Agent-Based Micro Simulation Approach to Freight Modeling

Kyungsoo Jeong

Abstract

This paper provides concepts and applications of agent-based simulation approaches to freight transportation via a literature review. The aggregate four-step modeling have developed and used for the state-of-the-art freight models. It cannot capture each vehicle's behavior such as route choice and the distinguishing feature of freight transportation that multiple decision makers are related to producing freight flows. Freight movement, generally demand for transportation, is the results from economic interactions between industries which are located in domestic area or international area. However, micro-level models can assess the impact of transport-related policy more sensitively. In agent-based simulation model for freight transportation, the individual actors (producers, transport operators and customers) and their choice are modeled. This model can evaluate operational strategies, such as transport pricing, time aspects, incidents, traffic control and etc. The objective of this paper is to understand agent-based micro simulation models conceptually and to research their applications through a literature review. This paper provides some insight how agent-based approach applies to freight models.

1. Introduction

The change of the industry structure and economic growth has affected the increase in freight movements. The changed trade pattern has led to appropriate freight forecasting models. Freight transport models have developed based on passenger transport model based on the assumption that freight model and passenger model share several features. However, there are fundamental differences between two travel models. The demand for freight transportation is a derived demand as it arises from the value that consumers assign to the products being transported between spatially separated markets. Freight

transportation uses multiple dimensions, such as volume, weight, and vehicle trips. Also, multiple decision makers are related to the freight flow. Therefore, various modes and commodity types are used in freight movement, and commodity flow dose not directly produce vehicle flow. In addition, the data for freight movement are limited, and some of them are not sufficient. The private shippers are reluctant to provide their good movements for security reasons of their customers.

Among the features of fright movement, the most distinguishing feature is the derived demand from commodity trades. It is related to economic activities. Therefore, it is important to understanding economic structure for freight movement at first. Freight movement, generally demand for transportation, is the results from economic interactions between industries which are located in domestic area or international area. There are the exchanges of commodities among the industries. In an industry, to produce a commodity, commodities from other industries and itself are consumed. This commodity is consumed by industries again or by personal consumer finally. This economic structure generates freight movement.. Economic activity interacts with land use. When economic activity of an industry in a region increases, land use related the industry increase. Reversely, if new facility for an industry develops in a region, economic activity involved in the industry will increase. Congested time on transportation network impacts on industry location, and then the changed land use affects economic activity or directly impact on economic activity.

To forecast freight flows, commodity-based freight demand models have been developed and used for macro analysis. In other words, it used at county and state level. These models commonly follow the aggregate four-step models like passenger 4-step models which consist of trip generation, trip distribution, mode split and network assignment. Sometimes, excluding mode split, truck trip model have applied to macro level freight forecasting models. Since macro freight models assume homogeneous and aggregate behavior related to freight flows, they have problems with developing models reflecting the features of freight movement as mentioned above. These cannot capture that each vehicle has its own route to analyze relatively small area. Additionally, these cannot assess the impact of transport-related policy more sensitively. Recently, to overcome shortcomings, micro freight transport models have been studied. At micro level, tour-based models, supply chain and logistical models have been developed. However, since those models focus on firm-to-firm or a few firm-to a few firm flows, it is hard to apply to decision-making for public sector. Agent-based simulation models for freight flows are introduced to analyze urban freight, even inter-city and national freight.

Agent-based micro-simulation models can capture the distinguishing features of freight movements: 1) there are diverse actors involved in the production and distribution goods. 2) the interactions between firms are diverse and 3) business models are changing over time (Roorda et al. 2010). Through

these approaches, we can conduct not only micro level analysis, but also meso and macro level analysis after aggregating micro level freight flows.

The objective of this paper is to understand agent-based micro simulation models conceptually and to research their applications through a literature review. This paper provides some insight how agent-based approach applies to freight models.

