SimMobility Mid-Term Simulator: A State of the Art Integrated Agent Based Demand and Supply Model

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Abstract

Agent based models have gained wide acceptability in transport planning, however, the modelling frameworks have been facing a practical dilemma: demand and supply sides are not fully integrated with each other. So overcome this problem, time-dependent OD matrices are traditionally used to integrate sophisticated agent based demand (Activity-based models) and supply (Dynamic Traffic Assignment) models, which doesn’t allow exploitation of several advantages offered by these rich frameworks. Earlier integration efforts exist, such as TRANSIMS and MATSim, however these are still based on various simplifications.

This paper reports development of the SimMobility mid-term simulator, which is an agent based, fully econometric, activity-based demand model, integrated with a dynamic traffic assignment model. This SimMobility mid-term is part of a much larger simulation platform that also contain long term and short term models.

The SimMobility mid-term architecture comprises three interconnecting components, namely the pre-day, within-day and supply simulators. Models within these simulators are developed utilizing the various datasets from Singapore. The paper also presents some preliminary results obtained from the current implementation to provide an idea about its efficiency in terms of computational time and predictions accuracy. Avenues of future work are also mentioned to improve the capabilities of the modelling framework.

1. Introduction:

Agent based simulation models have gained wide consideration within the transport planning practice as the framework allows explicit modelling of individual decision process at demand and supply levels *(1)*. However, in practice, research efforts have been rather disjointed *(2)*. At the demand side, some efforts are more focused on development of sophisticated activity-based (AB) modelling systems that focus on individual's entire day activity pattern using two distinctive approaches i.e. econometric and rule-based heuristics. Examples of such systems are ALBATROSS *(3)*, Day Activity Schedule Approach *(4, 5)*, CEMDAP *(6)* and TASHA *(7)*. On the other hand, at the supply side, efforts are made to develop a more realistic representation of network dynamics through simulation based dynamic traffic assignment (DTA) models. Examples of such developments are VISTA *(8)*, CONTRAM *(9)*, DYNASMART-P *(10)*, DYNAMIT *(11)*. There are a few efforts reported that attempt to consider both sides, however, these frameworks assume some simplifications especially for generation of activity-based demand. TRANSIMS *(12)* and MATSim *(13, 14)* are examples of such efforts. This paper presents the *SimMobility mid-term (SimMobilityMT)* simulator, which integrates AB and DTA models within an agent based environment. Besides this mid-term model, the SimMobility project also contains long term and short term modules, which will be briefly described in the subsequent sections.

Review of literature suggests that, traditionally, AB model outputs are aggregated in terms of time-dependent OD matrices that are fed into the DTA model to work out flows and travel times. Using a similar notion, a study from Lin et al *(15)* presented an equilibrium solution by forming a fixed-point problem between the CEMDAP (demand) and VISTA (supply) frameworks. Balmer *(16)* pointed out several disadvantages of using OD matrices as an integrating mechanism, e.g. loss of disaggregation of travelers that is gained through the agent based AB model, and in addition to this, an iterative feedback from the supply model may only be based on aggregate performance measures not on individual performance on the network. Furthermore, aggregation of travelers in the form of OD matrices does not allow explicit representation of re-scheduling or en-route decisions during execution of activity patterns and, due to this, reported results may be misleading. It is therefore, appropriate to have travelers as individual entities (agents) throughout the whole process. The SimMobilityMT simulator presented in this paper is completely agent based at all the stages of the modelling process.

Comprehensive agent based modelling structures developed so far can be listed as TRANSIMS *(12)*, MATSim *(13, 14)* and FEATHERS *(17)*. Computational efficiency of such platforms has always been a major concern as they usually deal with the entire population of an area which is synthetically generated. This causes introduction of various simplifications in their modelling processes. There exist four distinctive modules in TRANSIMS such as Population Synthesizer, Activity Generator, Route Planner and Microsimulator. The Activity Generator module in TRANSIMS uses collected household survey data to work out almost all scheduling dimensions of activity patterns of synthetic individuals using some rules, random selection and matching of few socio-economic characteristics of individuals from the survey *(12)*. Further within TRANSIMS, there is a feedback mechanism introduced between Router and Microsimulator, which attempts to bring the system into equilibrium. However, during that process, individuals can only change their routes with no flexibility of changing other dimensions of their activity patterns. Like TRANSIMS, the MATSim toolkit is also an open source platform that works on similar notions. MATSim assumes individuals initial plans of the day which are derived on the basis of the household survey data. These initial plans are then executed in MATsim demand-supply simulator and, based on the score, agents adapt their plans in response to conditions that arose during the simulation *(13)*. The scores within the MATSim are based on heuristic utility functions with a limited set of variables, mostly network performance related. The new plans are generated based on iterative feedback mechanism by modifying few scheduling dimensions of initial plans in order to get a stable solution, which they called as schedule user equilibrium *(18)*. Recently, Bellemans et al *(17)*, reported FEATHERS' modular platform that along with other processes also models the generation of activity patterns of individuals unlike TRANSIMS and MATSim. This is done using a rule-based AB model system known as ALBATROSS.

