Activity-Based Daily Travel Pattern Model

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The following table gives an overview of the elaboration and processed changes in the document:

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1	02/10/2023	DTU	First draft
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Executive Summary

The objective of this D2.1 is to present the demand generation component of SORTEDMOBILITY's simulation assessment platform. It is composed of two modules: an activity-based demand module – that predicts planned trips and activities for a synthetic population of agents and a multi-modal transportation system. This report presents the first.

Chapter 1 contains an Introduction to the goal and contents of the report. Chapter 2 presents the simulation platform used. Chapter 3 provides the modelling framework of the activity-based model in SORTEDMOBILITY. The Danish case is presented in Chapter 4, with details on the data used and estimation considerations. Finally, the results obtained for the Danish case are presented in Chapter 5 before a brief Discussion and Conclusions end this report in Chapter 6.

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Table of abbreviations

ABM	Activity-based model
DAS	Daily Activity Schedule
LT	Long-term
MT	Mid-term
ST	Short-term
MNL	Multinomial Logit
BL	Binary logit
TAZ	Traffic Analysis Zone
DAS	Day Activity Schedule
TU	Danish National Travel Survey
VD	Danish Road Directorate (Vejdirektoratet)

1 INTRODUCTION

SORTEDMOBILITY (Self-Organized Rail Traffic for the Evolution of Decentralized MOBILITY) aims at developing concepts, models and algorithms for self-organizing management of public transport operations in urban and interurban areas, specifically focusing on rail transport as a mobility backbone. In addition, a detailed simulation assessment platform will be developed to assess the proposed self-organization approach against a centralized one.

This deliverable reports on the demand generation component of the SORTEDMOBILITY simulation assessment platform. The component is responsible for producing realistic choices for passengers of the multi-modal transportation system in reaction to changes in operations. It is composed of two modules: an activity-based demand module – that predicts planned trips and activities for a synthetic population of agents and a multi-modal transportation system. This report presents the first.

The report starts by presenting the simulation platform used. Next, it provides the modelling framework of the demand generation in SORTEDMOBIITY and its key details. The Danish case is presented next, with details on the data used and estimation considerations. Finally, the results obtained for the Danish case are presented before a brief Discussion and Conclusions close this report.

2 SORTEDMOBILITY SIMULATION FRAMEWORK

2.1 Simulation Overview

In previous deliverables, the SORTEDMOBILITY team presented the framework for the traffic management solution in SORTEDMOBILITY, depicted in Figure 1. The framework determines the way in which the control architecture interacts with the transport (simulation) system, identifying relevant flows of information between the modules.

The Transport Simulation System is composed of two key simulation pillars: (1) the Passenger Behaviour and (2) the Railways Operations modules.

The aim of the Passenger Behaviour component is to produce realistic choices for passengers of the rail system in reaction to changes in operations. This component is based on several behavioural models that follow the random utility theory and choice modelling to formulate the many decision-making processes of passengers at the individual level. More specifically, the Passenger Behaviour component is composed of two modules: an activity-based demand module – that predicts planned trips and activities for a synthetic population of agents and multi-modal transportation system and the Demand re-routing, which interacts dynamically with the supply simulator for modelling route and re-route decisions considering the changes in the performance of the rail system. This report presents the details of the first one, the activity-based demand module. For the details on the route-choice module, the reader is referred to D4.2.