2. Agent-Based Modeling

Agent-based modeling is a kind of computational models to simulate the actions and interactions between agents which affect a system. It consists of combined elements such as game theory, complex systems, computational sociology and etc. It has been used in scientific area instead of mathematical and statistical models. This approach can simulate complex behavior by using simple behavioral rules for agents. Therefore, agent-based modeling can mimic hetetogeneous and decentralized system quite well.

Davidson et al. (2005) shows common features to apply agent-based approach to developing models based on Parunak (1999)'s research as follows:

- *Modular: each entity has a well-defined set of state variables*
- *Decentralized: the application can be decomposed into stand-alone software processes capable of performing useful tasks*
- *Changeable: the structure of the application may change quickly and frequently*
- *Ill-structured: all information about the application is not available when the system is being designed*
- *Complex: the system exhibits a large number of different behaviors which may interact in sophisticated ways*

Since freight movement at micro level has these characteristics, agent-based approach can be one of good method to develop freight micro simulation for freight. Usually, agent-based models are used for micro simulation models because of above features although micro simulation models cannot employ agent-based technics. With respect to developing micro simulation transport models, many of the micro simulation models include agent-based technics even though they are not conceptualized or implemented in such terms in their model (Donnelly, 2009). The reason is that agents represent decision makers in transportation system such as individuals in passenger travel or firms and industries in freight travel.

Agent-based models have been used for passenger travel demand model at first and then have applied to freight logistic model. Davidson et al. (2005) conducted survey of the literature on agent-based model for logistics. They

studied 64 papers on this area and analyzed them by using several categories. Figure 1 and Figure 2 show the distribution of studies which have been studied. In terms of study area, most of studies focused on traffic analysis. The models for air and road were frequently used agent-based model. In Figure 2, most of model has developed for operational purpose. It represents agent-based approach is related to short term and micro level analysis rather than long term analysis. Based on their survey, most of papers have studied conceptual frameworks and tested with artificial data even though some of them conducted simulation. Therefore, they have shortcomings in terms of using real data and quantitative evaluation. Also, agent-based model have very few applications to real area and large-scale area. Their paper provides that the research for agent-based micro simulation model for freight modeling is in its early stages and there are some room that can be improved. We can develop a more solid model by applying it to real world problems and using real data from various sources. Since some of studies ignored the issue of calibration and validation, the models lacked justification of application. Qualitative and quantitative assessments for the developed models are required to obtain a proper model. In addition, we can extend study area to studies related to strategic decision-making or sub-area studies by aggregate individual flow resulting from simulation.

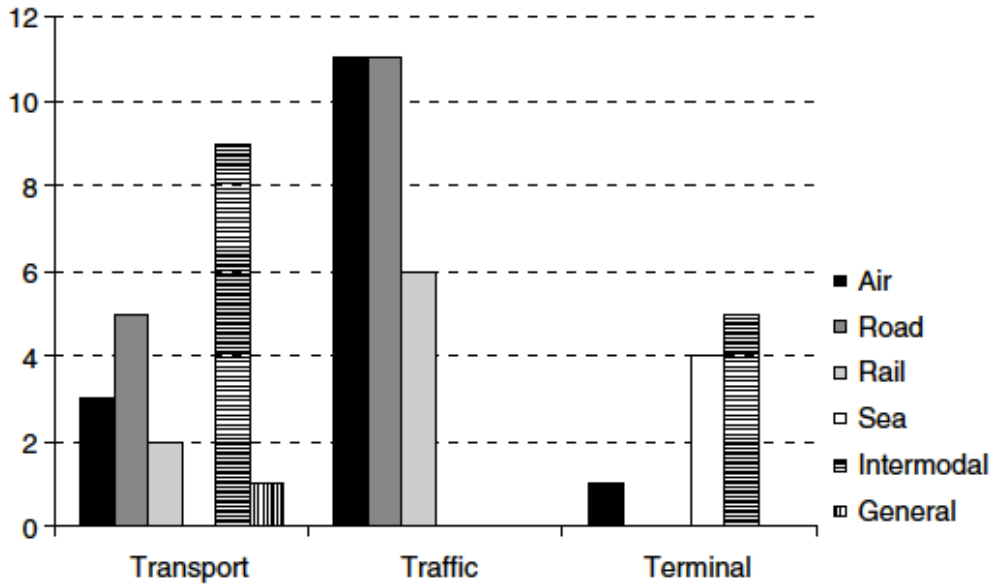

Figure 1. Distribution of study area (Davidson et al., 2005)