In relation to the above review, this paper reports development of the SimMobilityMT modelling framework that can be claimed (to the best of our knowledge) as the first agent based integration of a fully econometric AB demand model system with a simulation-based DTA system. It consists of three interacting simulators: the *Pre-day* simulator, which is responsible for modelling and simulating individual daily activity travel pattern; the *Within-Day* simulator, whose function is to simulate departure times and route choice behavior incorporating en-route decisions (re-scheduling); and the *Supply* simulator that takes care of network attributes and supply system in relation to both public and private transport.

This paper is structured as follows: Next section presents the overall SimMobility modelling framework, with emphasis on the midterm model; the third section discusses development of this model; the fourth section discusses preliminary results and the paper ends with the conclusion and future work.

2. SimMobility framework and the mid-term model

SimMoblity is a new simulation platform, developed at the Singapore-MIT Alliance for Research and Technology (SMART), that integrates various mobility-sensitive behavioral models within a multi-scale framework that considers land-use, transportation and communication interactions.

The high-level architecture of SimMobility is shown in Figure 1. SimMobility comprises three primary modules differentiated by the timeframe in which we consider the behavior of an urban system. The short-term model functions at the operational level: it simulates movement of agents at a microscopic granularity (within day). It synthesizes driving and travel behavior in detail and also interacts with a communication simulator that models the impact of device-to-device communication on these behaviors. The mid-term (day-to-day) simulator handles transportation demand for passengers and goods; it simulates agents' behavior which includes their activity and travel patterns. The mid-term represents moving vehicles in aggregate, and routes are generated by behavior-based demand models. The long-term (year-to-year) model captures land use and economic activity, with special emphasis on accessibility. It predicts the evolution of land use and property development and use, determines the associated life cycle decisions of agents, and accounts for interactions among individuals and firms. Roughly speaking, the short, mid and long term correspond to the traditional micro, meso and land use levels of simulation.

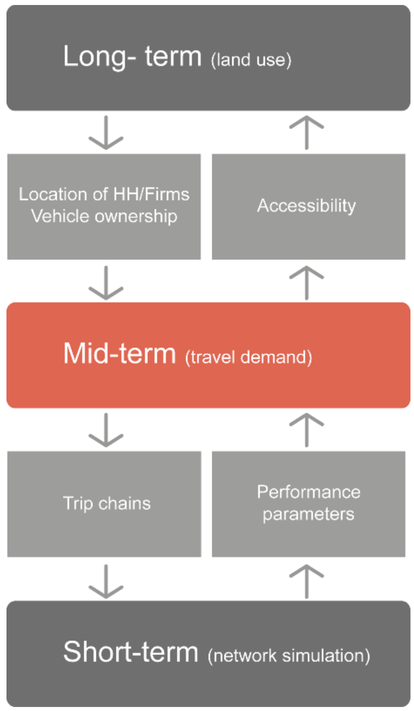


Figure 1: High level architecture of SimMobility

The SimMobility framework is fully modular in a way that each level can run independently and only access the other level when necessary. The key to multi-scale integration in SimMobility is a single database model that is shared across all levels. Every agent exists and is recognized at all levels simultaneously, and information is used according to each level's needs. In this way, the behaviors will remain consistent and, even if run separately, the impacts from one level's model are propagated to the others gracefully.

Components of SimMobilityMT are shown in Figure 2. It receives population with agent's socio-economic characteristics, vehicle ownership etc. & land use information from the Long term simulator (SimMobilityLT). SimMobilityMT consists of three main components: Pre-day, Within-day, and Supply simulator. The pre-day model provides the activity schedule, comprising the planned activities with corresponding times, together with the main transport modes between activities. This pre-day level is a high level plan, including only important choices. Lower level choices are made during the day when those plans are executed. During the day, agents can be either doing an activity or executing a trip. While at an activity, they are stationary at one location and then, at the beginning of each trip, agents further detail their plan. For example, they need to make (revise) mode, route and departure time choice. Once the detailed plan is made and the start time is reached, the supply simulator moves the agent accordingly. Vehicle trajectory and network performance are passed to the day-to-day learning module, which feeds back to the pre-day model to update agent's knowledge (either as a calibration procedure or for a multiple day simulation).