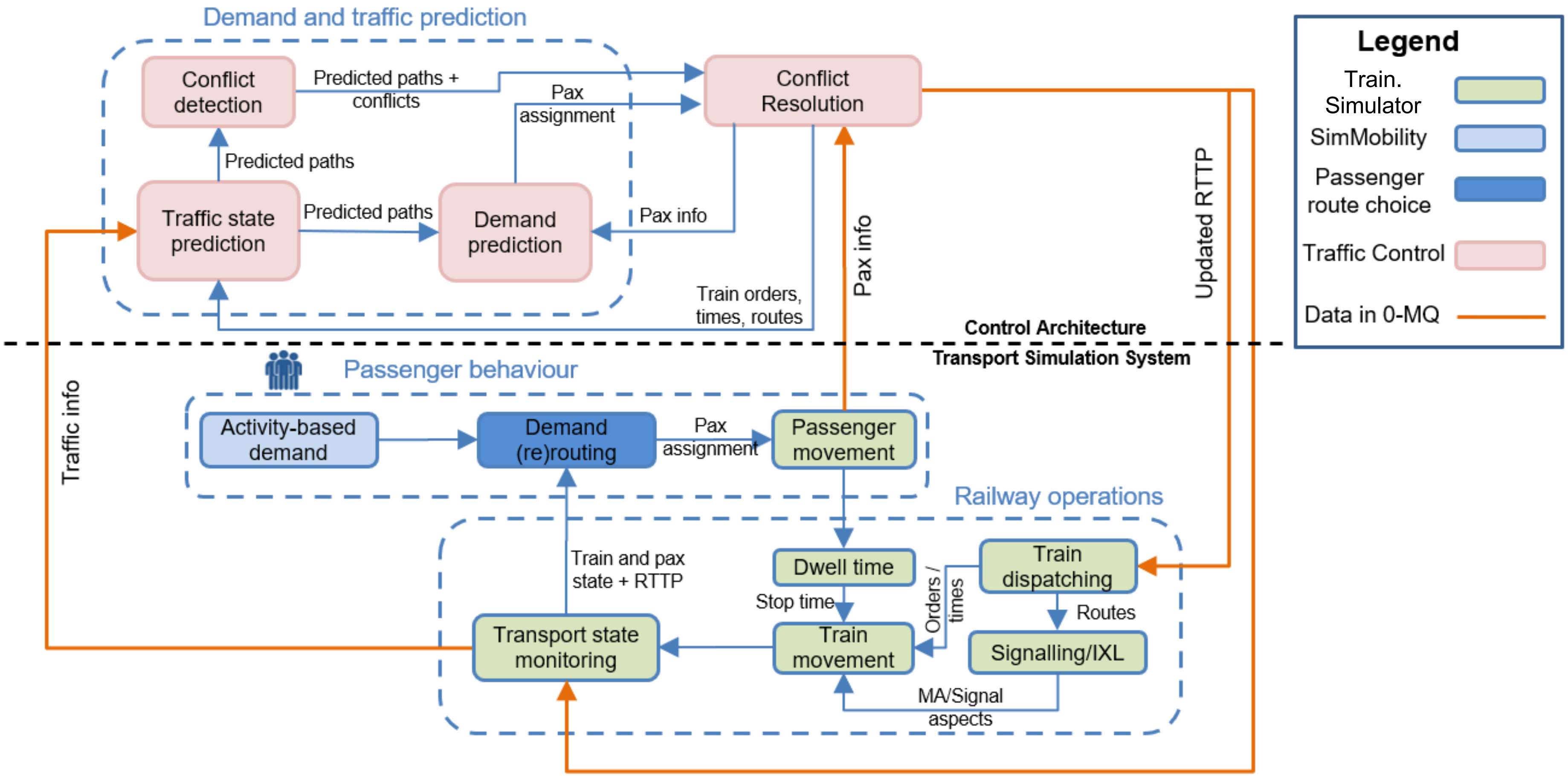


Figure 1: Modelling framework of the SORTEDMOBILITY traffic management

The activity-based module of SORTEDMOBILITY follows the structure of SimMobility (https://github.com/smart-fm/simmobility-prod/).

SimMobility is an open-source integrated agent- and activity-based simulation platform that has been developed by the Massachusetts Institute of Technology (MIT) and the Singapore-MIT Alliance for Research and Technology (SMART) since 2012 (Adnan et al., 2012). It supports the activity-based modelling paradigm and allows for individual behaviour simulation in different time (from seconds to years) and spatial scales, simultaneously simulating demand and supply.

The high-level design of SimMobility incorporates three primary modules (Figure 6), which consider different timeframes: long-term, mid-term and short-term. The Long-term (LT) module simulates year-to-year dynamics, capturing long-term land use and economic changes. The Mid-term (MT) module simulates the day-to-day dynamics of travel demand, i.e., agents' daily travel and activity patterns. The Short-term (ST) module simulates what happens within a day, i.e., the movement of agents at a microscopic granularity.

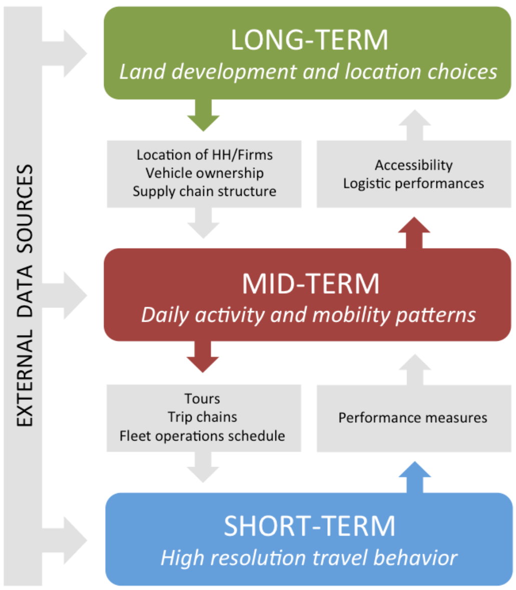


Figure 2: SimMobility Modelling Framework

2.2 SimMobility Mid-Term

The Mid-term (day-to-day) simulator handles transportation demand for passengers and goods. It is a mesoscopic simulator that simulates agents' behaviour, which includes their activity and travel patterns using activity-based models, with explicit pre-day and within-day behaviour, including re-routing and rescheduling, and multiple transport modes. The Mid-term module of SimMobility consists of three interacting simulators (Figure 3):

