Multi-agent simulation of regional freight transport with incorporated price signals

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ABSTRACT

An implementation of a multi-agent simulation-system of urban commodity transport and logistics activities is presented. A behaviour-sensitive rule-based carrier model is connected with a shipment-size choice-model. The shipment-size model is based on total logistics cost minimization. Feedbacks between the carriers and shippers are assured using tariff tables. Carriers perform complex vehicle routing. A high intensity of competition between carriers is assumed and thus, a cost-oriented price setting. The case relates to the Tokyo Metropolitan Area. Location patterns and flows of goods between firms are deduced from a firm-to-firm commodity-flow model. In simulation experiments, the impacts of transport policy instruments on carrier behaviour and indirectly on shippers' behaviour are studied. It is shown that time restrictions have similar effects as a charge imposed on stops for loading and unloading.

Keywords: Commodity Transport, Shipment Size, Urban Transport, Urban Logistics

1 INTRODUCTION

On a word-wide scale, population and economic activities agglomerate in city regions and in mega-cities. In those areas, traffic planners, policy makers and private companies are concerned with a sustainable management of the urban commodity transport systems. Among all urban traffics, freight transport occupies a significant amount of energy consumption and pollution. Emission rates from trucks are the highest comparing with other motor vehicles. Truck transport also causes important safety issues in the cities. However, in urban area, truck is an unavoidable mode for freight transportation. Because of the high space requirement of trucks compared to cars and frequent stops, urban commodity transport is major cause of traffic congestion.

For these reasons, transport policy and land use planning measures aim at increasing the economic and ecological efficiency of commodity transport in large cities. Efficiency improvements can be achieved in several ways: (i) increase the efficiency of tours to reduce energy consumption, (ii) modifications of the transport market structures (mergers of transport companies, fostering of collaboration) to achieve better consolidation and a higher stop-density of delivery vehicles, and (iii) shifts towards larger shipment sizes to reduce the number of stops and trips, respectively.

To give incentives for increased efficiency, a couple of prominent instruments is being discussed in the academic sphere as well as in policy making: Cordon tolls, mileage dependent road user charges, vehicle bans, policy support for collaborative logistics centres, fostering of alternative modes of transport (waterways, tunnel systems), parking space management and capacity allocation mechanisms.

It should be noted that most of the already implemented measures (in particular: city tolls) address route choices, mode choices and the temporal structure of passenger flows in the first instance. In relation to logistics, efficient policy instruments could and should lead to a modification of vehicle fleets and of the shippers' behaviour as, for instance, to a reduction of the delivery frequencies.

The development of purposeful transport policy measures needs to assess them. Transport models are an appropriate tool to examine the reactions of the affected individuals on transport policies. Furthermore, microeconomic models can measure the impacts of measures on individual welfare (persons) and costs (firms). Although models are not capable of elucidating all aspects of a certain setting, they should display all relevant decisions of the parties involved. In the case of transport decisions, the relevant parties are the shippers and the recipients. They behave in a profit maximizing manner facing transport conditions and constraints set by the transport suppliers. In particular, these conditions are reflected in the prices for transport services that have to be weighed up against other costs that are linked to the size and frequency of shipments on both the consignor and consignee side. Such costs are due to logistic treatment of the goods as for example storage and consignment.

In a consistent multi-actor transport model, the behaviour of all three actor groups, shippers recipients and forwarders, has to be brought in agreement with each other. This agreement has to be reached especially with regard to the repercussions that decisions on both sides have on each other. A way to display the links between both the logistics decisions of the shippers and the transport related ones of the forwarders is the pricing scheme the latter apply. If rational behaviour of all agents is presumed and the total costs of transportation as well as handling and storage of the goods are the sole decision criterion, it suggests itself to examine if pricing of transport services is a means capable to reach environmental or traffic planning goals that public authorities are aiming at.

The research question is therefore, what are the appropriate signals capable of coordinating the behaviour of actors both on the logistic and transport side. In the following we model companies that are acting as rational cost minimizers who demand or supply transport services on a market. This market is assumed to be in such a state of competition (perfect or monopolistic), so that the prices called coincide with the costs accruing during the transport process. These costs are reflected by a tariff table that allows forwarders to call prices prior to the actual service provision. We thus state that prices are an appropriate measure to pass information from the supply to the demand side. Further, we examine if these prices are a means capable of propagating regulatory measures that aim at influencing the demand behaviour of the actors.

The paper is structured as follows: After reviewing the recent literature on agent based freight transport modelling in section two, the freight transport model is introduced. In successive sections, we introduce our model including the generation of firms in space, the derivation of their relations and the agents' decision models. We differentiate between two types of agents, the shipper and the carrier. The shipper decides about shipment-size. In turn, the carrier builds tours and transports these shipments. Section four describes our case study. We chose to model an excerpt of firms in the Tokyo Metropolitan Area. Here, we apply the introduced model components to assess a number of policy measures. Finally section six shows an outlook on future research.

