Available online at www.sciencedirect.com

ScienceDirect

Transportation Research Procedia 00 (2018) 000–000

Transportation Research Procedia

www.elsevier.com/locate/procedia

World Conference on Transport Research - WCTR 2019 Mumbai 26-31 May 2019

Modeling Freight in SimMobility, A Multi-scale Agent-based Urban Simulation Platform

Takanori Sakai[a,] *, André Alho[a], Bhavathrathan B. K.[b], Giacomo Dalla Chiara[c], Raja Gopalakrishnan[c], Peiyu Jing[d], Tetsuro Hyodo[e], Lynette Cheah[c], Moshe Ben-Akiva[d]

[a] *Singapore-MIT Alliance for Research and Technology, 1 CREATE Way, #09-02 CREATE Tower, Singapore, 138602, Singapore*
[b] *Indian Institute of Technology Palakkad, Ahalia Integrated Campus, Kozhippara, Palakkad, Kerala, 678557, India*
[c] *Engineering Systems and Design, Singapore University of Technology and Design, 8 Somapah Road, Singapore, 487372, Singapore*
[d] *Intelligent Transportation Systems Lab, Massachusetts Institute of Technology, 77 Massachusetts Avenue, Room 1-181 Cambridge, M.A., 02139, United States*
[e] *Department of Logistics and Information Engineering, Tokyo University of Marine Science and Technology, 2-1-6, Etchujima Koto-ku, Tokyo, 135-8533, Japan*

Abstract

In the last few decades, a number of innovative freight modelling methods which apply disaggregate, agent-based approaches, have been proposed. However, the integration of advanced models that focus on freight transportation, as well as that of passenger and freight agent-based models, have not been fully achieved for real-world urban transportation analysis. In this paper, we propose the framework of SimMobility Freight, which is one of the main components of SimMobility, a multi-scale agent-based urban simulation platform. We design SimMobility Freight with the aim of the full-scale integration of disaggregate, agent-based freight and passenger simulation, which is flexible and extendable. SimMobility Freight is capable of simulating commodity contracts, goods vehicle parking, logistics planning, and goods vehicle behaviors in a fully-disaggregate manner, which allows us to measure the impacts of changes in various aspects of logistics operations. Currently, the estimated and calibrated models of the SimMobility Freight are available for Singapore. We discuss the ongoing and the future research works towards the enhancement of the modeling system.

Peer-review under responsibility of WORLD CONFERENCE ON TRANSPORT RESEARCH SOCIETY.

Keywords: Freight transportation modelling; Urban freight; Goods movement; Agent-based simulation

* Corresponding author. Tel.: +65-6601-1636.
E-mail address: takanori@smart.mit.edu

Peer-review under responsibility of WORLD CONFERENCE ON TRANSPORT RESEARCH SOCIETY

1. Introduction

Against the backdrop of the expansion and densification of the metropolitan areas and the recent evolutions in logistics (such as demand-driven supply chain practices), the social impact of urban freight movements is a significant concern. A small share of goods vehicle movements among all vehicle movements account for a disproportionally large share of environmental impacts in a metropolitan area (Coulombel et al., 2018). A new set of policy approaches have been proposed to mitigate the negative impacts associated with the urban freight movement (Taniguchi et al., 2016) and, for fulfilling the policy evaluation needs, a number of novel urban freight modeling frameworks have been proposed (Chow et al., 2010; Comi et al., 2012; De Jong et al., 2013). Such models often take disaggregate, "agent-based" approach, partially at least, to simulate the behaviors of agents that are engaged in urban freight-related activities, and interactions of thereof, for evaluating policy measures which the traditional aggregate models could not provide insights on. However, urban freight simulators using such agent-based models are still limited in use for the real-world policy evaluations due to the lack of data for calibrating models. Furthermore, a number of the novel modeling frameworks still remain in isolation and their integration is an outstanding research task. Moreover, most of the existing agent-based urban freight models were developed independently from their counterparts for passenger trips; to the best of our knowledge, the full-scale integration between the agent-based freight and passenger models that considers the same agents (e.g. individuals, establishments, and drivers) consistently, has not yet been available for policy evaluations (Schroder and Liedtke, 2017).