- Pre-day (which is used by SORTEDMOBILITY): simulates individuals' daily activity and travel patterns according to the activity-based models estimated. More details can be found below;
- Within-day: simulates both departure times and route choice behaviour, allowing for rescheduling depending on real-time network conditions (provided by the supply simulator);
- Supply: simulates the transport network and its attributes, including both public and private transport.

The Mid-Term simulator takes input in the form of a synthetic population that contains detailed characteristics of each agent in the simulation region and processes the day activity schedule of each agent. The pre-day models follow an enhanced version of the econometric Day Activity Schedule (DAS) approach to decide an initial overall daily activity schedule of the agent, particularly its activity sequence (including tours and sub-tours), with preferred modes, departure times by half-hour slots, and destinations. This is based on the sequential application of hierarchical discrete choice models using a Monte-Carlo simulation approach. As the day unfolds, the agents apply the within-day models to find the routes for their trips and transform the activity schedule into effective decisions and execution plans. Agents may get involved in a multitude of decisions, not constrained to the traditional set of destination, mode, path and departure time depending upon their state in the event simulation cycle, such as re-routing in the middle of a trip (including alighting a bus to change route).

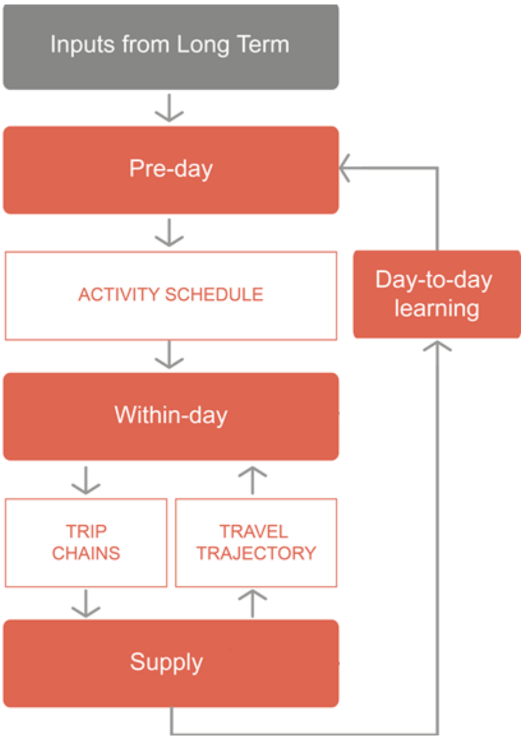


Figure 3: SimMobility Mid-Term Model

2.3 Computational Features

SimMobility is entirely developed in C++, using the boost threads library for parallelization. It is able to do runtime load balancing by taking advantage of individual agents' context (e.g., neighbour agents can be grouped together; agents of similar type can be grouped together). SimMobility takes advantage of state-of-the-art computational efficiency tools to increase scalability. The embeddable and lightweight scripting language LUA is used for implementing the models' specifications (Viegas de Lima et al., 2018) (Lu et al., 2015) due to its relatively simpler and more intuitive language syntax. For more information on installing and running SimMobility, please refer to the following link: https://github.com/smart-fm/simmobility-prod/.

The next sub-sections will present the pre-day models, which were adapted for Denmark's case.

3 MODELLING FRAMEWORK

3.1 Model Overview

The modelling framework introduced, originally proposed by Siyu (2015) for Singapore, employs a utility-maximization approach to generate a diverse set of Daily Activity Schedules (DAS). The DAS encompasses a sequence of stops constituting tours. Each tour is centred around a primary activity, and each stop is characterized by an arrival time, departure time, purpose, and the mode of transportation used, all constructed through a series of discrete choice models, the framework incorporates various personal characteristics and network parameters.

Each individual's DAS is organized into three primary segments: (1) Day Pattern Level, (2) Tour Level, and (3) Intermediate Stop Level. These levels are interdependent, with each one conditioned upon the preceding ones, forming a sequence of discrete choice models linked by inclusive values.

The Day Pattern Level determines whether an individual will engage in tours, the activity purposes of those tours, and the potential types of intermediate stops within those tours. It also influences the number of tours an individual will undertake for each chosen tour purpose.

Subsequently, the Tour Level is executed for each selected tour, determining the mode of transportation, destination, and start and end times for each activity. Work tours may involve a work-based sub tour, originating and concluding at the workplace during the designated work activity duration. The specifics of these sub-tours, including mode, destination, and time of day, are also modelled.