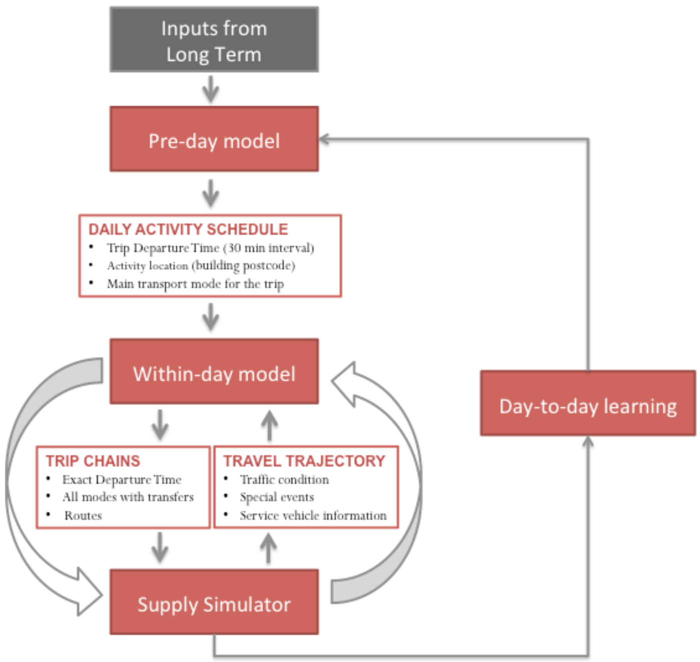


Figure 2: SimMobility Midterm Modelling Framework

SimMobilityMT is designed to work on a hybrid simulation paradigm in that demand is event driven and supply is time step based. Agents are *dormant*, with fixed plans that are executed by the supply. However, before handing over to supply, they subscribe to events of their interest, such as occurrence of an incident, arrival at some decision point (e.g. bus stop, intersection), end of an activity, excessive delay (e.g. waiting in a bus stop). Agents can also evaluate their decision regarding some strategic choice when they are on a regular update point. This event subscription mechanism aims to emulate agent's perception. On the other side, the supply is time-step based, emulating the dynamics of the full system.

SimMobilityMT is an open source framework and aims to simulate millions of agents for a large network, which requires very high computing capability. Developed in C++, the performance improvements rely on parallel processing and distributed computing through *boost threads*, *boost mpi*, respectively. A lightweight, embeddable scripting language LUA is used for model specification. PostgresSQL database is used to store relational data and MongoDB is used for non-relational data.

3. Midterm SimMobility Modules

3.1 Pre-day Model and Simulator

The pre-day simulator consists of an AB modelling framework through a system of interconnected discrete choice models representing choices at distinct dimensions. An agent based demand simulator is developed with respect to the model structure and is capable of generating detailed activity and travel plans for a synthetic population. The pre-day model development follows the Day Activity Schedule approach *(4,5)*, which focuses decisions related to daily activity and mobility. The inputs to the model system are based on the outcome of SimMobilityLT, and in the context of this paper may be considered as exogenous.

Figure 3 shows pre-day model components and logic flows. The overall system can be viewed as a hierarchical (or nested) series of choice models. The solid arrows in figure 3 indicate that the models from lower level are conditioned on decisions made with models from higher level. The dashed arrows represent the accessibility measures described subsequently. There are three different hierarchies in the system: day pattern level, tour level and intermediate stop level. Day pattern level defines the participation of agents in activities as primary, and secondary. This level will generate a list of tours as well as intermediate stop availabilities for the synthetic population. The tour level includes multiple discrete choice model types: attend usual work location; travel mode choice, and travel mode/destination choice; work-based sub-tours; tour time of day; and stop generation. The intermediate stop level includes two types of discrete choice models: mode/destination, and time of day. The current version of the model; the time resolution of departure time for each trip is half hourly time interval, the origin and destination of each trip are building postcodes and the mode can be bus, subway, car, car passenger, motorbike, taxi and walk. Daily activity schedule is the interface between pre-day and within day models.