In this paper, we present the framework of an urban freight simulator, SimMobility Freight, which is developed as a component of SimMobility, an agent-based urban simulation platform. SimMobility is designed with multi-actor and multi-temporal dimension settings and its passenger travel simulation follows an activity-based paradigm, and is currently implemented for Boston, Massachusetts (US) and Singapore. Together with the other modules in the SimMobility, SimMobility Freight aims at the first full-scale integration of disaggregate, agent-based freight and passenger simulation model. The main components of SimMobility Freight simulate commodity contracts, logistics planning, and goods vehicle behaviors. The disaggregate model setting allows one to measure the impacts of the changes in various aspects in logistics operations, for example, production and consumption, supplier locations, number of suppliers, shipment size, goods vehicle availability, vehicle loading (due to consolidation or deconsolidation), delivery time windows, and vehicle operation patterns. SimMobility Freight is also able to simulate goods vehicle parking and pickup/delivery parking decisions. The full-scale system of SimMobility Freight is currently being developed for Singapore, one of the largest metropolitan areas in Asia, and is being used for policy analysis.

2. Literature review

The past couple decades saw significant developments in freight modeling. A noteworthy advancement is the shift from traditional aggregate freight models to disaggregate, agent-based logistics models, for all of the regional, state, and urban scales. A lot of efforts have been made for incorporating "logistics components" into the modeling framework for the realistic simulation of logistics agents and freight demand (Chow et al., 2010; Tavasszy et al., 2012). Several papers are available for understanding the recent advances on freight modeling (Chow et al., 2010; Tavasszy et al., 2012; de Jong et al., 2013; Comi et al., 2012). This section offers a review of agent-based urban freight simulators developed since the year 2000.

GoodTrip model (Boerkamps et al., 2000), developed for the city of Groningen, Netherlands, is notable as the first-generation agent-based urban freight microsimulation model. The novelty of the GoodTrip model comes from the simulations of the interactions between various actors (shipper, transporter, receiver and policy maker) in four distinct markets (commodity market, transport service market, traffic service market, and infrastructure market) for the estimation of freight traffic. Many models proposed after the GoodTrip model similarly apply the multi-level structure. The GoodTrip model also introduced the concepts of supply chain and distribution channels into freight distribution, in order to capture supply chain structures in the freight distribution process. Wisetjindawat et al. (2005) proposed a system that consists of models for sales (of retailers), production, purchasing decision (i.e. supplier selection), inventory and transportation, within a fully-disaggregated setting. Their transportation module included a carrier-vehicle choice model and a delivery sequence model based on a traveling salesman problem (TSP). Fischer et al. (2005) proposed a three-layer structure for logistics chain modeling, consisting of economic, logistics, and transport layers, for Los Angeles County, California. Roorda et al. (2010) proposed a conceptual framework of an agent-based microsimulation that involved four types of decisions having distinct temporal dimensions: fundamental business decisions, supply chain management decisions, market interaction decisions, and operational decisions. They introduced the concept of a “contract”, which defines the business relationships for the exchange of commodities or services (logistics and other trip generating services). The contract formulation depends on the attributes of business establishments and prices. Their framework for the logistics services contract formation was further detailed by Cavalcante and Roorda (2013). de Bok and Tavasszy (2018) also proposed a conceptual framework for an agent-based simulation system for urban goods transport (MASS-GT). Four distinct markets, like the GoodTrip model, are considered for the MASS-GT. They presented a prototype model that consists of a shipment synthesizer and a tour formulation model as the first step for the model development. As disaggregate data are often not available, aggregate models are partially applied in some cases. For example, Nuzzolo and Comi (2014) proposed a multi-stage model with a strong focus on goods vehicle operations. The model consists of a “quantity model” sub-system (for generation and commodity flow), a “delivery model” sub-system (for shipment size and delivery time) and “vehicle model” sub-system”. While the shippers and the receivers are considered in an aggregated manner using zone-based models, the vehicle model considered several aspects in logistics operations at the vehicle level (i.e. the number of deliveries per tour, departure time, vehicle type, and delivery locations).