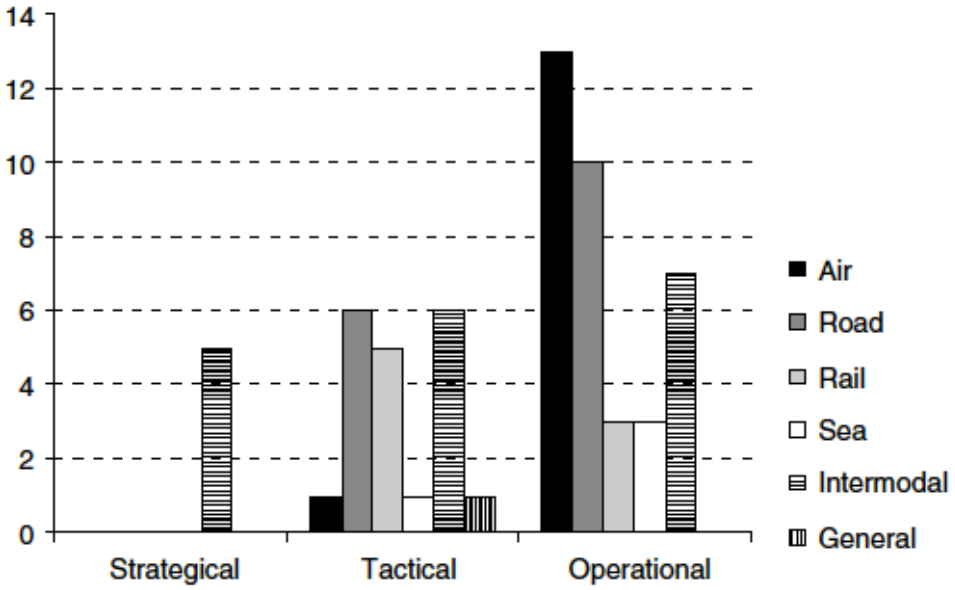

Figure 2. Distribution of time horizon (Davidson et al., 2005)

In agent-based simulation, entities are represented as autonomous or semi-autonomous components that interact with each other as well as with their environment through a set of rules that govern their movement, actions, decisions, and interaction with other agents (Chatfiel et al., 2007). Therefore, agent-based approach to freight movement includes autonomous components related agent's choices such as selecting firms for trade, transportation forwarder, route choice, time periods and etc. These autonomous components are based on agent's behavior. According to the given rules to agent, each individual or agent produce their behavior or good movement. The simple behavioral rules for each decision makers in freight transportation system can make complex freight movement by using agent-based approaches. Therefore, this agent-based approach can be used for micro-level freight model properly. The sum of individual movement represents the performance for an entire system, transportation network. This process can explain as bottoms up approach which means that we develop a model for disaggregate level and aggregate result from disaggregate level and then finally lead proper result we want to know. In contrasts, traditional commodity based macro model follows top-down approach which means that we can obtain the result from aggregate data, usually aggregate socio economy data which effect on freight movement. Table 1 represents the general differences between four-step models, macro freight model, and agent-based model, micro simulation model. Generally, unlike macro model, agent-based simulation model focuses on individual transport chain and choice related to decision-maker, individual or a group of individual. The decision makers in freight transportation usually can be shipper or consumer. Therefore, agent-based model can capture logistical process, while

four-step model cannot take the logistical process such as choice of carrier type and ordering strategies. Since simulation model usually includes time horizon components, different time perspective analysis can be conducted. Therefore, we can use this model not only for short term but also long term analysis. Additionally, this model can be applied to various study area. Basically, micro simulation models were developed for small area such as sub regional or intra regional analysis, but can be implemented macro level analysis via aggregation method.