2 BACKGROUND

In recent years, green freight and logistics has been in a worldwide focus. Many policy makers and traffic planners discuss strategic planning to reduce and control truck movements in urban areas. Several freight measures are proposed and adopted in many countries, such as load factor control, cooperative freight delivery, public logistics terminals, advanced information systems, underground freight transport systems, and many other policies on freight movement (Taniguchi et al, 1999). Importantly, freight movement involves many sectors (both private and public sectors). Therefore policy decisions on freight movement have to be considered carefully. Furthermore, in free market economies, the organisation of freight movements is handled over to the private sector. Under absence of compensation, urban transport policy generally affects the competiveness of the private sector companies in that region negatively, compared to other regions where such measures are not applied.

A mathematical model is usually used as a tool to assess to the impact of policy decision. The model helps to prioritize the policies by estimating the impact of a transport policy decision in terms of economic, environmental, and safety aspects. The freight system involves many sectors and freight actors, including customers, shippers, carriers, and administrators (Taniguchi et al, 1999), that contribute to the difficulty of the modelling task. In addition, the complexity of the system is added up by the various characteristics of commodities (they vary significantly in volume, weight, value, and shape). Such variations and the complex interactions cause the modelling of freight movements much more difficult than the modelling of the passenger movement (Friesz et al, 1983). Another key challenge to modelling urban freight transportation results from the presence of complex truck trip chains, which are usually not considered in models for inter-city freight transportation. In urban areas, this characteristic is very important because shipments of different destinations are consolidated in a truck, whereas in the case of inter-city freight, the majority of the commodities have already been consolidated in the hubs of transport and logistics service providers. Most existing freight models mostly focus on the inter-city freight transportation which generally adopt the traditional four-step approach and do not consider the characteristic of trip chain.

Models considering freight transport demand can be divided into macro and micro models. Over the macro approach, the micro model tends to gain more favour in the modelling since it is applicable of analysis more various policies. The structure of a micro model allows incorporating many characteristics and behaviours of freight actors and goods in the model, resulting in a more realistic result. An example of a micro model is the Activity-based approach for passenger travel demand model which focuses on the individual's daily activities so that the model can reflect the mechanisms and the fundamentals of the movement.

Up to recent, modelling freight demand can be categorized into two main streams: econometric and rule-based approaches. Econometric models mainly rely on empirical data in which functional relationships (often regression models) between freight flows with some indicators are established. This model is often an adapted version of the traditional macroscopic four-step approach. Depending on the data availability, the steps mainly include commodity generation, distribution, transformation from commodity flows to vehicle flows, and network assignment. However, in practice, there are several factors that cannot be obtained from a survey. There are increasingly models where the econometric models are calibrated with stated or revealed preferences – disaggregate choice models. As the micro-econometric models depend on survey data, many times, the parameters from the survey cannot explain enough the behaviour of the movements and accuracy problems result. Since the behaviour of actors and characteristics of freight movements are rather complicated, survey parameters and econometric models cannot cover all the decision factors of freight actors. As a result, econometric models might not always display the correct behaviour reactions. Alternatively, the behaviour of freight actors may be portrayed better in the rule based approach. The rule based approach models the complex decisions (hoierarcical decisions, combinatorial optimization problems etc.). It can be realised involving heuristic elements expressing bounded rationality decision making. The agent-based modelling paradigm has been suggested as an appropriate framework to build a model of different individuals (Roorda et. al. (2010)). It is evident that the representation of individual agents or proxies for certain more or less homogenous groups of them does not only require data input describing the different types of agents, but also behaviour models covering the variety of different behaviours.

However, there are gaps between the figures about macroscopic freight flows that are available on regional levels for different types of goods and the input requirements for microscopic models. Sjoested (2004) called the mismatch between the different perspectives from which the transport system can be looked at the micro macro gap. Various attempts have been made to close this gap in recent years aiming at the explanation of structures that emerge when single commodity flows are combined in transport chains which on their turn cause vehicle movements that can be observed on the roads, railways, airports and waterways. Sjoested (2004) also identified another gap – the one between the perspectives of shippers and the perspectives of transport service providers. Shippers deal with commodity flow systems; they do not perceive the planning problems and the operations of the transport agents. Operators of individual transport systems, on their turn, deal with carrying goods only knowing less about the logistics systems in which they are embedded. Sjoested called this mismatch the complementariness of transport and logistics.

Thus, a further problem needed to be addressed – the relationship between the single agent and the observed system as a whole. Each agent is in charge of a planning problem, but at the same time there is a loose tie to the other agents of the same kind by the means of transport market interactions. Thus, an Agent-based modelling approach needs to map optimization of individual agents, but also interactions between agents. Several authors address the problem of embedding optimization of firms into an environment of competition and interaction: Friedrich (2010) used a multi-stage optimization model to describe logistics network design in the whole food retail sector in Germany. In his model, elements of interactions between retail corporations and logistics service providers are integrated. Groothedde (2005) addresses the problem of network design in the presence of the possibility to realize synergies from integrating logistics systems. Carrillo and Liedtke (2013) describe the formation of colloidal structures in transport (collaborations of competing firms realizing synergies from agglomeration) using a monopolistic competition model.