Hunt and Stefan (2007) proposed a tour-based microsimulation system for Calgary, Canada. Unlike the models mentioned above, their simulator does not involve or require an estimation of commodity flows. The estimation process starts from tour generation and the model simulates the “growth” (i.e. the addition of a new trip destination) or “termination” of each tour, using multinomial logit models. The exclusion of the complexities on the commodity flow estimations and the relationship between commodity flows and vehicle flows have both advantages and disadvantages. While the approach significantly simplifies the modeling system, it restricts the use of the model for evaluating policy measures which are related to commodity flows and shipments (e.g. the changes in supply chain structure and the consolidation of shipments).

While most of the disaggregate urban freight models are developed independently from passenger models, MATSim, a multi-agent transportation simulation system (Schroeder et al., 2012; Schroder and Liedtke, 2017) aims at the integration of disaggregate passenger and freight models. In the MATSim, passengers and carriers are both simulated as agents in a road network based on the cost minimization principle. However, the simulation is limited to the one using a simple grid network and the calibration is not reported as implemented yet. Also, commodity flows are not simulated.

In the U.S., several agent-based freight models were developed for some metropolitan regions, including the Chicago Region (RSG, 2015) and the Arizona Sun Corridor Mega-region (Livshits et al., 2018). Particularly novel in these models is the specification of supplier selection models taking a deterministic selection approach, using the procurement market game (PMG), developed upon the trade network game framework (RSG, 2015), and the agent-based computational economics (ACE) market-clearing algorithm (Livshits et al., 2018). These deterministic approaches allow the simulations with a relatively small calibration dataset, but, at the same time, rely on economic data, such as input-output tables, as the key inputs, and the simulation results are dependent on the assumptions and the rules. Both the Chicago and Arizona models use tour-based truck models: for developing a stop sequence, the former uses a greedy algorithm, while the latter uses multinomial logit models.

3. SimMobility platform and SimMobility Freight

3.1. SimMobility

SimMobility is an agent-based urban simulation platform for simulating land-use changes and passenger and freight movements (Adnan et al., 2016; Alho et al., 2017), with an open-source code-base. SimMobility runs a fully disaggregate simulation, which maintains the consistency of the agents across different temporal scales and applies the principles of dynamic planning and reactive behaviors. Its tight integration among various model components allows for feedback and minimizes the needs of exogenously generated inputs that potentially lead to the partial equilibrium results. The goal is to make the SimMobility a comprehensive and flexible urban and transportation simulation tool that is applicable to the cities around the world through the proper calibration with local data.

SimMobility consists of three distinct temporal dimensions (Fig. 1). The long-term (LT) model focuses on strategic decision making that require a long-term perspective, such as land developments, residential locations, job locations, establishment locations, vehicle ownerships and overnight parking locations, and also, commodity contracts. The process of estimating business establishments in the LT model is detailed by Le et al. (2016). The mid-term (MT) model covers the decisions that are directly connected to day-level activities, such as schedules for passenger travels, pickups and deliveries, and transportation system and vehicle operations, route choices, and en-route parking locations. The MT model incorporates a meso-scale traffic simulator which is computationally efficient and suitable for a large-scale (such as a metropolitan-scale) simulation (Lu et al., 2015). Finally, the short-term (ST) model conducts the micro-simulation of vehicle behaviors on the road network, replicating their behaviors in detail (Azevedo et al., 2017). The above three temporal layers share the same external dataset, such as demographic information and transportation systems, and are connected through down-stream and upstream data sets.