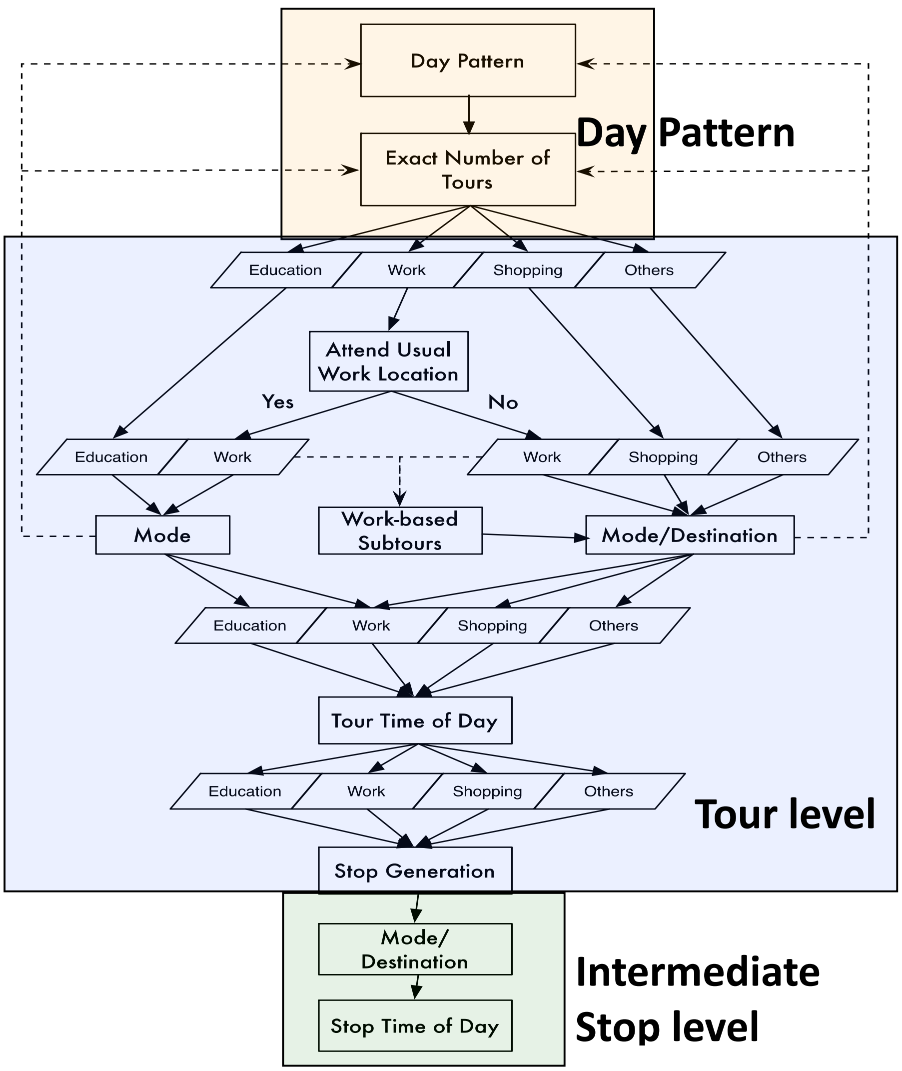


Figure 3: Pre-day Model Structure within SimMobility Midterm

The pre-day simulator contains model estimation results and simulation logic to generate daily plan of activity and travel (i.e. day activity schedule). The simulation process follows the sequential approach respecting the hierarchy presented in the pre-day model structure as described in Bradley et al *(19)*.

For the purpose of estimation of pre-day model, data from multiple sources are obtained from Singapore. The variables related to network performance and level of service comes from network skims and GPS data. The GPS-enabled travel time data along with network skims, after application of data fusion techniques, allows generation of more realistic travel time data for the whole day. Landuse data, which forms the basis of attraction variables for destination choice models is zonal based. With these data sets, household interview and travel survey conducted in 2008 (HITS 2008) in Singapore is used as data for the model estimation. The model estimation usually follows procedures similar to those described in Bowman et al *(20)*.

3.2 Within-Day Simulator:

The within-day module of the mid-term simulator is designed to simulate travelers' various decision making process before and during their trips. The conceptual flow of the within-day module is illustrated by figure 4.

The pre-trip behavior model converts the day activity schedule into more detail travel itinerary which is *traveler trip chain* through a series of choice models. Then the traveler trip chain is feed into a multi-modal supply simulator where the actual movement trajectories are simulated. On the other hand, Mode specific service controller is responsible for generating the trip chains of all service vehicles (bus, taxi, etc.).

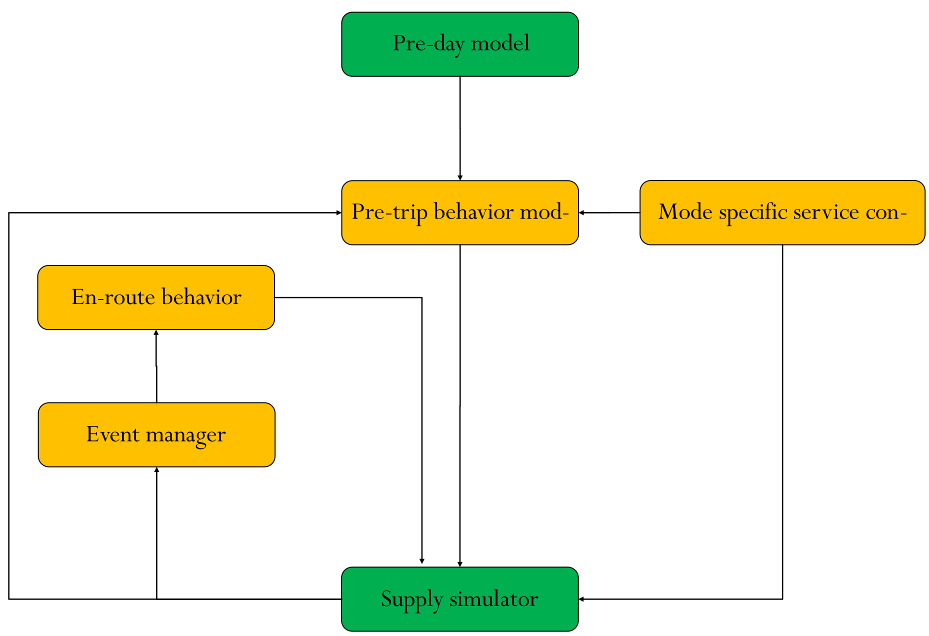


Figure 4: Main components and conceptual flow of within day simulation

From supply module, the simulated traffic conditions (density, travel time, etc.) and special events (incidents, heavy congestions, etc.) are passed back to pre-trip and en-route models. The former feeds directly into the pre-trip behavior model for pre-trip decisions and the latter is sent to event manager which in turn notifies corresponding travelers for en-route decisions.

Pre-trip behavior models include departure and route choice model for private traffic and public transport and pre-trip activity rescheduling; the en-route behavior model includes re-routing and en-route activity re-scheduling. The within-day module is an event driven system where all the behavior models are triggered by assorted events. From traveler's perspective, the simulation flow is driven by a cycle called within-day simulation cycle which is divided into two distinct states: performing activity and undertaking a trip. When a traveler is performing activity, incoming events are handled by corresponding pre-trip behavior models; while when a traveler is undertaking a trip, events are handled by en-route behavior models. The concept of within day simulation cycle is presented by Figure 5.