Table 1. Differences between 4-step model and agent-based model for transportation

4-step model	Agent-based model
• Macro-level (equation-based) model • Societal perspective • Aggregate approach • Top-down approach • Choice relates to transport demand • Do not take the logistical processes (e.g. choice of carrier type and ordering strategies) • Long term planning	• Micro-level (simulation-based) model • Individual transport chain • Disaggregate approach • Bottoms up approach • Choice related to decision-makers (usually the shippers) • Can capture the decision making of actors involved in logistical process • Short term and long term planning

3. Agent-Based Model Framework

Agent-base micro simulation model is considered as the state-of-art technic for freight model. However, applications to real world problem are very limited, and most of studies have focused on developing conceptual framework. Recently, Liedtke (2009), Donnelly (2009) and Holmgren et al. (2012) developed agent-based approach to micro simulation for freight transportation and apply the suggested model to analyzing real world problem in a certain area, respectively. This section presents key components of agent-based micro simulation model for freight transportation, their frameworks, and applications based on above three references.

3.1 Agent

Objective-oriented programming skills are used in contemporary micro simulation model. Objective-oriented design focuses on decomposing a sysyem into relatively self-contained units, called objects (Chatfiedl et al., 2007). A set of objects can be considered as an agent which has its own behavior feature and

behavior rule for decision. Therefore, agent is a key component of agent-base micro simulation model. It is important to understand what are agents and how they interact with each other in freight models. Generally, agents represent a group of objects or individual object affects the state of system, especially generation and distribution of goods in freight transportation. For example, agents can be firms that are related to production and consumption or sometimes shipments as mentioned in economy activity of freight movement.

Donnelly (2009) used the economic values, shippers, carriers, intermediaries, and consumers as agents. Those agents include several attributes that are mobile, goal-oriented, adaptive, loosely coupled, stochastic behavior, and local view. As objects, shipments, vehicles, facilities, transportation networks, information networks are used, which are the components of agents or the components related to interrelationship between agents. Also, those objects have their own attributes that are variable mobility, contextual, not self-directed, deterministic behavior and global optimization possible. In general, to produce behavior of each agent, sampling methods are used from observed data and then stochastic approach were used for a simulation model instead of equation approach which includes the parameters and the coefficients. In his research, various data from multiple data source were used to develop agent's attributes and their behavior model. The data source and corresponding data are as follows:

- *Commodity Flow Survey: Value-to-ton ratios, Mode shares by commodity, and Long distance trip lengths*
- *Vehicle Inventory and Use survey: Average weekly miles by commodity, Distribution of carrier type by commodity, Distribution of truck type of commodity, and Average stops per week*
- *Truck intercept surveys: Average and total shipment weights by truck type*
- *Employment by firm: Attribution of Firm agents, and Discrete destination choice*
- *Make and use coefficients: Shipment generation, and Discrete destination choice*
- *Truck events: Attribution of import and export agents, and Model assessment and validation*

Some of data like CFS and VIUS should be used for traditional four-step model, while last of them can be obtained from public data source and excluded from macro model because of data availability or needless.

Liedtke (2009) developed inter-regional commodity transportation model, called the INTERLOG model based on integrating elements of normative logistics models. The model consists of three main modules: 1) generation module which produces location patterns of heterogeneous companies related to production, consumption and shipment, 2) sourcing module which represents the choices of suppliers and the exchange of good at micro level and 3) interactive market simulation module which shows individual shipments and assigned flow on the transportation network. He didn't explain about agents in detail, but each

module includes agents which are industrial company, forwarder, shipper and transport operators. Each module has their own basic algorithm such Monte Carlo algorithm, I-O structural model and dynamic equilibrium based on minimizing cost strategy. In this model, shippers control the system. He produced the behavior of agents by using Germany freight data sources.