Finally, the Intermediate Stop Level generates stops for trips to and from the primary activity, with each stop having a designated purpose, mode of transportation, destination, and time of day.

Inclusive values from lower-level models are incorporated into higher-level ones, reflecting the nested nature of the decision-making process. Higher-level decisions are influenced by the expected utilities derived from lower-level choices. The overall framework, as illustrated in Figure 4, is further discussed, and all models can be estimated using travel diaries containing individual and household characteristics.

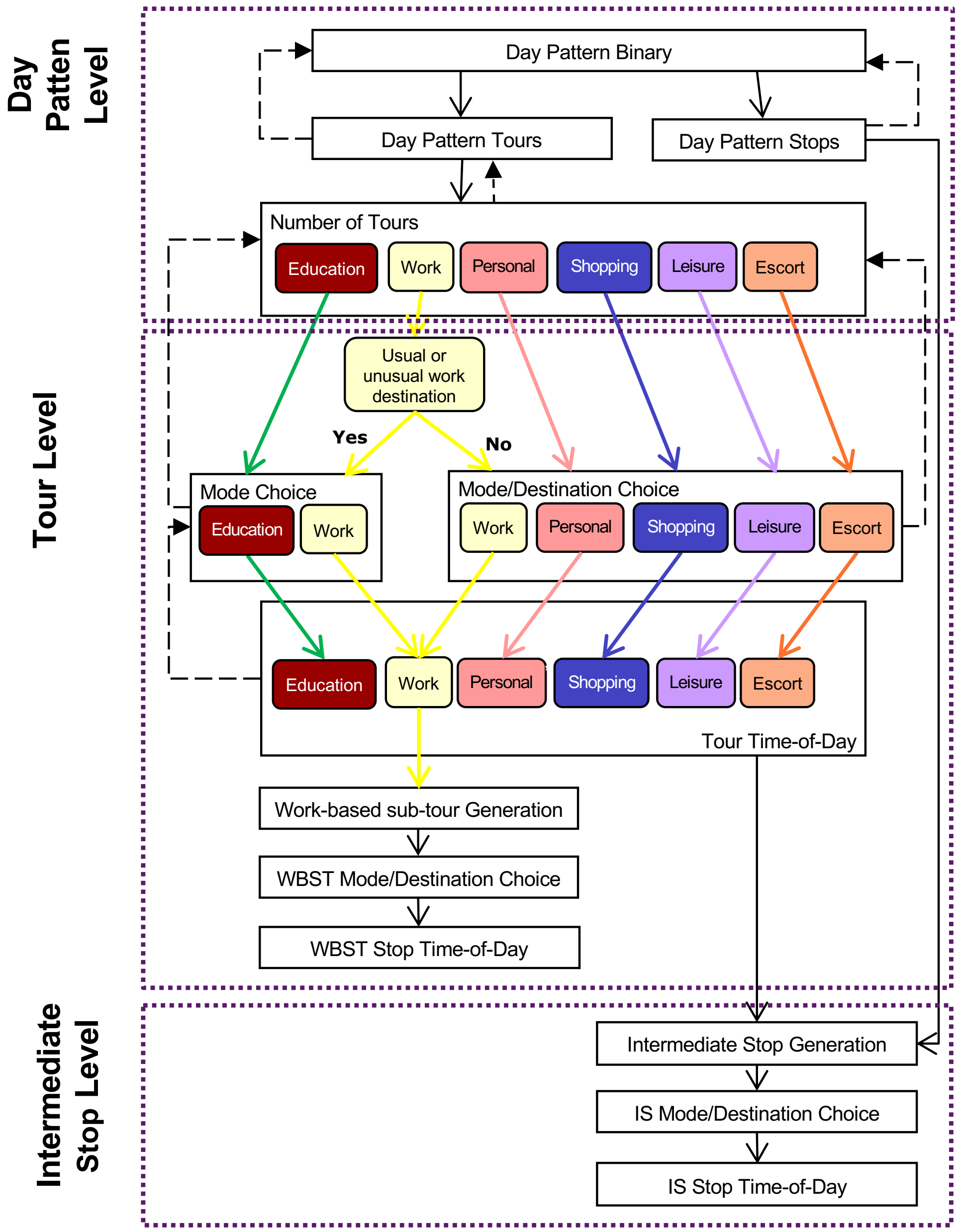


Figure 4: Model framework schematic for the Danish Case.

The articulated framework exhibits a high degree of flexibility across multiple levels and enhanced adaptability to variations in network conditions, including the rail system performance, land-use measures, and individual characteristics.