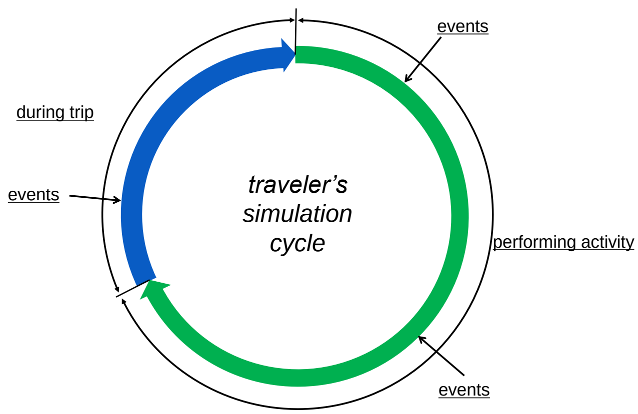


Figure 5: Traveler's within day simulation cycle

Note that due to the enormous number of events, it is not feasible to enumerate the definition of each event in this paper. However one of the key tasks of within-day module is to establish connections between different events and corresponding behavior models. And each behavior model may also generate new events according to traveler's decision in response to external events. Such kind of event chain allows the system to simulate complex interactions between transportation system and travelers and interactions among travelers.

In the remaining part of this section, some of the behavior models are briefly explained.

Pre-trip route choice for private traffic

The pre-trip route choice model contains two essential components: 1) choice set generation and 2) utility function estimation. The choice set generation in within day adopts a combined method which integrates link elimination method *(21)*, labeling method *(22)*, k-shortest path method *(23)* and simulation method *(24)*.

Taxi GPS points are converted to observed paths through a map matching process based on the SimMobility Singapore road network. Then the coverage of the integrated path set generation algorithm is tested with observed taxi paths. Finally, the utility function of the choice model is estimated based on observed taxi trip paths and the choice set generated by the proposed method using path-size Logit model *(25)*.

Pre-trip route choice model for public transport

The public transport network in mid-term is represented by a directed graph composed of nodes and arcs. Each node represents a bus stop and each arc represents either a route segment or a walking transfer. Here the route segment is defined as a collection of all direct line services between two stops all of which using the same set of road segments.

The route choice set generation for public transport network is a combination of labelling method, link elimination method, k-shortest path method and simulation method. EZ-link card data collected in Singapore is used for coverage test and utility function estimation. Similar with private traffic route choice model, detail estimation result and modeling process are not shown here. More discussions will be included in later papers related to SimMobility

En-route re-routing model for private traffic and public transport

The en-route re-routing model simulates the process of route change caused by various external events. The basic idea of re-routing is to allow drivers (or bus passengers) to modify their current path information during their trips.

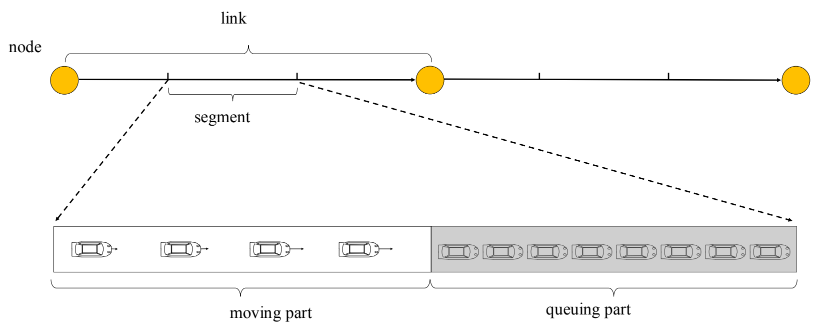
The en-route re-routing model (for both private traffic and public transport) consists of five steps: event notification, re-routing point identification, re-routing path set generation, travel/cost update and path modification. In the event notification phase, traveler receives external notification regarding the network condition changes and makes decision on whether or not modify his current path. Then travelers identify all possible nodes from where the current path can be shifted. These nodes can be referred as re-routing nodes or decision nodes. Main factors affect the selection of re-routing nodes include traveler's current path, current location and the traffic condition of the network. Then in the re-routing path set generation phase, the path set generation algorithm is applied between each re-routing nodes and the destination node in traveler's current path. By integrating the current path and all the re-routing paths, one can form a new path set from which the new route can be selected using discrete choice model. The link travel time and cost should be updated based on the newest traffic information that is reported to the traveler through the event system.

3.3 Supply Simulator:

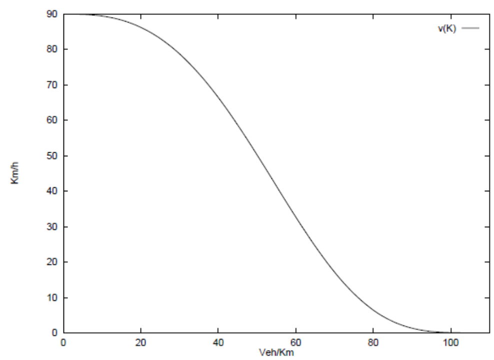
The mid-term supply simulator is a mescoscopic traffic movement simulator that shares many common features with DynaMIT supply module *(26, 27)*. The design motivation of mesoscopic supply simulator is to combine the high computational performance of macroscopic traffic flow models and the capability of microscopic simulation models in terms of replicating route choice behavior. Given the path of each traveler (the path in this context can be a sequence of road segments or public transport route segments depending on the type of network), the objective of the supply simulator is to estimate the actual movement trajectory of each vehicle.