Holmgren et al. (2012) presented the Transportation and Production Agent-based Simulator (TAPAS). The TAPAS has two simulator, decision making simulator and physical simulator as shown in Figure 3. In physical simulator, there are vehicles, production facilities and transportation network for each mode. Those components are objects in Donnelly (2009)'s model. In decision making simulator, there are transportation chain coordinator, customer, product buyer, production planner, transport buyer and transport planner. Those actors are considered as agents in agent-based approach. Each agent in decision making simulator act independently and potentially proactively (Holmgren et al., 2012). The TAPAS has a assumption that decision makers in decision making simulator want to minimize their cost locally. Therefore, the cost functions were developed for each decision makers. Moreover, in physical simulator, each object also has its own expected time and cost functions. Based on cost functions for each agent, agent decides their choice to responds massage calling that represents interrelationship between agents. The relationship is represented in Figure 3.

Three developed model shared agents they used for their simulation framework. Decision makers should be included in the model as agent, and then proper behavior rules should be developed from observed data or logical concept to produce freight movement.

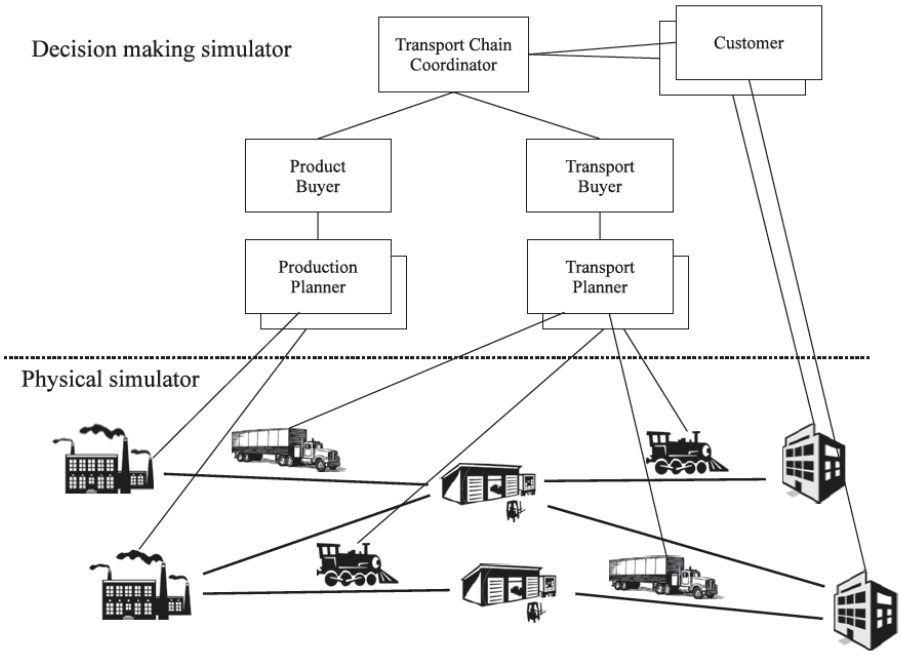

Figure 3. Agents of TAPAS

3.2 Assumptions

There are several assumptions to develop proper framework including agents and their behavior rules in agent-base micro simulation model. The assumptions are as follows (Liedtke, 2009 and Roorda et al., 2010):

- *The firms can usually be the main decision makers. It means shipper, forwarder, transportation chain coordinator decides amount of commodities, modes, location, and etc. Sometimes, the customer can also be the main decision makers.*
- *With respect to short-term analysis, the location of firms and the interaction between firms are independent from time horizontal policies. However, for long-term analysis, this assumption is not restricted.*
- *The amount of commodities from interactions between agents is the flows at micro level. It means the flows might be fixed for a given time period.*
- *Various choices are based on behavior rule or functions.*
- *Supply chains increasingly affect long-term contract between agents.*
- *Each agent wants to maximize their utility or minimize their disutility.*
- *Each agent decides their choice based on meeting their optimality. It means optimization technics can be used for a model. For example, supply chain model minimize their travel cost.*

3.3 Model

By using defined agents and assumptions which make attributes and behavior rule of agents, agent-base micro simulation models are developed in a literature review. The interactions between agents and the decision chains produce commodity flows and then those flows convert into vehicle flows on the transportation network by each mode.