3.2 Model Components

This section provides detailed insights into each model illustrated in Figure 4, detailing their structure, inputs, and outputs.

3.2.1 Day Pattern Level

3.2.1.1 Day Pattern Travel

The Day Pattern Travel model defines whether an individual performs tours during a given day. Structured as a Binary Logit (BL) model, the choices encompass travelling or staying at home. Personal characteristics of the individual, along with inclusive values from the Day Pattern Tours model (discussed subsequently), serve as inputs. Opting to travel activates the Day Pattern Tours model.

3.2.1.2 Day Pattern Tours

The Day Pattern Tours model determines the primary activity purpose(s) an individual will participate in the form of tours. A tour is considered as two-way travel, starting from home. Utilizing a Multinomial Logit (MNL) framework, the choice set comprises a combination of available activity purposes. The limit on the number of activity purposes in the combinations is determined empirically. Utility for each choice incorporates pattern-specific parameters, individual-specific parameters (such as socio-demographics), and inclusive values from tour-level models of each activity type. Work tours are exclusively available to employed individuals, while education tours are restricted to those enrolled in educational institutions.

3.2.1.3 Day Pattern Stops

Similar to the Day Pattern Tours model, the Day Pattern Stops model addresses the choice of additional activity purposes, this time for stops occurring before or after the primary activity of the tour. It encompasses the same variables as the Day Pattern Tours model, excluding inclusive values. Availabilities are determined in a parallel manner. The Day Pattern Stops model's output influences the availability of stops in the Intermediate Stop Generation Model, detailed in Section 2.2.3.

3.2.1.4 Number of Tours

Building on the Day Pattern Tours model output, the Number of Tours is subsequently determined for each tour purpose. Depending on the purpose, the models are either BL if the choice involves one or two tours or MNL if more tours are included. The number of tours in the choice set for each purpose is empirically determined, incorporating individual characteristics and inclusive values from tour-level models.

3.2.2 Tour Level

Following the output of the Number of Tours model, each tour undergoes processing (1) first at the Tour Level and (2) subsequently at the Intermediate Stop Level.

3.2.2.1 Usual Work

Exclusive to work tours, the Usual Work model discerns whether the individual is headed to their usual work location or not. This decision is formulated as a BL model. The model incorporates individual characteristics and the inclusive value of either the Tour Mode model or the Tour Mode and Destination model for work. If the usual location is selected, the Tour Mode is then used; otherwise, the Tour Mode and Destination model is employed.

3.2.2.2 Tour Mode

Tour Mode is a key model in SORTEDMOBILITY, and it determines the transportation mode for work tours with a usual location and other tours with fixed locations, such as education. The Tour Mode choice is structured as an MNL, offering a choice among available mode alternatives. This structure allows for the inclusion of new modes, such as on-demand mobility or automated mobility. The models are specified differently for each purpose and consider individual-specific characteristics, travel time, and cost for each alternative mode.

Alternative availabilities are determined based on distance thresholds for walking and biking, transit availability between different origin-destination pairs, and household characteristics like owning a car or bicycle.

3.2.2.3 Tour Mode and Destination

Tour Mode and Destination were estimated for tours with non-fixed (work or education) destinations. The choice set encompasses all combinations of modes and destinations represented by traffic analysis zones (TAZ) in the modelled region. The model integrates travel times and costs for each mode, with size variables for each possible destination, such as area, employment, population, and urban area dummy variable. These are incorporated using the aggregate spatial method outlined by Ben-Akiva and Watanatada (1981), and the model is estimated as an MNL.

3.2.2.4 Tour Time-of-Day

Tour Time-of-Day models determine the start and end times of the primary activity. The continuous 24-hour day is discretized into 48 half-hour segments, resulting in 1,176 alternatives for the activity starting and end time possible combinations. Alternative specific constants follow a continuous and cyclical form outlined by Ben-Akiva and Abou-Zeid (2013), utilizing a trigonometric utility functional form. Activity duration, travel times, and travel costs are considered. If no available time is feasible, the tour is removed.

3.2.2.5 Work-based Subtour Generation

Subtours may be generated for work tours, and the Work-based Subtour Generation is modelled as a quit/no-quit Binary Logit (BL). While choosing not to quit, individuals continue scheduling sub-tours, with individual characteristics and the tour mode serving as parameters.

3.2.2.6 Work-based Subtour Mode and Destination

The Work-based Subtour Mode and Destination are modelled similarly to the primary activity Tour Mode and Destination model. However, modes are restricted based on the hierarchy outlined by Siyu (2015), determined by the work tour mode. In this hierarchy, individuals can only choose the mode of their tour or other readily available options. For instance, a person may not take a personal vehicle for a sub-tour if they do not drive to work.