Before cargo can be consolidated on the various links of a certain transport chain, the microscopic flows of goods are partitioned into single shipments. As such shipments are actually the most disaggregate elements from which transport-related consolidation and coordination can be performed, lot size considerations play a crucial role at the cutting line between logistics and freight transport. Transport space for certain shipments is the good that is traded on transport markets. Transport serviced offered, cargo on board of different vehicles, the workload of transhipment facilities as well as the inventories held at different stages of distribution chains are ultimately influenced by single shipments. Holguin-Veras et. al. (2011) mentioned the importance of the shipment size in mode choice as well as various others who included it into the objective function of econometric mode choice models (e.g. Arunotayanun and Polak (2011)). De Jong and Ben Akiva (2007) chose the decision about lot size as the starting point for a large scale transport chain model that was applied for modelling freight transport in Sweden. Combes (2011) examines the applicability of a simple economic order quantity model (EOQ) to model decisions of shippers. Thus, the assumption of some kind of lot-size optimization behaviour and the application of econometric models describing EOQ behaviour seems to be well justified.

Thus, when it comes to assessing urban logistics measures aimed at influencing logistics decisions, it seems to be worth and appropriate to combine the econometric approach for modelling lot size choices with the rule based heuristics optimization approach to tour construction. A focus will be put on price signals assuring a link between both types of optimization problems.

3 THE MODEL

Agent based modelling of freight transport requires input data at the level of single agents. In this case these are individual firms. The next three sections introduce firm and commodity flow generation developed by Wisetjindawat (2007, 2009). Basically, two data sources are used: First, the general statistic data on firms in the Tokyo Metropolitan Area (TMA) from the Statistics Bureau and second, the Goods Movement Survey conducted by the Japanese Government in 2004.

3.1 Generation of synthetic Firms and Commodity Flows

For the generation of synthetic firms, Monte Carlo simulation (MCS) is applied. The MCS is fed with empirical data of firms located in Tokyo such as location, firm size and industry type. The data have been provided by the Statistics Bureau. As a result of this simulation, the firms located in space as well as their attributes are obtained.

For each firm the monthly production and consumption quantities of goods era estimated for every firm separately by industry and commodity type. The estimation is based on a firm size indicator, which is a combined measure of the number of employees and floor area. Production and consumption of firms can be expressed as follows:

$$G_i^k = f(x_{1i}, x_{2i}, ..., x_{ni}) \quad (1)$$

$$A_j^k = f(x_{1i}, x_{2i}, ..., x_{ni}) \quad (2)$$

with,

G_i^k = amount of commodity *k* produced by firm *i*,

A_j^k = amount of commodity *k* consumed by firm *j*,

x_{ni} = attribute *n* of firm *i*. (from step one)

In the next step, the commodity flows between firms are derived with a commodity distribution model. The idea behind our approach is that firm relations are the result of interactions on markets with complete information. Thus, we assume an optimal allocation of demand and supply. To maintain the characteristics of a commodity, we develop an individual model for each commodity type. The cost optimal allocation is assumed to be described by the following minimization problem:

Minimize $$Z^k = \sum_{i=1}^{m} \sum_{j=1}^{n} c_{ij} x_{ij}^k \quad (3)$$

Subject to; $$\sum_{j=1}^{n} x_{ij}^k = G_i^k$$

$$\sum_{i=1}^{m} x_{ij}^k = A_i^k$$

$$x_{ij}^k \geq 0$$

Where,

Z^k = total cost of movement of goods *k*

x_{ij}^k = monthly amount of commodity *k* transported from supplier i to customer *j*,

c_{ij} = transport cost between supplier i and customer *j*,

The solution yields a firm-to-firm matrix differentiated between 13 industry and eight commodity types.

To analyse the effects of urban logistics measures, it is appropriate to consider the flows of goods between firms as given and fixed. In particular, we are interested to study the emergence (and the behaviour reactions) of the spatiotemporal structures of transport, i.e. shipment structure, time profiles, vehicle fleets, tours and route choice. The basic components to modelling these structures in a constructive fashion are the decision models of the two most relevant actors in the freight transport system, i.e. shippers and carriers.

3.2 Shippers

In the underlying model, shippers choose their shipment size to minimise total logistics costs. These costs include transportation, handling and storage costs and are the sum of the following components:

- Transportation costs (consisting of the cost share for the main run and the pre- and post- haul)
- Any fees or tolls that are charged due to policy or pricing measures
- Loading and handling costs
- Storage costs to cover the demand between two subsequent deliveries

The transport-related costs, i.e. cost for the main run, pre- and post- haul as well as for loading and unloading. This cost is expressed with the following function:

$$C(q_{ij}) = \alpha + \beta q_{ij} + \gamma q_{ij}{}^2 \qquad (4)$$

where q_{ij} denotes the size of a shipment from consignor i to consignee j. This function is composed of the linear distance dependent costs and the quadratic loading and unloading costs. The cost function will be communicated from the carrier to the shipper.