To generate behavior model of agents, mathematical equations, statistical distribution, and optimization used. For example, mathematical equations used for 1) estimation of gross urban product, 2) translation of gross urban product to of commodities, 3) translation of value of commodities to tonnages using value-density functions, 4) derivation of peak and off-peak travel times, and 5) tour optimization using TSP algorithm and traffic assignment, and sampling from statistical distributions used for 1) decision whether to ship when total value falls below threshold, 2) generation of discrete shipments from total tonnages shipped, 3) discrete choice of destination firm and its distance from shipper, 4) firm's choice of carrier, 5) incidence of trans-shipment, 6) choice of import and export agents, 7) carrier's choice of vehicle, 8) number of hauls per day, 9) number of stops on each itinerary, and 10) selection of routing inefficiency factor (Donnelly, 2009).

This paper does not include mathematical equation and stochastic functions or programing code in detail from a literature review. Instead, each model structure provides some insight to understand and develop micro simulation model. Figure 4 shows the framework of Donnelly (2009)'s model. Macroeconomic data, census data, commodity flow survey, and input-output data, truck surveys and transportation network presents exogenous data used to develop and apply the model. The rest of them represent endogenous components which produce the decision chains in the model.

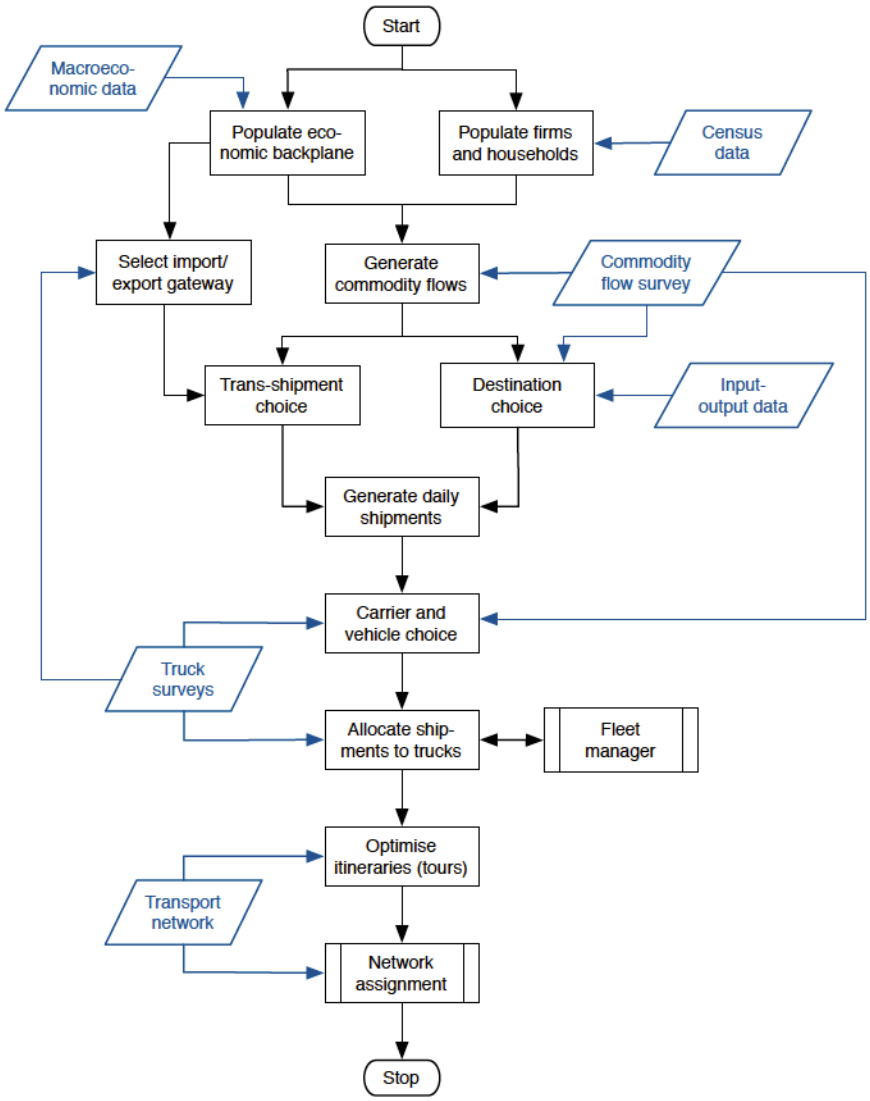

Figure 4. Donnelly's model framework (Donnelly, 2009)