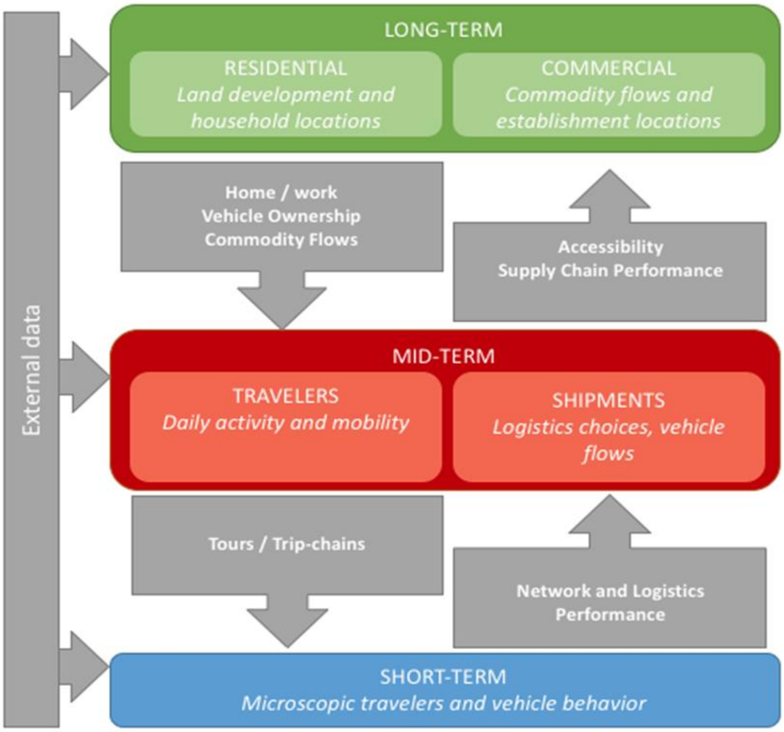

Fig. 1 Overall framework of SimMobility

3.2. SimMobility Freight

SimMobility Freight, an urban freight simulator, is one of the major components of SimMobility and the focus of this paper (Fig.2). The structure of the SimMobility Freight follows the above-mentioned temporal dimensions. The LT model simulates commodity contracts and goods vehicle overnight parking based on the data of establishments, goods vehicles, and the "overnight" parking supply. The MT model has three components, simulating "pre-day" logistics planning, "within-day" goods vehicle behaviors, and traffic movements (mesoscopic traffic simulation), respectively, based on commodity contracts and goods vehicle population. As shown in the literature review, the multi-temporal layer approach is also applied by other freight simulation frameworks. The simulation system of the ST model, i.e. a microscopic traffic simulator, is the same for both passenger and freight vehicle movements. The ST model is not treated in this paper as Azevedo et al. (2017) provide the details.

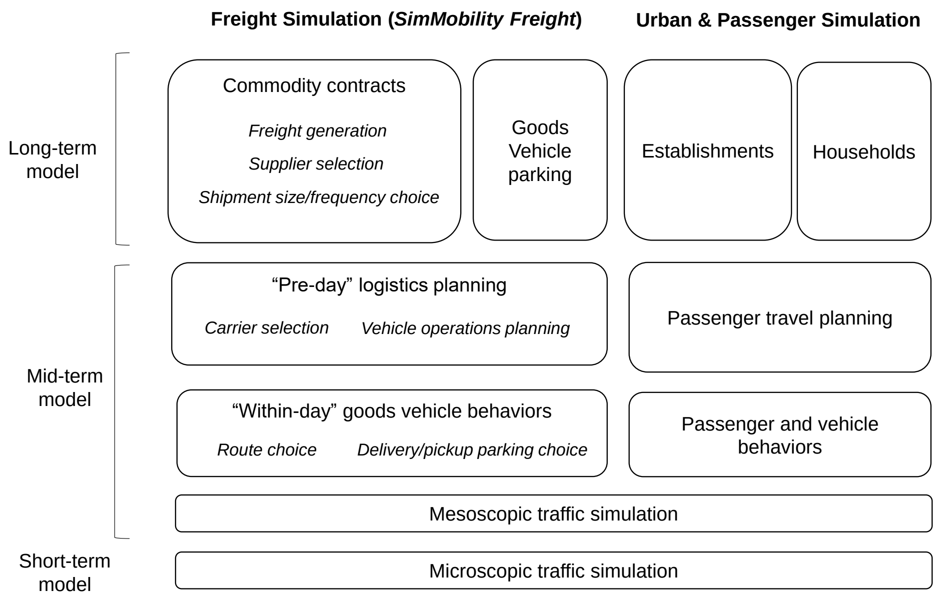

Fig. 2 Main components of SimMobility with details on SimMobility Freight

There are several agents considered in SimMobility, and business establishments (termed "establishments") are especially important in freight simulations. An establishment has a specific location with the characteristics of employment size, floor area, function type, and industry type, and can participate in freight activities with one or more roles – a receiver, a shipper (or supplier), and/or a carrier (or a third-party logistics service provider). The commodity contracts and logistics planning are simulated at the establishment level. In the current version of the SimMobility, the company memberships of establishments are not considered and thus each establishment is treated as an independent entity. Another key agent in urban freight simulations are the goods vehicle drivers, employed by establishments that own goods vehicles. In the "within-day" simulation of the MT model, the vehicle driver is considered a decision making agent while a vehicle is the base unit of analysis.