Simulation of heterogeneous vehicle types

The road network in SimMobilityMT is represented by a hierarchical structure composed of links, segments, lane groups and lanes. Segment is the basic processing unit of the supply simulator. Each segment represents a section of homogeneous roadway which is further divided into two traffic flow regions: the moving area and queuing area (see Figure 6 (a)).



(a)



(b)

Fig. 6 Segment structure (a) and macroscopic speed density function (b)

Vehicles in the moving area travel at some uniform positive speed determined by the traffic flow density of the area and a pre-defined macroscopic speed-density function (Figure. 6 (b)). Vehicles in the queuing area form a horizontal queue whenever the arrival rate of the traffic flow exceeds the outgoing (sending) capacity of the segment. As a result, two important supply parameters dominating the supply model are respectively the macroscopic speed density curve and segment sending capacities.

In order to advance the position of each vehicle, two time intervals are defined: the advance interval and update interval. During each advance interval, the vehicle positions are updated according to their current status (moving or queuing) and macroscopic traffic flow parameters of the segments (density, capacity); then at the end of each update interval, the flow densities of the entire network are updated.

Since the mid-term supply simulator needs to accommodate multiple car types with different physical characteristics, the passenger car unit (PCU) concept is adopted. The idea of PCU is to convert larger vehicle such as bus or truck into equivalent number of passenger cars. In mid-term supply, the PCU concept is used for consider the impact of large vehicles when computing flow density, queue length and capacity consumption of different vehicle types.

Virtual bus stop and bus simulation

Another major innovation in terms of supply is the simulation of bus movement. Because buses need to enter bus stops and interact with passengers, the simulation logic of bus is different from that of other vehicles. Two crucial aspects of bus simulation are bus stop modeling and bus movement logic.

In mid-term system, the bus stop is modeled by adding a logic unit called *virtual bus stop* to the end of segments. Virtual bus stop is essentially a logic structure that encapsulates all the parameters of a bus stop. And in order to insert the virtual bus stop into the network at correct location, the original road segments are split into multiple new segments at the bus stop locations. The idea of virtual bus stop and re-segmentation of the network is illustrated by Figure.7.

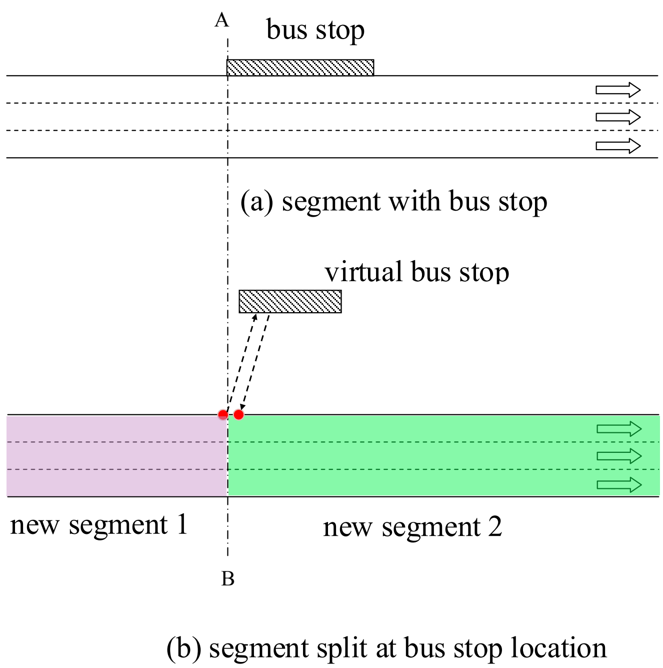


Figure 7: Illustration of different bus stop types and virtual bus stop concept, re-segmentation

The simulation of buses near bus stops is composed of four steps: lane selection, entering bus stop, boarding & alighting and re-joining traffic flow. The interaction between buses and the main flow traffic is also considered under this framework (such as queue spillback from bus stop). Due to limited words restriction, detail discussions regarding the bus supply is not presented here.

Simulation of pedestrian/passenger

The pedestrian (passenger) movement is also simulated in mid-term supply model. Pedestrians always choose the shortest path between different stops and move at constant walking speed (3.6 km/h) which is configurable.

4. Preliminary Results

First phase of the SimMobilityMT is fully functional with parallel software framework to simulate large population. We performed preliminary test with population scaled from HITS 2008 data. Below are the experiment setup and the preliminary results.

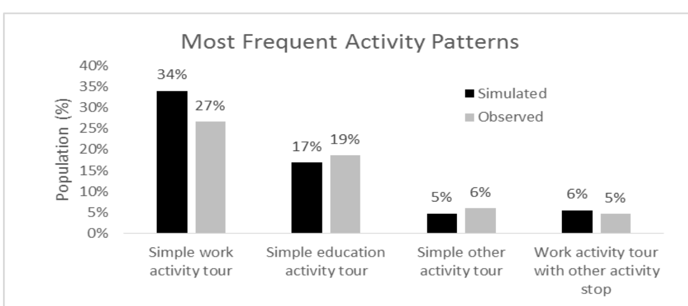
4.1 Experiment Setup

Experiment was conducted to generate all agents' daily activity schedule for over 2.61 million population for entire Singapore. The experiment was carried out on a Intel(R) Xeon(R) E5-2620 running Ubuntu 14.04 LTS with 12 physical cores at 2.00GHz and 32GB of RAM. Within-day and supply simulator was run to simulate for one hour (340000 trips and 491000 activities) at the peak period from 8:30 am to 9:30 am for entire Singapore road network with 5 seconds advance interval and for private traffic only as the public transit implementation is in progress at the time of writing this paper.