3.2.2.7 Work-based Subtour Time-of-Day

The Work-based Subtour Time-of-Day is modelled in the same manner as the Tour Time-of-Day. However, alternative availabilities are influenced by the duration of the primary work activity.

3.2.3 Intermediate Stop Level

Within the Intermediate Stop Level, tours undergo segmentation into inbound and outbound segments—preceding and succeeding the arrival at the primary activity, respectively. Each of these segments is individually processed and evaluated for stop creation.

3.2.3.1 Intermediate Stop Generation

The Intermediate Stop Generation model serves as a Nested Logit quit/no-quit model, wherein opting for a no-quit scenario leads to the creation of a new intermediate stop. One nest exclusively includes the quit option, while the other encompasses various activity purposes. The model incorporates individual attributes, tour purpose, and the remaining time window - determined by the start or end time of the primary activity, as well as preceding or subsequent stops - as variables. The available stop purposes are based on the outcomes of the Day Pattern Stops model, and stops are scheduled in a sequential manner.

3.2.3.2 Intermediate Stop Mode and Destination

The Intermediate Stop Mode and Destination model mirrors the Tour Mode and Destination structure. For inbound and outbound stops, the considered travel time and travel cost are those between the planned stop and the one following or preceding it, respectively. The mode availability adheres to the hierarchy outlined in the Work-based Subtour Mode and Destination model.

3.2.3.3 Intermediate Stop Time-of-Day

Unlike tour and sub-tour activities, intermediate stops are confined by the start and end times of adjacent activities. Consequently, their choice set is a subset constructed from the 48 half-hour time periods. The Intermediate Stop Time-of-Day still features trigonometric functional forms, but they interact differently for various stop purposes. Travel time and travel cost are also incorporated, and the model follows an MNL approach, with alternatives defined akin to the generation window.

4 APPLICATION TO THE DANISH CASE

4.1 Introduction

Within SORTEDMOBILITY's Copenhagen case study, the modelling framework described above is applied to the Danish context, where the population accounts for 5.8 million individuals. Data from the Danish National Travel Survey (TU)[1] and skim matrices detailing car and transit travel times and costs, provided by the Danish Road Directorate (VD or Vejdirektoratet[2]), are utilized to estimate the models. The TU is an interview survey which serves to document the travel patterns of the Danish population. In our modelling estimation, we used activity diaries for 19,588 individuals collected between 2017 and 2019. Participants were tasked with recording all activities performed on a designated weekday (24 hours, Monday to Friday) in chronological order, specifying activity locations, transport modes, arrival and departure times, and accompanying household or non-household members through web or phone interviews. The survey also gathered individual and household characteristics for participants.

4.2 General Estimation Procedure

The estimation process for the models used Biogeme[3] and involves two phases. First, all models were estimated using only the processed TU and VD data. Within SORTEDMOBILITY, inclusive values derived from the lower-level models are being computed and will be used in a second round of estimation.

4.3 Data Preparation

4.3.1 Tours, Subtours, and Intermediate Stops

TU trip diaries were scrutinized to identify tours, sub-tours, and intermediate stops. A tour, defined as a series of trips and activities commencing and concluding at home, classifies activities into work,

[1] https://www.cta.man.dtu.dk/english/national-travel-survey/what_is_tu
[2] https://www.vejdirektoratet.dk/
[3] https://biogeme.epfl.ch/

education, shopping, personal, recreation, or escort. The primary activity for a tour is determined based on a hierarchy: (1) work, (2) education, (3) personal activities, (4) shopping, (5) leisure, and (6) escort. For full-time students, education takes precedence over work. Tours featuring two or more highest-priority activities of the same type have the primary activity determined by the longest duration. All other activities within the tour are classified as intermediate stops. Work-based subtours merge work activities before and after subtours into a single activity.

4.3.2 Day Patterns Models

Sixty-four activity patterns can be formed with six activity purposes, but after analyzing the TU data, it was observed that most individuals engage in at most four primary activity purposes in a day, reducing the possible patterns to 50. Work-related patterns are restricted to part-time or full-time employees, while education-related patterns are limited to enrolled students. Similarly, 50 activity patterns are identified for intermediate stops, reflecting the combinations of activities individuals undertake during stops. The number of tours for each activity type per individual is determined, with the TU data indicating that individuals generally perform at most two tours per activity type per day, except for leisure and shopping tours.