4. Commodity contract estimation in Long-term model

A commodity contract defines the origin and destination of a commodity flow, commodity type, contract size, and shipment size and frequency. We borrowed the term, "commodity contract", from Roorda et al. (2010). Commodity contracts determine commodity flows and are the main inputs for simulating goods vehicle behaviors. In the simulation, nine commodity types are considered including: (1) agricultural products, (2) food products, (3) household/light manufacturing, (4) wood and paper products, (5) minerals, ore, stone, cement, ceramics or glass, (6) metals or articles of metal, (7) machinery, appliances, and mechanical parts, (8) chemicals, rubber or plastics, and (9) mixed goods and parcel.

The estimation of commodity contracts consists of three steps: freight generation, supplier selection, and shipment size/frequency choice. Three modules are developed for the three steps: Freight Generation Module (FGM), Shipper Selection Module (SSM), and Size & Frequency Module (SFM) (Fig. 3). The main input to the simulation is the list of establishments located in the study area, with the details of employment, floor area, industry type, and function type. The SimMobility LT model has a functionality that constructs the synthetic population of establishments based on various statistics available to public agencies (Le et al., 2016).The 12 industry types (chemical manufacturing, steel manufacturing, metal manufacturing, machinery manufacturing, light manufacturing, road freight transportation service, water/air freight transportation service and transportation related service, warehousing, material wholesale, product wholesale, retail, and restaurant and service) and five function types (office, factory, retail and restaurant, logistics facility, and others) are considered.

We consider three levels of units for commodity flows (Fig. 4). The simulation starts from the annual quantity, i.e. the annual total amount for an establishment to ship (or supply) or receive. We call the annual quantities shipped and received, "production" and "consumption" respectively, following the commonly used definitions in freight simulations. This annual quantity can be translated into one or more contracts. Each "contract" is associated with a shipper-receiver pair. Often, a receiver requires multiple contracts as a single shipper cannot supply the entire demand and/or a variety of items included in the demand. For example, a food wholesaler establishment may require multiple shippers for different types of food products such as beverages, agricultural products, meats, and processed foods. Once established, a contract can be translated into "shipments", the smallest unit, by estimating the size of shipments. A shipment is the fundamental dimension and represents the amount of goods that is transported together at the same time between a shipper and a receiver (de Bok and Tavasszy, 2018). The three modules in the commodity contract estimation correspond to these levels of units, respectively.