It is now assumed that the whole quantity Q_{ij} of goods (measured in kilogram per time period) is divided equally into n shipments that are transported in equidistant points of time. The optimal shipment size is derived by minimizing:

$$C_{Total} = \frac{Q_{ij}}{q_{ij}}\left(\alpha + \beta q_{ij} + \gamma q_{ij}^2\right) + q_{ij} w \qquad (5)$$

with w being a proxy for the overall storage costs per kilogram and month on either side of the supply relationship. The value for w was determined to 2000 yen per month and kilogram in an initial data fitting. α, β and γ are parameters that vary in the course of calculation. From the minimization of expression (4) subject to q_{ij} follows the optimal lot size:

$$q_{opt} = \sqrt{\frac{\alpha Q_{ij}}{w + \gamma Q_{ij}}} \tag{6}$$

3.3 Carriers

Carriers execute all the transport related tasks, i.e. pickup and delivery of shipment as well as the actual transport of shipments from one firm to another. For simplicity, we assume that carriers have an arbitrary number of vehicles at its disposal. They can reduce and increase their vehicle fleet without additional transaction costs. It is assumed that there is only one type of vehicles, namely trucks with a payload of 9 tons.

The transport of the various shipments from the sender to the receiver is organized in tours that are constructed by applying the vehicle routing algorithm specified in Schroeder (2012) and Schroeder et al. (2012). The tours are carried out on a plane using Euclidean distances. It should be noted that this tour construction algorithm deals with a flexible and heterogeneous vehicle fleet. It is easy to relax the assumption of having only 9-ton trucks.

After having completed all transport tasks, costs that accrued are allocated to the various shipments of which each tour was made of. Cost allocation serves the purpose of generating prices. For this reason, two assumptions are made. First, the carrier operates in a market that is in perfect competition, so that prices do reflect (allocated) full costs. Second, the carrier applies an accounting mechanism that requires every tour to recover its total costs.

In allocating costs, a distinction between the main run and the pre and post haul is made. In the former case, costs are allocated to the shipments proportionally to their share of vehicle capacity utilization. In the latter case the costs for all trips are added up and divided by the number of shipments. Thus, every shipment has costs assigned depending on its size and the tour it was transported in. The following table summarizes the cost allocation principles:

Activity	**Cost driver**	**Cost allocation key**
Main run	Distance dependent costs that are linear in distance with a positive intercept.	Capacity requirements of shipment proportional to overall vehicle utilization
Pre and post Haul	Distance dependent costs between stops in the origin and destination area. (For simplicity only distribution in the destination area was modeled in detail and costs were doubled to mirror the situation in the origin area)	All costs are divided by the number of shipments in the tour.
Loading and unloading	Costs for two people loading respective unloading the vehicle with minimum stop duration and a concave course of the function.	Size of shipment in kilogram
Storage at the shipper and recipient	Costs per month and kilogram as an overall proxy. Constant costs per quantity unit without intercept.	Each shipper faces the same costs for storage and has to cover it individually

Table 1: Allocation principles for the transport and storage related costs

In calculating prices, the carrier faces two problems. On one hand, customers demand that prices are quoted in advance, so that they can adjust their lot sizes to them. On the other hand the costs that actually accrue depend on specific circumstances as the demand for transport space at a given day or the assignment of the shipment to a certain tour. For this reason, tariffs are unified for all shipments regardless of the actual tour they are assigned to. After performing all tours of a day, costs in each of them are assigned to the shipments as outlined in table 1. This ensures that for each tour, full cost coverage is achieved. From this assignment, pairs of weight, cost combinations result, that constitute a scatterplot. This scatterplot is the input basis for a linear regression.

The concavity of the cost function is thereby insured by the loading costs that are added to the actual transport costs and that have a negative coefficient assigned to the quadratic component.

The parameters of the cost function / tariff function is updated as follows between two simulation periods t and t+1: $\alpha_{t+1} = \lambda \cdot \alpha_{t+1} + (1-\lambda) \cdot a_t$ with the same holding true for parameters β and γ and the initial values obtained as mentioned above and λ ranging between zero and one.

3.4 Shipper and carrier interaction

The introduction of transport tariffs enables a feed-back between carriers' and shippers' behaviour. The model prepares for an explicit modelling of market entries and exits, which are, however, not considered at the current stage of development. For the model, some overall assumptions were made. For the moment, the model considers only two regions, so that the main run has the same length for every shipment. This is important when it comes to cost allocation and the formation and update of the tariff table assuring the link between transport and logistics. If there were more than two regions involved, the regression had to be extended by a further dimension that embodies the different distances.

4 APPLICATION CASE RESULTS FROM A TWO REGION MODEL

4.1 Spatial setting

From the synthetic firm-to-firm flow data, two regions were selected. The origin region contains only shippers whereas the destination region contains the corresponding receivers. To put it in other words, we selected only those firm pairs with consumer ends in one and supplier ends in the other region. The selected regions are contiguous settlement areas rather than administrative zones. As figure 1 shows the origin region is located at the coast between Tokyo and Yokohama and the destination region lies northwest of the city centre of Tokyo.

As far as commodities were concerned we limit our examination to Light Industry Products according to the Japanese Statistic Bureau.