Table 1: Number of tours per purpose (TU, 2017-2019)

# of tours	Work	Education	Personal	Shopping	Leisure	Escort
1	6824	3732	983	3712	4875	689
2	148	18	85	272	811	208
3	6	-	8	18	135	16
4	2	-	3	-	27	2
5+	-	-	2	-	9	-

4.3.3 Mode and Mode Destination Models

The mode is determined using a hierarchy similar to Siyu (2015): public transit, car passenger, driving alone, biking and bike-sharing, and walking. Rare modes, such as boat, airplane, etc., were excluded. For modelling tours and sub-tours, trip chains are simplified by eliminating "change of transport mode" stops, and a primary mode is assigned for each trip using the specified hierarchy. In Mode and Mode and Destination choice models, walk and bike availability are determined based on the maximum walking and biking distances observed in the TU: 7 km and 22 km, respectively. Biking is available only for individuals whose households own at least one bike, and driving alone is available only for individuals with a driver's license and at least one car in their household. Public transit availability is sourced from the VD skim matrices, while car passenger is assumed to be available to all individuals.

4.3.4 Time-of-Day Models

In Time-of-Day models, time availabilities are assigned following the order of activity priority. For instance, the primary work activity is scheduled first, and all possible arrival and departure times are available for that activity. The second most important primary activity has all available times except those occupied by the primary work activity and so on. Time availability for intermediate stops and work-based subtours is defined as specified in the framework (Section 3).

5 RESULTS

5.1 Estimation Results

Twenty-two models were estimated for the Danish implementation, and this sub-section delves into the noteworthy values for key models and model groups. In the Day Pattern Travel model, age, gender, education, employment, driver's license, and income emerged as significant. The Day Pattern Tours and Day Pattern Stops models, alongside the previously mentioned variables, also highlighted the significance of the fixed work location binary variable. In the majority of the Number of Tours models, the vehicle ownership category also came out as significant. Travel time and costs, as well as zone-specific population, area, employment and urban area binary, tended to be significant in the Mode and Mode-Destination models. Each Time-of-Day model, characterized by varying trigonometric components, showcased the significance of travel time and cost. Lastly, for Intermediate Stop Generation, the remaining time window in the day, coupled with the number of stops already performed for that half-tour, emerged as significant. The tour purpose also played a significant role.

For comprehensive estimation results and model specifications, kindly refer to the following repository: https://github.com/MLSM-at-DTU/SimDanmark

5.2 Simulation Results

The proposed activity-based approach provides a dual benefit: it facilitates the derivation of aggregate metrics for demand and enables the simulation of demand on a network, specifically the rail network in EGTRAIN or other simulator. Here, we provide the comparison between the simulated output for a synthetic population used in estimation and the original TU data set, together with aggregated statistics of a simulation run.

Figure 5 shows the distribution of simulated tour purposes. The results are consistent with the TU overall. Note that the work purpose is slightly overestimated and that the remaining purposes are, on the other hand, slightly underestimated.

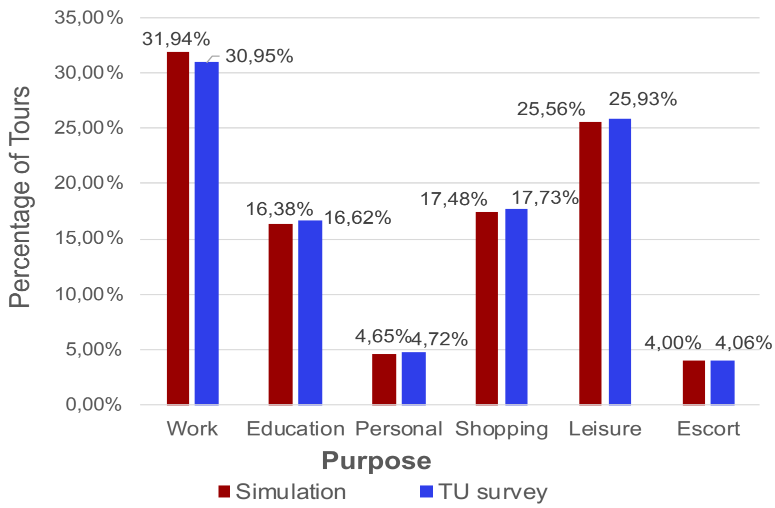
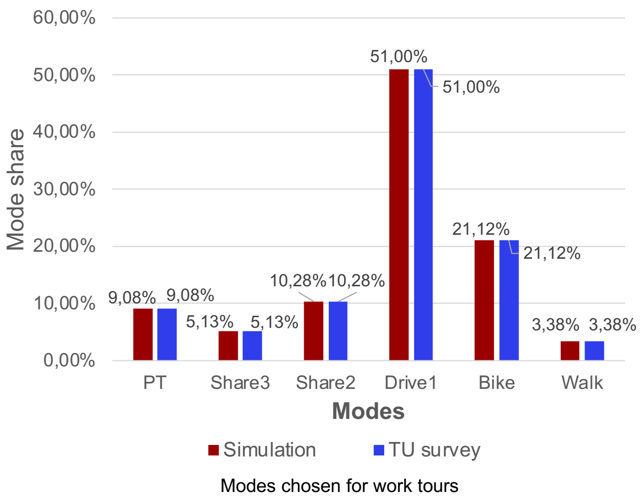


Figure 5: Tours by purpose.

