between ActivitySim and MATSim

Once the simulation is calibrated, MATSim provides detailed information about all trips conducted during the last iteration, including origins, destinations, departure times, travel times and the modes used for the trips. This information is aggregated into level-of-service matrices of morning peak (7 to 9), evening peak (16 to 18) and the rest of the simulated day. Since changes in agents' travel behaviours and network conditions are expected during this co-simulation process, an iterative process between ActivitySim and MATSim is foreseen. The stopping criteria for the proposed co-simulation framework are defined based on changes in the level-of-service matrices [15] as:

$$\frac{1}{N}\sum_{i}\frac{|C_i(a,b) - C_{i-1}(a,b)|}{C_{i-1}(a,b)} \times 100 < \epsilon$$

Where N is the total number of the origin-destination pairs in the level-of-service matrices, $C_i(a,b)$ and $C_{i-1}(a,b)$ represent the generalised travel cost between zones a and b from the consecutive iterations *i-1* and *i*, respectively. For this research, the convergence threshold ϵ is set as 5%. It is worth mentioning that the convergence of the co-simulation framework can be achieved relatively quickly for modelling the base-year reference scenario since the original level-of-service matrices inputted into ActivitySim are derived from real-world mobility data. Nevertheless, the framework becomes particularly valuable when assessing the impact of mobility interventions that have not yet been implemented in reality, as the changes in both individual activity scheduling (through AcBM) and the incurred network dynamics (through AgBM) are not known. Compared to simulation studies using only activity-based or agent-based simulation, such an integrated approach provides a more comprehensive assessment of mobility interventions and their effects on transport networks.

4. Outcome and Conclusion

In this paper, we present an initial framework that integrates ActivitySim and MATSim to expand the analysis scope by enabling interaction between individual activity scheduling and detailed urban traffic dynamics. The framework starts with ActivitySim, which generates synthetic travel demand by considering individual characteristics, land use patterns, and household travel interaction. MATSim then simulates detailed mobility patterns based on the generated demand, with its output aggregated into level-of-service matrices and fed back into ActivitySim for an iterative co-simulation process. Based on the ActivitySim model generated and calibrated by [12], an initial example of the proposed framework is conducted for the MRDH region in the Netherlands, where the calibrated model represents the first mobility model for the MRDH region on the Activity- and Agent-based level

Although the generated Activity- and Agent-based model for the MRDH is calibrated and validated against real-world mobility patterns, it does not yet fully illustrate how the proposed co-simulation framework outperforms standalone activity-based and agent-based models. The full potential of the co-simulation framework can only be demonstrated when the combined model is used to assess the impact of mobility interventions which require fine granularity (i.e. person-centric) analysis, such as ride-pooling, ride-hailing and Mobility-as-a-Services. The authors are currently developing relevant research in this direction. Another potential future research lies in improving the spatial and temporal disaggregation approach when transforming the output of ActivitySim into MATSim's synthetic travel demand: Since ActivitySim operates on the TAZ and hourly levels, whereas MATSim requires detailed coordinate (spatial)- and second (temporal)-level inputs. While ensuring the continuity of the results, the random sampling we employed could be enhanced by, for instance, incorporating real-world point-of-interest coordinates similar to [16] for a more realistic representation of real-world mobility patterns.

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