Available online at www.sciencedirect.com

ScienceDirect

Transportation Research Procedia 12 (2016) 925 – 937

Transportation Research Procedia

www.elsevier.com/locate/procedia

The 9th International Conference on City Logistics, Tenerife, Canary Islands (Spain), 17-19 June 2015

A framework for incorporating market interactions in an agent based model for freight transport

Tilman Matteis[a,*], Gernot Liedtke[b], Wisinee Wisetjindawat[c]

[a]Karlsruhe Institute of Technology (KIT), Institute for Economics (ECON), Kaiserstraße 12, 76131Karlsruhe, Germany
[b]German Aerospace Center (DLR), Institute of Transport Research, Rutherfordstraße 2, 12489 Berlin, Germany
[c]Nagoya Institute of Technology, Department of Civil Engineering and System Management, Gokiso, Showa, Nagoya 466-8555, Japan

Abstract

A model is sketched that allows to display the reaction of the supply side in the freight transport market on changes in demand and on policy measures. Considerations are made on how to include the concept of monopolistic competition into an agent based market simulation. Methods of price formation and rules for entries and exits of suppliers in the market are given.

Peer-review under responsibility of the organising committee of the 9th International Conference on City Logistics

Keywords: Freight Transport; Market Model; Monopolistic Competition

1. Introduction

Freight transportation requires the interaction of a multitude of actors. This holds true for the relationships between shippers and recipients as well as for their business connections with transport companies. However, interactions between single actors alone cannot explain the observable movements of heavy goods vehicles, nor can information on such movements be traced back to single interactions. Thus, there is an apparent mismatch between observed respective observable states in the transport networks and the behavior of single actors involved in freight transport.

---

[*] Corresponding author. Tel.: +49-721-608-46042 ; fax: +49-721-608-48923 .
E-mail address: Tilman.Matteis@kit.edu

Peer-review under responsibility of the organising committee of the 9th International Conference on City Logistics
doi:10.1016/j.trpro.2016.02.044

Research has identified two main reasons for this gap between individual behavior and the behavior of the transport system. The first one is the necessity of coordination between the involved companies. On the demand side of the freight transport market, companies often do not act independently, as they are part of logistic chains. These chains become more efficient if the involved parties on all chain links collaborate. Collaboration on all chain links means that the requirements of all concerned companies are passed on through the chain and that the actions of single companies implicitly take the requirements of all other actors into account. Moreover, logistic chains have to adapt to requirements from outside. In many cases transport services are performed by a transport company and not by the shippers or recipients. Additional outside influences on logistic chains in these cases are the actions taken by transport companies.

The existence of an own business sector for freight transport is the second reason for the gap mentioned above. Single transport companies optimize the freight flows of many logistic chains. At the same time, competition on the market forces them to operate at the lowest possible costs given the requirements of their customers. For this purpose, they maintain networks of facilities to fulfil transport tasks in a competitive way. In particular smaller shipments are not suitable to be transferred directly from the shipper to the recipient but rather have to be fed in such networks. These networks entail vehicle movements that deviate from the original flows of goods, as such deviations are cost minimizing given all the orders handed over to a certain transport company.

Movements of freight transport vehicles are thus the result of the continuous adaptation of many actors to each other. This adaptation goes along with phenomena of emergence that influence the observable traffic flows. Moreover, emergent phenomena can lead to changes in the structure of demand and supply on the transport market that are also partially observable. One of these changes is the entry and exit of transport companies in a certain market segment. We want to address such emergence by composing a transport market of its constituent parts. For these purpose, we want to outline an approach to model the interactions between supply and demand on the market for mixed cargo. With supply, transport companies are meant that carry shipments on their own account. The demand side is represented by shippers and recipients of goods. As decisions are drawn decentralized on such a market, agent based simulation will be employed. Agents are to a certain extent heterogeneous, pursue their own goals and adjust to the influences of the market. From the behavior of single agents, the market outcome and thus the generation of vehicle movements will be put together. A specification for a model to be implemented is sketched in which some aspects on the intersection of transport demand modelling and microeconomics will be dealt with. The present paper will outline a model for a market under monopolistic competition. The reason for the choice of this market form is that some properties of the suppliers, i.e. the transport companies will be explained endogenously by the model.