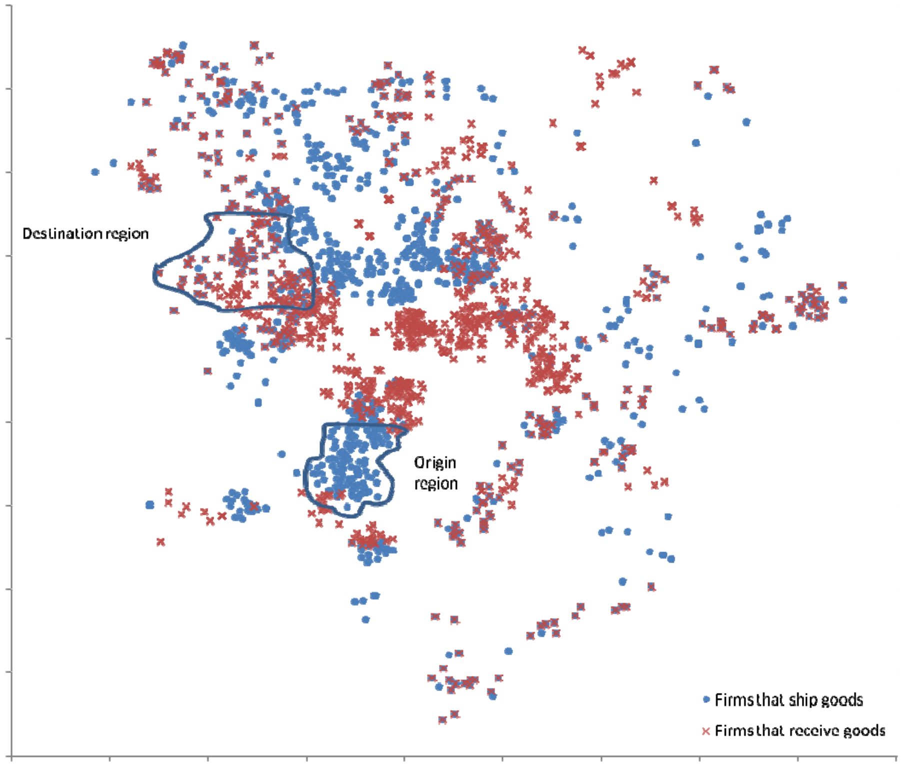

Figure 2: Location pattern of shippers and receivers in the Tokyo Metropolitan Area

4.2 Initial model state

In a preparatory calibration step, the model is brought into a situation where following conditions are fulfilled:

- The shippers determine shipment sizes according to a EOQ quantity model
- The shippers face transport tariffs as they are observed in reality, too.
- The lot size distribution in the initial state is similar to those one which is observed in reality.

Full-truck transport cost accrues according to the operation of a truck with a payload of 9 tons. According to a tariff table, the transport cost function is linear with an intercept of 15535 yen and a slope of 238,55 yen per kilometer. At both the origin and destination end of each of the goods flows described above the shipment has to be loaded on respective unloaded from the truck. For this purpose the driver of the truck as well as an employee of the respective firm are occupied at least ten minutes and up to 45 Minutes for a full truck. In the initial state, the cost for a shipment (including transport and handling) is therefore calculated to $C(q) = 4000 + 4{,}9q - 0{,}0002q^2$.

Assuming this cost function as given and fixed, the lot size model needs to be calibrated. For this purpose, the storage costs are adjusted in order to replicate the lot size distribution in the whole population. With this initial values, lot sized are calculated according to equation (5) and the shipments are transported. Having performed the first transport run, real costs are allocated and the transport cost function is updated. As can be seen from figures 3 and 4 an equilibrium is reached after a few iterations.

4.3 Scenarios

Different scenarios are now simulated and compared to each other.

(1) Reference Scenario: In a base scenario, shippers choose their lot sizes according to the cost minimization calculation and there are no further restrictions than the payload of the used vehicles (9 tons).This is used as a reference scenario against which different intervening policy measures are compared. The lot-size distribution of the reference scenario as well as the tariff functions observed correspond approximately to the initial state described in the previous subsection.

(2) Stopping fees: A policy measure that seeks to remedy the problem of vehicles that park on the curb in order to load and unload cargo in front of shops or other business establishments is established. In fact, one of the major negative interferences of urban commercial transport on other activities is provides by parking, stopping, unloading, and maneuvering. Each additional stop also creates a small additional trip. In this second scenario, the visit of consignors and consignees is charged with an additional penalty fee of 1500 yen for every loading or unloading stop. All other conditions are equal to those of the base scenario.

(3) Time restrictions on vehicles: The computations of scenario (1) and (2) revealed that the tour construction heuristics yields a high utilization of vehicles, as long as there is enough time to fill the vehicle additional time constraints are imposed. This is not unrealistic: Especially in the parcel express service segment one can observe tong and complex tours. In this way, a lot of vehicles collect extremely small shipments and cause significant congestion. We now introduce an overall time limit of eight hours per day and vehicle. This is realistic with regard to working hours restrictions of the drivers. Further, at least ten Minutes are required in order to unload or load a vehicle with the time increasing concavely up to 45 minutes for a full truck load. This adds a second constraint dimension that is supposed to increase lot sizes and hence decrease demand frequency.