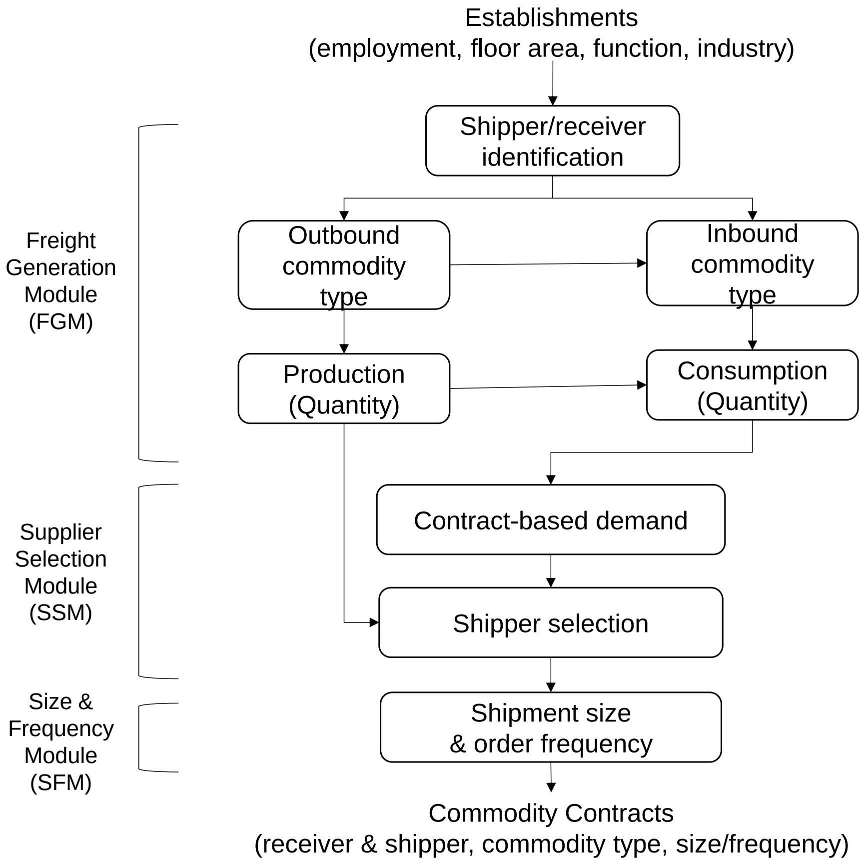

Fig. 3 Process of commodity contract estimation in the Long-term model

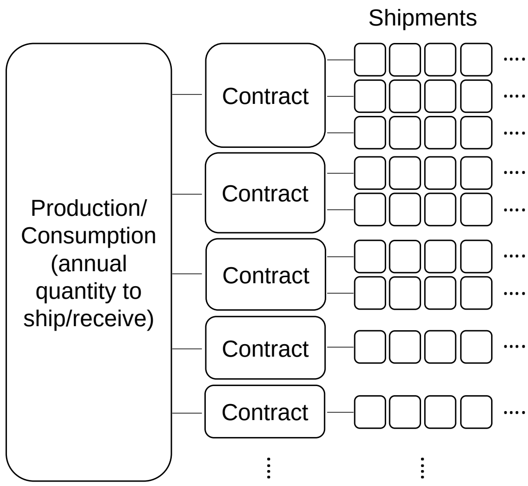

Fig. 4 Units of analysis in commodity contract estimation

5. Mid-term model

As mentioned earlier, the MT model system consists of three components, "pre-day" logistics planning, "within-day" goods vehicle behaviors, and a mesoscopic traffic simulation (Fig.6). The overview of the three components is provided as follows.