2. Literature overview

There are many scientific disciplines that deal with the interactions of a system and the parts that it is comprised of. Many of such interactions have been described quantitatively in natural sciences, such as physics. From there, concepts were transferred to social sciences in general and economics in particular (c.f. Weidlich (2006)). In such models, single actors take into account the behavior of their environment to varying extents. Models in which actors explicitly anticipate the actions of all other players also occur in industrial organization that uses game theoretical concepts to study the connection between a market and the firms that are active there.

Such approaches try to look for solutions in closed form. In more complex settings this is not possible anymore, so that it is resorted to simulation models, in which a myriad of possible system states can be displayed in comparatively short time. In social sciences, agent based models have been used to address situations in which the state of a collective of individuals has to be explained from the decisions that single members of this collective draw. For the special case of economic models an own branch of research called Agent Based Computational Economics (ACE) has emerged. Tesfatsion (2006, p. 835) states “ACE is the computational study of economic processes modelled as dynamic systems of interacting agents”. Agents in the sense of Wooldridge & Jennings (1995) are computer systems that can act autonomously to reach a certain predefined goal.

Models of market simulation have already been applied to transport markets in the past. One of the first of them is the one of Holguin-Veras (2000). Starting from the assumption of Cournot competition between two carriers, vehicle tours are built, so that all transport demand can be satisfied and both carriers maximize their profits. Dimitriou and Stathopoulos (2009) also model oligopolistic behavior in the competition between three maritime container terminals in the east Mediterranean with each terminal operator trying to attract the profit maximizing share of demand. In their model operators can invest money to accelerate transport in the ports and on hinterland links. By means of a co-evolutionary genetic algorithm, a solution is obtained.

Competition between various modes and carriers operating on the same freight corridor is modeled by Baindur and Viegas (2011). The market for truckload transportation is regulated by the number of active companies which in turn depends on the prices that can be charged from the customers. The latter can choose between one of the many active road transport companies and an intermodal carrier.

In the concept that Roorda et al. (2010) propose for an agent based framework for freight transport, markets play a crucial role. Agents can interact on markets for commodities, services and logistics, where they make contracts on exchanging goods or services for money and on transporting the goods that were exchanged in the corresponding purchase contracts. Cavalcante (2013) extends these conceptual considerations and implements the agent based model FREMIS. There, parts of the concept are made operational for a transport market in an urban area. Customers select carriers according to a logit model and carriers charge prices depending on incremental costs caused by the shipment at hand and the intensity of competition. As deep market knowledge is required for implementing a detailed model, an extensive survey was conducted in the Greater Toronto and Hamilton Area.

A fundamental problem of price calculation is that not all customer orders are known at the beginning of the planning horizon. Offers made to customers have to anticipate the quantities of future demand. In the freight transport business, this context dependence of costs is more pronounced as temporal and spatial aspects are added. Costs caused by empty trips and idle times have to be quantified and covered by total revenue. Mes (2008) deals with this problem for a company in the full truckload business. He introduces day plans for the vehicles similar to the ones for people in passenger transport. In these plans, incoming orders are inserted subject to spatial and temporal constraints in order to calculate costs and prices. Figliozzi (2004) also deals with the problem of dynamically assigning incoming orders to vehicles that are already deployed to serve customers. He examines various learning techniques of carriers that compete for a certain shipment in an auction.

Krajewska and Kopfer (2009) deal with the decision of a freight forwarder to either operate vehicles on his own or to hand the shipments over to a transport company. A tabu search algorithm is applied to let the forwarder decide to give shipments to own vehicles or to choose one of several pre-defined subcontractors.

In freight market models, the prevailing market structure is oligopolistic competition in several shapes (e.g. Lee et. al. (2014), Nagurney (2010), Adler (2005)). Game theoretical models of this kind do not yield stable equilibria for all shapes of cost functions. Models of monopolistic competition set aside the explicit consideration of competitors' activities. Therefore a treatment of the interactions on the market is possible without using concepts of game theory. Along with this simplification goes the disadvantage of not being able to obtain provable market equilibria. This could be a reason why markets under monopolistic competition have been modelled by means of agent based simulation only seldomly. The most recent model is of Catullo (2013). He examines companies of a generic industry sector in a spatial setting with two regions. Companies can decide on prices, capacity, research and export in the other region by means of reinforcement learning. If suppliers have spent their initial endowments without making profit, they leave the market. In each iteration a new supplier enters the market. Number, size and research efforts of companies are endogenous to the model. However, the q-learning algorithm that is applied assumes complete independence of agents from each other. This neglects the fact that single suppliers in monopolistic competition indeed consider the actions of competitors on the market. They believe that the demand for the good they offer depends on the ratio of its price to an aggregate market price index.