(4) Additional time restrictions on pickups: A further constraint is added by the additional requirement that the shipments can only be delivered to the destination region in the late forenoon and early afternoon (11 a.m. – 1 p.m.) This could be seen as a measure to reduce congestion in the morning and evening peak hours caused by commuters.

The results can be seen in the figures below. The first figure shows the effect on average vehicle utilization. This indicator shows the tonnage of goods collected in pre-haulage in relation to available capacity. These indicators are close to one which demonstrates the efficiency of the tour construction heuristics. In fact, when using optimization engines for descriptive modeling, it can happen that the performance of the modeled situation greatly exceeds the performance indicators observed in reality. In the case where there are no time restrictions, a sophisticated tour planning concept can yield efficient results as far as capacity utilization and hence the number of active vehicles is concerned. It is shown that the number of stops can be effectively decreased by charging a fee as simulated in scenario 3. Almost equivalent to the fee is the restriction of accessibility for certain areas, so that on one shipment sizes increase. However, this entails a lower capacity utilization as can be seen in figure 3 so the tradeoffs have to be looked at carefully.

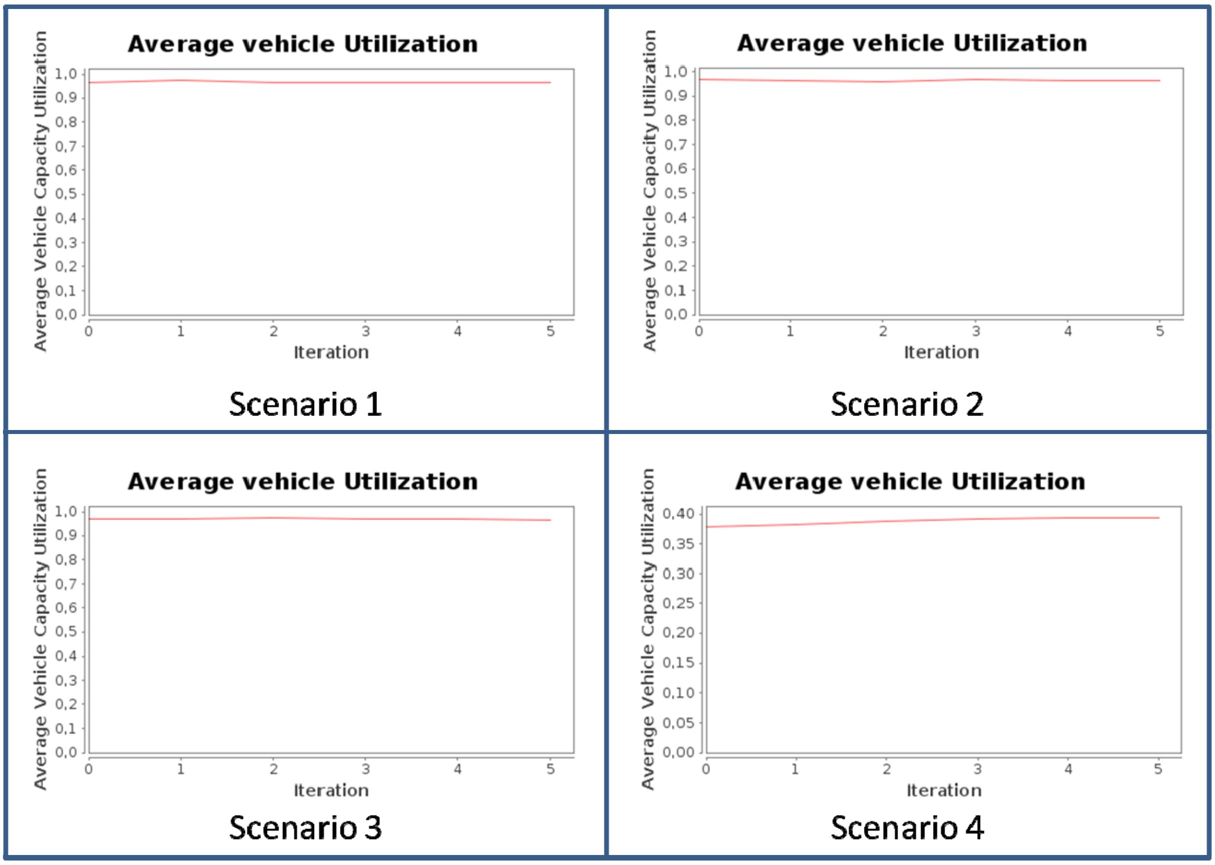

Figure 2: Various average capacity utilizations in the operating vehicles

Figure 3 shows the development of the lot sizes of five selected shippers in the course of the simulations. Scenario 1 relates to the calibrated initial state, too, the shipment sizes remain more or less constant.