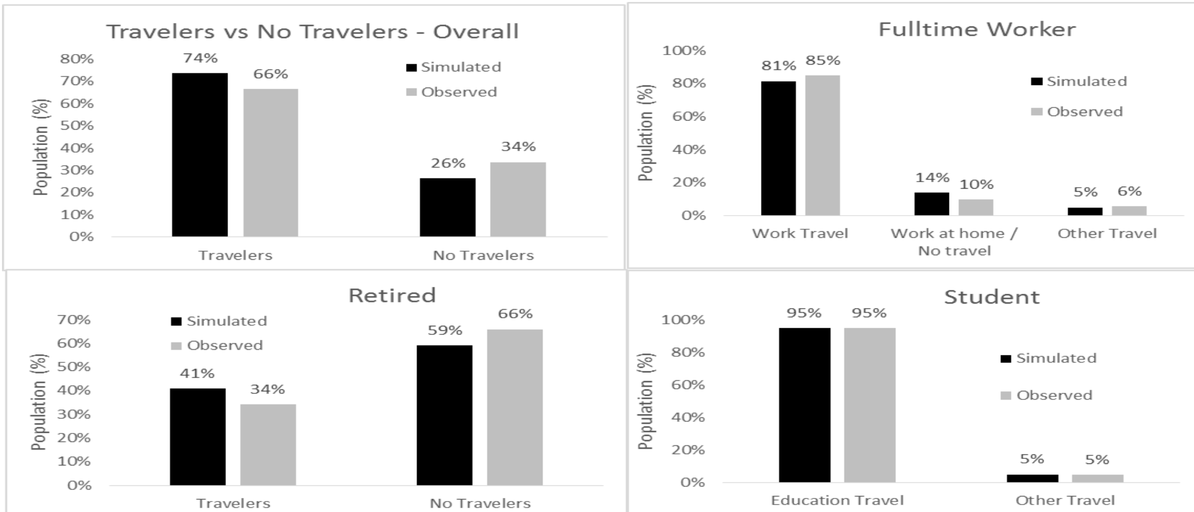
4.2 Experiment results

Figure 8 (a) and (b) present aggregate prediction results in terms of overall population and also based on few population classes from pre-day simulator. Based on the HITS 2008 data, we identified 51 different activity patterns for individuals comprising of simple (one-activity tour) and complex patterns (tours with stops or multi-tours). Figure 8(a) presents the predictions from the pre-day simulator for four most frequent patterns found in the HITS 2008 dataset. The predictions from the simulator seems reasonable. The highest difference is found for the simple work activity tour which is around 7%, the some of this difference may be contributed by the simulation error. In figure 8(b), there is a discrepancy of around 8% noted in the overall population plot, as pre-day simulator is overestimating number of travelers compared to the observed data. However, individuals belong to important classes of population such as Fulltime worker, Retired and Student have better predictions of their travel behavior from the simulator.