Monopolistic competition is particularly interesting for transport economical considerations. This is because in this market form the emphasis of the modeler can be put on entries and exits of suppliers and the emergence of spatial characteristics of the supply side from agent interactions that are endogenous to the model. As Carrillo and Liedtke (2013) showed for the example of intermodal container terminals, dynamic equilibria can be reached in a market under monopolistic competition. As far as market simulation is concerned, only one example of monopolistic competition in freight transport is known to the authors. The already mentioned market in the model of Baindur and Viegas (2011) has properties of monopolistic competition, such as the determination of market entries and exits by the model and preference for variety on the demand side.

3. A stylized transport market model

A simple spatial setting is assumed in which the supply of business establishments in a city from shippers that are located in a suburb is considered (see Fig. 1.). Starting with some initial data and an adaption process as simple as possible, an outline is given how a market equilibrium could be reached.

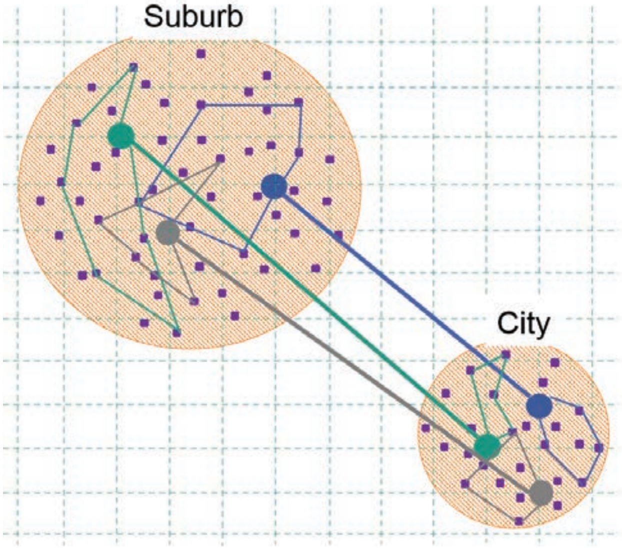


Fig. 1. Spatial setting of the transport market

3.1. The demand side of the transport market

Freight transport is an activity that is derived from trade relationships between buyers and sellers of goods. Unless they are one-off businesses, such relationships last for a certain period of time and encompass an overall quantity of goods that are exchanged. During their runtime such frame contracts cause more or less regular transport movements between shippers and recipients. In most cases the time span of the frame contract as well as the overall quantity of goods shipped requires the formation of several single shipments. The details of shipping have to be agreed upon by shipper and recipient. The formation of these relationships and their details are not considered here.

One of the contractual parties is in charge of organizing the transport of the shipments. In reality, the requirements of the shipper and the recipient have to be met, hence decisions on transport are usually drawn together or the requirements of the other party serve as restrictions for the party in charge. From now on, shippers are assumed to represent the customers on the market for freight transport services.

Transports are performed by third party companies that solicit orders from various customers. As there exist many shippers and several transport companies that look for business partners on their own initiative, the search for freight space respective cargo can be seen to take place on a market. The way how consumers act on a market depends on their preferences, their endowment with resources and the supply they face. Similar things hold for the supply side which adjusts behavior given own constraints, competition and demand.