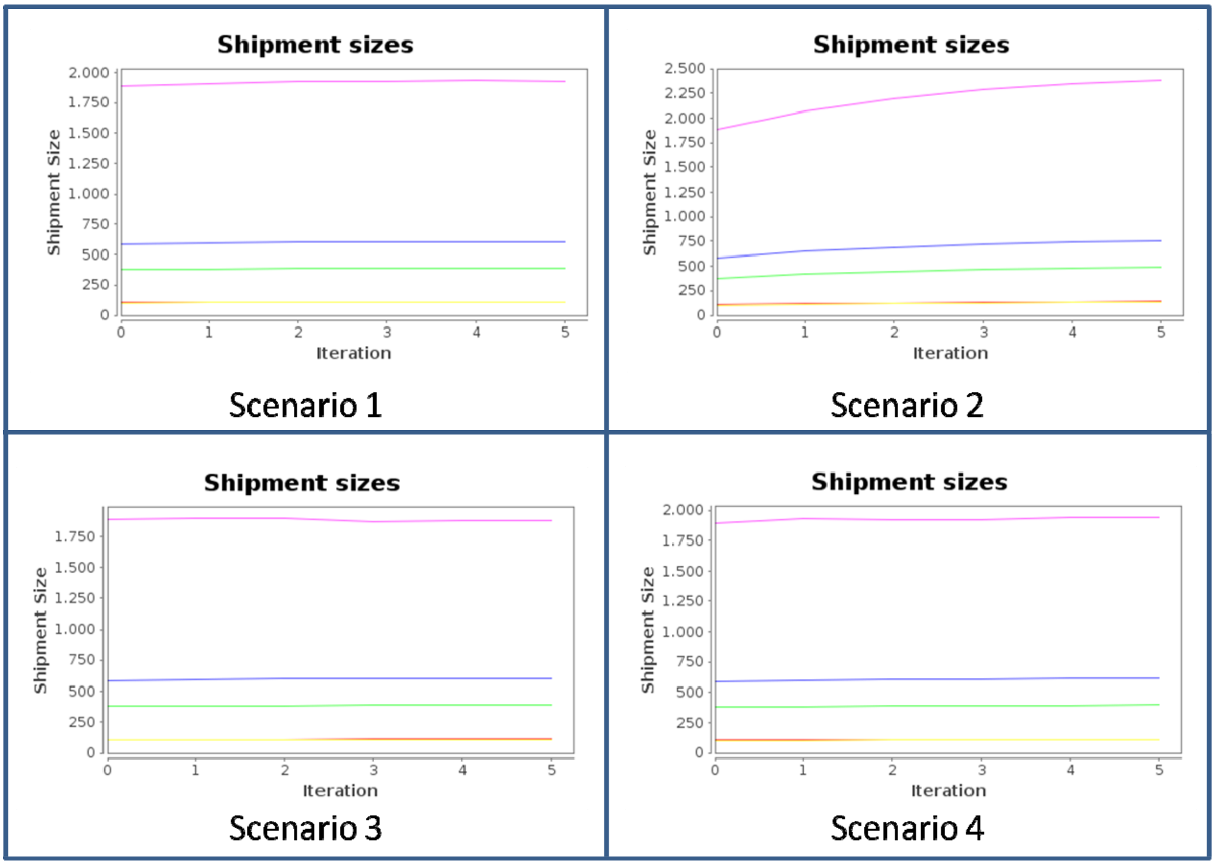

Figure 3: Various sample lot sizes in different scenarios

5 OUTLOOK ON FURTHER EXTENSIONS

The described model implementation and policy analysis is just one step towards an integrated Multi-Agent model of shippers and carriers. But already now, two aspects seem worthwhile to be examined further.

First, transportation is not only restricted to spatial aspects. In fact, in each transport problem, distances have to be covered meeting certain time restrictions. This holds for both the decisions on the supply as well as on the demand side, where the possibility to bundle shipments depends on the existence and economic reasonableness of inventory that can be held at both ends of the transport relationship. Clients whose operations do not depend on the exact arrival time of a shipment enable transport companies to realize economies of scale on their side. Interaction of supply and demand is thus not only limited to the local availability of certain transport solutions but also on the existence of such services that meet time requirements of a certain number of shippers. Transport solutions that have their raison d’être in bundling shipments of many shippers can only be established, if there is enough demand in both the origin and destination area and at the same point of time. This holds true especially for transport solutions that require a higher load than a single truck to work profitable, such as intermodal transport.

Further, there is reason to suppose that also the structure of both sides of the transport market as it emerges in time and space has a considerable influence on freight transport flows as they can be observed on the different modes of transport. Therefore the modeling of the endogenous market entry and exit of carriers is a preferable extension to the model outlined above.

The two region model above did not take into consideration the problem of backhauls and other possibilities of bundling shipments during the transport process (pre-, main and post-haulage). This together with a more detailed and probably stratified consideration of shipper behavior could help to assess policy measures aiming at the reduction or at least direction of urban and interregional freight transport.

6 CONCLUSIONS

An econometric lot size model, a tour construction model, and a cost-allocation model have been coupled in order to study the effects of transport policy instruments on both vehicle routing and stock replenishment policies. It became obvious that comparatively simple demand and cost allocation mechanisms are able to absorb information given by the transport provider. The continuously updated tariff table fulfils several functions: Firstly, it assures consistency between the different decision layers – the levels of lot-size choice, tour-construction and vehicle fleet composition decisions. Secondly, it transmits signals from the traffic system and policy measures to the upstream decision makers – shipment size choices of shippers. Thirdly, it stabilizes the dynamics of the interactions.