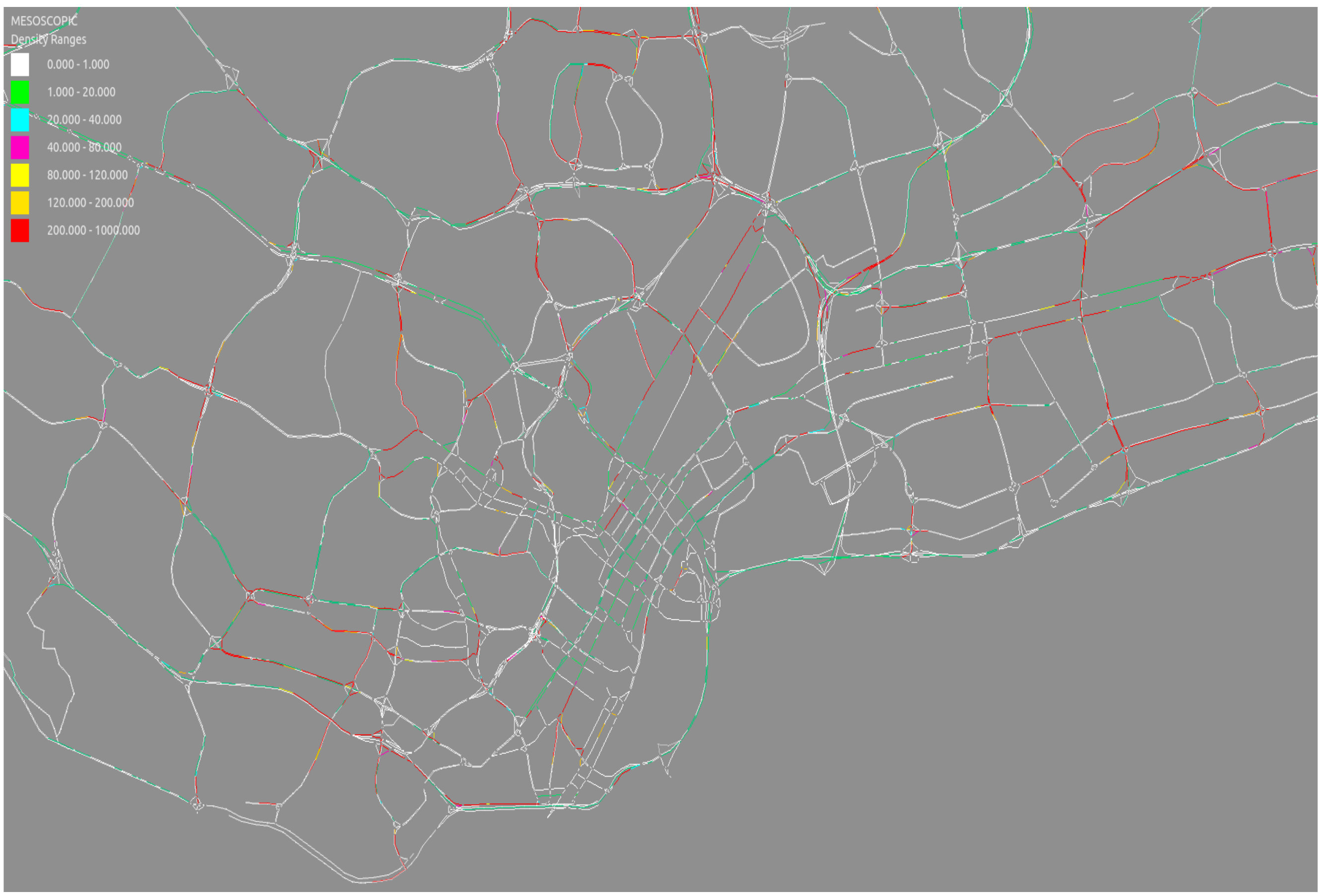
Fig. 8 (c) presents a snapshot of the simulated density map for the partial Singapore road network to visualize the outputs better. The unit of density is vehicle/km. The results obtained are as per expectations, as higher densities observed on roads segments which are representing key economic areas within Singapore.



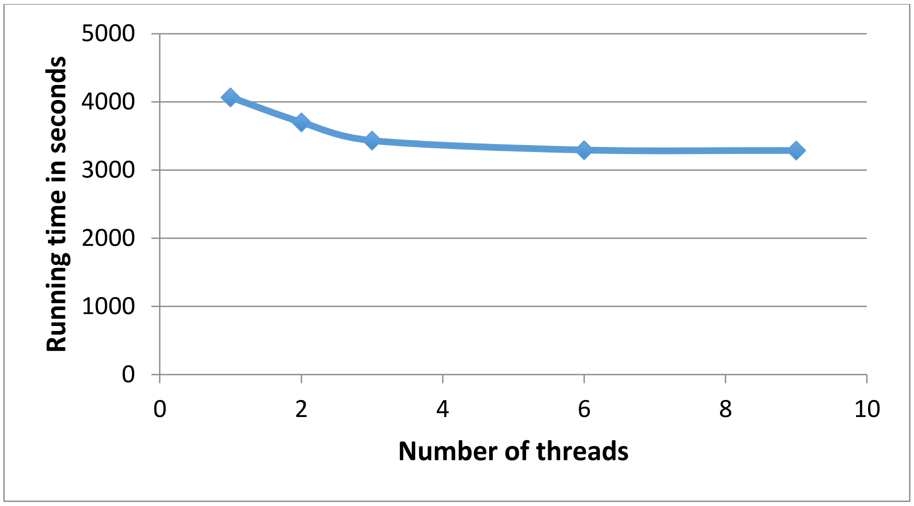
(a) Most frequent activity patterns of the population



(b) Activity pattern predictions for different population groups



(c) Simulated density map of morning peak hour of Singapore



(d) Computation time of within day and supply simulator for peak hour simulation

Fig. 8 System outputs from pre-day, withinday and computational performance

Pre-day demand simulator produced 3.35 million activities and 6.09 million trips for the entire 2.61 million populations in 10 minutes while running with 6 threads. Fig. 8 (d) presents the computation time of within day and supply module as a function of number of threads. The figure shows almost some improvement in the running time when number of threads are increased from one to three but further increase didn't show any significant improvement. The improvement of SimMobilityMT is in progress and there is lot of scope to optimize the performance for better computational efficiency.

5. Conclusion and Future Work:

This paper presents the design, concept and implementation of a state of the art traffic simulator – the SimMobilityMT. It is a fully integrated agent-based traffic simulator which is built on disaggregated behavior models in both demand and supply. The main innovations in pre-day, within day and supply modules are presented. Through the preliminary results, one can see that the mid-term simulator as an integrated system is already functional and generating plausible outputs.

As for the future work, we are working on further enhancement of the system in many aspects. For pre-day module, we are working on the model calibration using HITS 2008 survey data and moving to full population simulation; For within-day module, we are working on public transport route choice implementation and establishment of the simulation capability for taxi and mobility-on-demand vehicles. Also the modeling of freight simulation is another ongoing work for the SimMoblilityMT.

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