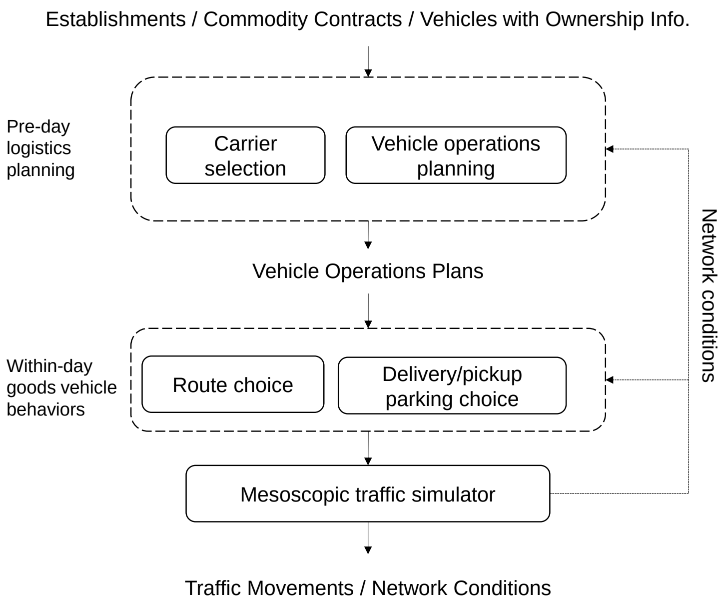

Fig. 6. Process of the Mid-term simulation

5.1. *"Pre-day" logistics planning*

The objective of logistics planning is to convert the shipments derived from commodity contracts to "vehicle operations plans", which define the movements (i.e. tours and trips) of goods vehicles, including stop locations, activities associated with the stop locations (pick-up, delivery, overnight parking), and expected arrival and departure times. The logistics planning process includes two modules: carrier selection and vehicle operations planning. The carrier selection module selects carrier(s) for each "outsourcing shipper", which requires third-party carriers for its shipments, based on the distance from the shipper and goods vehicle availability. The vehicle operations planning module matches shipments with goods vehicles, makes an order of pickups/deliveries and generates the vehicle operations plans. The links between vehicle operations plans and shipment records are preserved throughout a simulation, and therefore, the relationships between vehicle trips and shipments are identifiable. The logistics planning model is a rule-based process, based on a series of assumptions on the vehicle operations, and has a room for further enhancement, including considerations of receiver time windows and collaborative urban consolidation schemes among others.

5.2. *"Within-day" goods vehicle behaviors and mesoscopic traffic simulation*

The models of goods vehicle behaviors bridge the vehicle operations plans to a mesoscopic traffic simulation. The route choice model predicts the route a driver takes for each trip (i.e. a movement from one location to another), given traffic conditions. The delivery/pickup parking choice model, on the other hand, predicts the parking choice depending on parking infrastructure availability and/or suitability and conditions such as waiting time.

These two models are tightly connected with the mesoscopic traffic simulator (Lu et al., 2015). The simulator simulates traffic movements on a road network, which has a hierarchical structure with the information of links, segments (each link connects two nodes and consists of multiple segments), and lanes. By considering the two types of traffic status, moving and queuing, as well as the details of road and parking infrastructures (e.g. bus stops), the simulator allows of a detailed and realistic simulation of traffic movements.

6. Future works

While SimMobility Freight is currently available and being used for policy analysis in Singapore, the improvement and enhancement of the system is still ongoing. Model components that allow a wider range of policy analysis, such as an urban freight consolidation scheme and a crowd-sourced delivery system, are currently under development. Furthermore, as SimMobility is an open source platform aiming to be applicable to cities around the world, the development of a standardized calibration method based on local data is also an important ongoing research task.

Future research tasks are not limited to the further development of the modeling systems, but also their applications in policy evaluations. Such tasks include the evaluation of land use development scenarios, overnight parking policies, and pick-up/delivery parking facility planning. SimMobility Freight has a potential to become a common platform for testing new modelling approaches and components as well as innovative urban freight policies.

Acknowledgements

This research is supported in part by the Singapore Ministry of National Development and the National Research Foundation, Prime Minister's Office under the Land and Liveability National Innovation Challenge (L2 NIC) Research Programme (L2 NIC Award No L2 NICTDF1-2016-1.). We thank the Urban Redevelopment Authority of Singapore, JTC Corporation and Land Transport Authority of Singapore for their support. We also thank the Transportation Planning Commission of the Tokyo Metropolitan Region for sharing the data for this research. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) only.

References

Adnan, M., Pereira, F. C., Azevedo, C. M. L., Basak, K., Lovric, M., Feliu, S. R., … Ben-Akiva, M., 2016. SimMobility: a multi-scale integrated agent-based simulation platform, 95th Annual Meeting of the Transportation Research Board, Washington, D.C.

Alho, A., Bhavathrathan, B. K., Stinson, M., Gopalakrishnan, R., Le, D. T., Ben-Akiva, M., 2017. A Multi-scale Agent-based Modelling Framework for Urban Freight Distribution. Transportation Research Procedia 27, 188-196.

Azevedo, C. L., Deshmukh, N. M., Marimuthu, B., Oh, S., Marczuk, K., Soh, H., ... Ben-Akiva, M. E., 2017. Simmobility Short-term: An Integrated Microscopic Mobility Simulator. Transportation Research Record: Journal of the Transportation Research Board, 2622, 13-23.

Boerkamps, J., van Binsbergen, A., Bovy, P., 2000. Modeling Behavioral Aspects of Urban Freight Movement in Supply Chains. Transportation Research Record: Journal of the Transportation Research Board 1725, 17-25.

Cavalcante, R., Roorda, M. J., 2013. Freight Market Interactions Simulation (FREMIS): an Agent-based Modelling Framework. Procedia Computer Science 19, 867-873.