Price signals in form of interchanged tariff functions provide a possible key towards modeling the emergence of carriers endogenously. Especially during a business start up period, new carriers won't have a critical mass of customers to be competitive with the existing ones. At this time they could set tariffs according to prices they observe on the market. Over time they will switch to a profit maximizing pricing behavior, which in the case of dynamic market entries and exists corresponds to a cost-related price setting. In other words: The updated tariff function is one element in an algorithm resulting in long-term market equilibrium. Another important element is the tour construction heuristics which determines the number of trucks and the types of trucks employed endogenously.

For the moment, however, our analysis is restricted to a two actor case. Assuming one type of vehicles only, we analyzed the effects of traffic management measures on (i) vehicle routing, (ii) number of vehicles employed, and (iii) shipment behavior. It has been shown that both monetary and temporal interventions can effectively influence the logistics decisions that precede and partially determine the shape of freight transport movements. The overall utilization of the operating vehicles is not increased by fostering the creation of lesser and bigger shipments. By imposing time restrictions Instead, the mileage travelled in the origin and destination region can be reduced. This result is surprising because normally one would expect that time restrictions have a negative impact on the efficiency of tours. This effect cannot be denied, but at the same time, the tariffs in particular for small shipments will increase and this increase induces a reduction of delivery frequencies of the shippers.

In the end it does not matter who restricts the delivery time to a few hours per day. This could be local authorities or even the clients of transport companies themselves after having realized that a permanent arrival of trucks delivering only small shipments to their establishment causes additional complexity costs that were not taken into consideration in the original lot size determination.

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REFERENCES

Arunotayanun, K. and Polak, J. W. (2011). Taste Heterogeneity and Market Segmentation in Freight Shippers' Mode Choice Behaviour, Transportation Research Part E: Logistics and Transportation Review, 47 (2), 138- 148

Carrillo Murillo, D.G., Liedtke, G. (2013): A model for the formation of colloidal structures in freight transportation: The case of hinterland terminals Transportation Research Part E: Logistics and Transportation Review. 49(1), 55-70.

Combes, F., (2012). An empirical evaluation of the EOQ model of choice of shipment size in freight transport, Transportation Research Record - Journal of the Transportation Research Board 2269 ,92-98

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

Friedrich, H. (2010). Simulation of logistics in food retailing for freight transportation analysis. Dissertation, Fakultät für Wirtschaftswissenschaften, Karlsruher Institut für Technologie (KIT).

Friesz, T.L., Tobin, R.L, Smith, T.E., Harker, P.T. (1983). A Nonlinear Complementarity Formulation and Solution Procedure for the General Derived Demand Network Equilibrium Problem, Journal of Regional Science, 23(3), 337-359

Groothedde, B. (2005) Collaborative Logistics and Transportation Networks, The Netherlands Trail Research School, Dissertation, 2005

Holguin- Veras, J., Xu, N., de Jong, G., Maurer, H. (2011). An Experimental Econimics Investigation of Shipper- carrier Interactions in the Choice of Mode and Shipment Size in Freight Transport, Networks and Spatial Economics, 11, 509-532

Roorda, M., Cavalcante, R., McCabe, S., and H. Kwan (2010). A conceptual framework for agent-based modelling of logistics services. *Transportation Research Part E: Logistics and Transportation Review.* 46(1), 18-31.

Schroeder, S. (2012). Policy dependent vehicle routing: An approach for evaluating transport policy measures. Arbeitsunterlagen, Karlsruher Institut für Technologie (KIT).

Schroeder, S., Zilske, M., Liedtke, G., and Nagel, K. (2012).Towards a multi-agent logistics and commercial transport model: The transport service provider's view. Procedia - Social and Behavioral Sciences, 39, 649-663.

Sjoestedt, L. (2004) A conceptual framework for analyzing policymaker's and industry roles. In: Rietfeld, P., Roger, R.(eds): Barriers to Sustainable Transport, Taylor and Francis Group, London, 2004, 198–222

Takahashi, Y, and Hyodo, T. (1999). A simulation study on the effect of physical distribution facilities in the Tokyo Metropolitan Region. Journal of the Tokyo University of Mercantile Marine, 50, 119-130

Taniguchi, E., Thompson, R.G. and Yamada, T. (1999). Modelling city logistics In: E. Taniguchi and R.G. Thompson, Editors, *City Logistics I*, Institute of Systems Science Research, Kyoto (1999), pp. 3–37.

Wisetjindawat, W., Marchal, F. and Yamamoto, K. (2009): Methods and Techniques to Create Synthetic Firm's Attribution as Input to Microscopic Freight Simulation, Proceeding of the Eastern Asia Society for Transportation Studies, Vol.7.

Wisetjindawat, W., Matsumoto Sano K.,Raothanachonkun, P.(2007). Micro-Simulation Model for Modeling Freight Agents Interactions in Urban Freight Movement. Paper presented at the 86th TRB Conference.2007