Similarly, Figure 6 shows the comparison between the modal split of the TU and the simulated DAS. Overall, the framework properly models the observed tour modes.



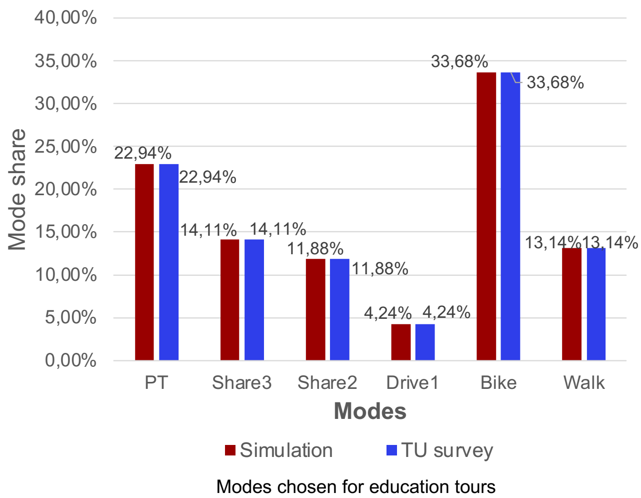
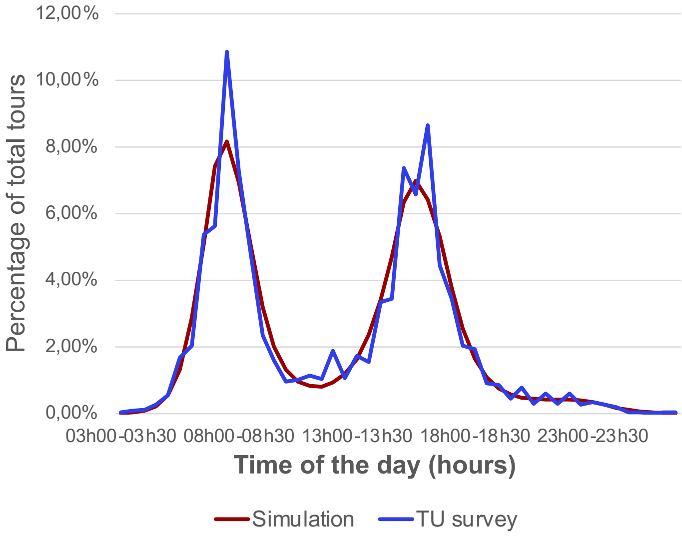


Figure 6: Tours by Mode for Work and Education Purposes

Figure 7 shows the simulated commuting patterns to and from work as the primary activity. The temporal peaks are evident in both the simulation (a) and the original TU data set (b). Additionally, it is observable that due to the hierarchical structure of tour purposes in the simulation, lower-priority tours are shifted to later times in the day.



Work tours by time of the day

Figure 7: Number of tours per person by mode.

6 DISCUSSION AND CONCLUSION

This report introduces the modelling formulation and estimation of the activity-based, agent-based demand simulator for SORTEDMOBILITY. It captures the project's multi-modality requirement and demand sensitivity to the rail systems' level of performance, namely costs and travel times. In contrast to existing approaches, this framework offers increased flexibility in depicting various demand patterns.

The estimated models were coded into the SimMobility simulation software using `Lua` files, facilitating the seamless configuration of parameters and change of model formulations if needed.

Nevertheless, there are several enhancements still ongoing in our current version. Firstly, we are including time variability and reliability measures to the set level of performance in the Mode, Mode and Destination, and Time-of-Day models. This will allow the model to respond to more dynamic operations as expected to be SORTEDMOBILITY's self-organized framework.

Current ongoing activities also include (1) the generation of a synthetic population for the whole of Denmark and (2) the aggregate calibration of the ABM models using machine learning techniques and data from flow counts for the different modes. These two tasks are expected to bring realism to the final set of simulations to be performed in the overall framework presented in Figure 1 for the Danish case.

In terms of limitations, beyond the scope of this project, the proposed framework currently encompasses route-choice and mode-choice models, addressing the potentially flawed assumption that individuals determine their activity mode and destination before the start and end time. These models should be expanded to incorporate the rescheduling of activities and re-planning for the remainder of the day. Also, in this framework, escort activities are modelled separately without considering household interactions. These activities aim to capture pick-ups, drop-offs, and trips accompanying someone. Ongoing research should be sought directly toward modelling social interactions, especially through joint household activities.

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