Figure 5 shows the model structure of Liedtke (2009)'s INTERLOG. As mentioned earlier, this model consists of generation modules, sourcing module, and market interaction module. Through data from various source and behavior rules, this model finally produces truck tours on the road network. TAPAS (Holmgren et al., 2012) has similar framework to two models base on the

interaction protocol which shows the main flow of messages between agents, decision makers. For example of massage, product request and product proposals exit between product buyers and product planners. Also, product booking and product confirmation exit between transportation coordinator and product buyer.

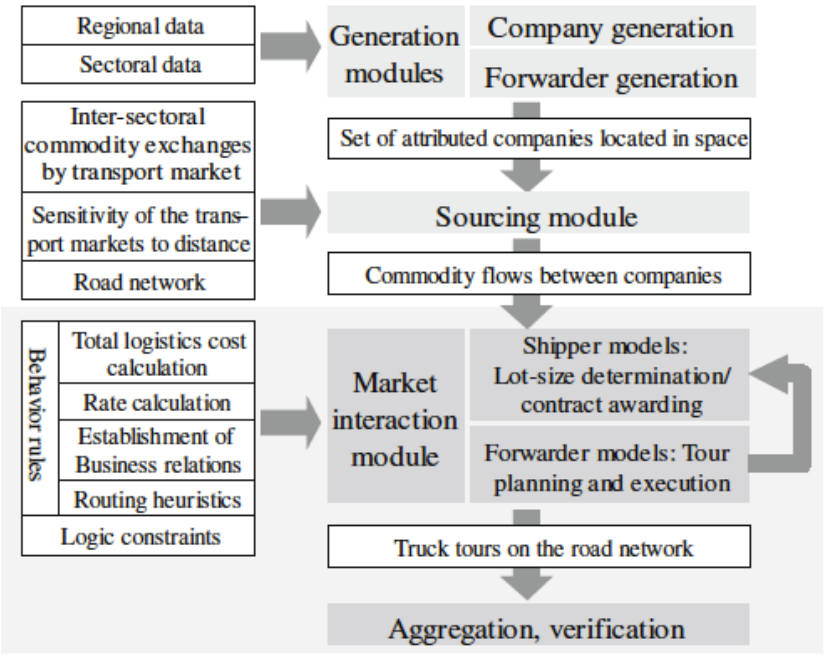

Figure 5. INTRLOG framework (Liedtke, 2009)

The suggested agent-based micro simulation models until recent have applied to real world problem by using real world data very limitedly. Above three models applied to inter-regional analysis and tested. In general, micro simulation model can meet the problem with validation of model. Especially, there are limited data at micro level and it is hard to gather and survey freight data because the private shippers are reluctant to provide their good movements for security reasons of their customers.

TAPAS were validated by interviews with experts related to transportation modeling and practitioners in logistics. This method provides that developed behavior rules of agent make sense. However, we cannot capture whether the results of the model is correct or not. In contrast, Donnelly's model and Liedtke's INTERLOG were validated by using bottoms up approach. This approach represents aggregate flows from disaggregate tour from simulation were used for validation. This method is very similar to traditional 4-step model which are used top-down approach. In this case, traffic count data, cordon line analysis and etc. were usually used.