Chow, J. Y., Yang, C. H., Regan, A. C., 2010. State-of-the art of freight forecast modeling: lessons learned and the road ahead. Transportation 37 (6), 1011-1030

Comi, A., Delle Site, P., Filippi, F., Nuzzolo, A., 2012. Urban freight transport demand modelling: a state of the art. European Transport / Trasporti Europei 51

Coulombel, N., Dablanc, L., Gardrat, M., Koning, M., 2018. The environmental social cost of urban road freight: Evidence from the Paris region. Transportation Research Part D: Transport and Environment, 63, 514-532.

de Bok, M., Tavasszy, L., 2018. An Empirical Agent-based Simulation System for Urban Goods Transport (MASS-GT). Procedia Computer Science, 130(C), 126-133.

De Jong, G., Vierth, I., Tavasszy, L., Ben-Akiva, M., 2013. Recent Developments in National and International Freight Transport Models within Europe. Transportation 40(2), 347-371.

Fischer, M., Outwater, M., Cheng, L., Ahanotu, D., Calix, R., 2005. Innovative Framework for Modeling Freight Transportation in Los Angeles County, California. Transportation Research Record: Journal of the Transportation Research Board 1906, 105-112.

Hunt, J. D., Stefan, K. J., 2007. Tour-based Microsimulation of Urban Commercial Movements. Transportation Research Part B: Methodological 41(9), 981-1013.

Le, D. T., Cernicchiaro, G., Zegras, C., Ferreira Jr, J., 2016. Constructing a Synthetic Population of Establishments for the SimMobility Microsimulation Platform. Transportation Research Procedia, 19, 81-93.

Livshits, V., You, D., Zhu, H., Jeon, K., Vallabhaneni, L., Camargo, P., … Pourabdollahi, Z., 2018. Mega-regional multi-modal agent-based behavioral freight model, final report, Strategic Highway Research Program 2 (SHRP2 C20 IAP Grant), http://www.azmag.gov/Portals/0/Documents/MagContent/TRANS_2017-02-13_SHRP2-TRANS_2017-06-06-C20-MAG-Next-Generation-Freight-Demand-Model-Update.pdf

Lu, Y., Adnan, M., Basak, K., Pereira, F. C., Carrion, C., Saber, V. H., ... Ben-Akiva, M. E., 2015. Simmobility mid-term simulator: A state of the art integrated agent based demand and supply model, 94th Annual Meeting of the Transportation Research Board, Washington, DC.

Nuzzolo, A., Comi, A., 2014. Urban Freight Demand Forecasting: a Mixed Quantity/Delivery/Vehicle-based Model. Transportation Research Part E: Logistics and Transportation Review 65, 84-98.

Resource Systems Group, Inc., 2015. User's guide and model documentation: agent-based supply chain modeling tool, the report for Chicago Metropolitan Agency for Planning, http://www.cmap.illinois.gov/data/transportation/modeling

Roorda, M. J., Cavalcante, R., McCabe, S., Kwan, H., 2010. A Conceptual Framework for Agent-based Modelling of Logistics Services. Transportation Research Part E: Logistics and Transportation Review 46(1), 18-31.

Schröder, S., Liedtke, G. T., 2017. Towards an Integrated Multi-agent Urban Transport Model of Passenger and Freight. Research in Transportation Economics, 64, 3-12.

Schroeder, S., Zilske, M., Liedtke, G., Nagel, K., 2012. A computational framework for a multi-agent simulation of freight transport activities, 91th Annual Meeting of the Transportation Research Board, Washington, DC.

Taniguchi, E., Thompson, R. G., Yamada, T., 2016. New Opportunities and Challenges for City Logistics. Transportation Research Procedia, 12, 5-13.

Tavasszy, L. A., Ruijgrok, K., Davydenko, I., 2012. Incorporating Logistics in Freight Transport Demand Models: State-of-the-art and Research Opportunities. Transport Reviews, 32(2), 203-219.

Wisetjindawat, W., Sano, K., Matsumoto, S., 2005. Supply Chain Simulation for Modeling the Interactions in Freight Movement. Journal of the Eastern Asia Society for Transportation Studies 6, 2991-3004.