4. Conclusions

This paper presents agent-based micro simulation approach to freight transportation model via a literature review. This approach has distinct features comparing to traditional four-step model. This can be alternative to mathematical based model. Since freight transportation have various decision makers and their interaction produce freight movement, usually commodity flows, it is hard to model by using mathematical equations. The stochastic method might be quite fit well to freight transportation model with respect to micro simulation. Through a literature review, advantages and disadvantages of agent-based model are recognized as follows:

The advantages are

- Characterized by quite heterogeneous actors and objects
- Simulate the decision making activities
- Allow the study of complex patterns as a reaction to changed environmental
- Access various policies for freight movement, such as fuel price change, introducing EV and etc.
- Complex reactions can be assessed
- Allow different aggregations. This can produce various sub-area analysis

The disadvantages are

- Most of studies are conceptual
- Problems to apply large scale area
- Problems with computing storage technically
- Few fielded experiments have been performed (still developing conceptual framework)
- Data availability for micro-level (e.g. firm locations, shipment cost, and etc.)
- Need to study Micro-behavior for logistic model more

Agent-based model are very attractive to freight model. However, these are closer to the beginning of development. There is room for improvement of the model structure, their components and behavior features.

References

Boerkamps, J.H.K., van Binsbergen, A.J., Bovy, P.H.L., 2000. Modeling behavioral aspects of urban freight movement in supply chains. Transportation Research Record: Journal of the Transportation Research Board 1725, 17–25.

Chatfiled, D.C., Hayya, J.C., Harrison T.P., 2007. A multi-formalism architecture for agent-based, order-centric supply chain simulation. Simulation Modelling Practice and Theory 15, 153-174

Davidsson, P., Henesey, L., Ramstedt, L., Törnquist, J., Wernstedt, F., 2005. An analysis of agent-based approaches to transport logistics. Transportation Research Part C 13, 255-271

De Jong, G., Ben-Akiva, M., 2007. A micro-simulation model of shipment size and transport chain choice. Transportation Research Part B 41, 950–965

Donnelly, R., 2009. A hybrid microsimulation model of urban freight transport demand. Ph.D. dissertation, University of Melbourne

Fischer, M.J., Outwater, M.L., Cheng, L.L., Ahanotu, D.N., Calix, R., 2005. An innovative framework for modeling freight transportation in Los Angeles County. Transportation Research Record: Journal of the Transportation Research Board 1906, 105–112.

Hensher, D.A., Figliozzi, M.A., 2007. Behavioural insights into the modelling in freight transportation and distribution system – guest editorial.
Transportation Research Part B: Methodological 41 (9), 921–923.

Holmgren, J., Davidsson, P., Persson, J.A., Ramstedt, L., 2012. TAPAS: a multi-agent-based model for simulation of transport chains. Simulation Modelling Practice and Theory 23, 1-18.

Hunt, J.D., Stefan, K.J., 2007. Tour-based microsimulation of urban commercial movements. Trans. Res. Part B 41, 981-1013.

Liedtke, G., 2009. Principles of micro-behavior commodity transport modeling.
Trans. Res. Part E 45, 795-809.

Meixell, M.J., Gargeya, V.B., 2005. Global supply chain design: a literature review and critique. Transportation Research Part E: Logistics and Transportation
Review 41 (6), 531–550.

Roorda, M.J., Cavalcante, R., McCabe, S., Kwan, H., 2010. A conceptual framework for agent-based modelling of logistics services. Trans. Res. Part E 46, 18-31.

Wang, Q., Holguin-Veras, J., 2008. Investigation on the attributes determining trip chaining behavior in hybrid micro-simulation urban freight models.
Transportation Research Record: Journal of the Transportation Research Board 2066, 1–8.