This situation will be addressed in the model. In the problem at hand, a market under monopolistic competition will be modeled. Monopolistic competition can be seen as a limit case of oligopoly, where every supplier believes to have some market power left. This results from the perception of shippers that distinguish between different carriers according to service characteristics or the location of the carrier’s business seat. Transport companies that offer the same service for the same price are therefore seen to be slightly different from each other. Shippers do not only notice this difference, but also exhibit a certain preference for variety of transport companies to choose from. Of the various models developed on this market form, the one of Dixit and Stiglitz (1977) will be taken as a base. In the original work, preference for variety was modeled by means of a CES utility function. In the present example this is not possible, as a shipment can only be handed over to exactly one carrier. Therefore, shippers ask several carriers for prices and decide according to a logit model. As Anderson et. al. (1992) showed, such a choice is similar to a consumer that decides according to a CES utility function in the case when only one item of a certain good has to be consumed. Regarding the demand side, the trade relationships are given and fixed. This means that the quantities of goods and the transport distances are constant and especially independent of transport prices. Such an assumption restricts the scope of the model to short- to medium term considerations. Nevertheless it does not limit the explanatory power of the model, as in reality most transports from and to urban areas serve business sectors such as retail or crafts that do not change their demand with altered trade patterns (c.f. Schoemaker et. al. (2006)).

Expressed more formally, the demand side consists of a set of shippers which is indexed by i. Each shipper i can ship various flows that are gathered in the set F_i. Each flow f of a certain shipper has a strength of Q_{if} and is subdivided in shipments s_{if} with equal quantity $q_{s_{if}}$. It holds $\sum_{s_{if}\in f} q_{s_{if}} = Q_{if}$. In the following, only the shipments s_{if} and their sizes $q_{s_{if}}$ will be of interest. For each shipment, offers are requested from several transport companies that are also called suppliers or carriers. Note that for the sake of simplicity an aggregation of shipments from different flows that originate from the same shipper is not done.

Shippers choose a carrier to whom they will hand over their shipments. For each single shipment s_{if} this choice is made according to a multinomial logit model. The probability with which shipper i chooses carrier j for his flow f is:

$$P(s_{if})_j = \frac{exp\left(\alpha V_{if}\left(p_j\left(q_{s_{if}}\right)\right)\right)}{\sum_{k\in Ch_{if}} exp\left(\alpha V_{if}\left(p_k\left(q_{s_{if}}\right)\right)\right)} \tag{1}$$

Despite its obvious shape, equation (1) requires some explanation. Choices are made depending on the utility function $V_{if}\left(p_j\left(q_{s_{if}}\right)\right)$. This function allows all shippers a choice according to a model with the same parameter α. As in the less-than-truckload (LTL) segment, shipment sizes can vary within a wide range, a single parameter α estimated from a sample drawn from all shipments in a certain lane would not lead to sound results. This is due to the price differences of shipments that can have different orders of magnitude. For small shipments, the choice decision would be completely random, whereas for large shipments, the cheapest carrier would be chosen almost certainly. To arrive at a behavioral sound model, parameter values for various categories of shipment sizes had to be estimated. In the absence of such data, an assumption that can be justified is that shippers react uniformly on relative price differences. The indirect utility function in equation (1) thus scales all prices in the choice set, so that $V_{if}\left(p_j\left(q_{s_{if}}\right)\right) = \frac{p_j\left(q_{s_{if}}\right)}{p_{min}\left(q_{s_{if}}\right)}$ with $p_{min}\left(q_{s_{if}}\right)$ being the lowest price in the choice set Ch_{if}.

A choice of the carrier in charge could also be modeled by means of a master equation, as for example suggested by Carrillo (2011). In such a model, shippers switch between carriers according to a transition function. In the simplest case of such a function, transition probabilities between the present and all other available carriers also have the type of a multinomial logit function (c.f. Helbing (2010)).

The second fact worth to be mentioned in connection with equation (1) is the importance of the choice set Ch_{if}. Provided that there are many shippers on a market, a single one of them does not have enough power for negotiating prices with any of the carriers. Thus the choice set is the only thing that can be decided upon by the shipper given that the shipment size $q_{s_{if}}$ was already determined together with the recipient of the concerned flow f. The size of the choice set can be determined using the expected benefit that the shipper can gain and that reads:

$$E\left(W_{Ch_{if}}\right) = \frac{1}{\alpha}\ln \sum_{k\in Ch_{if}} exp\left(\alpha V_{if}\left(p_k\left(q_{s_{if}}\right)\right)\right) \tag{2}$$

The value of equation (2) reflects the expectation of the maximum value that $V_{if}\left(p_k\left(q_{s_{if}}\right)\right)$ can attain. In models that incorporate discrete choice into industrial organization (e.g. Anderson et. al. (1992)) equation (2) was used for forming choice sets as its value is strictly increasing in the cardinality $\left|Ch_{if}\right|$ of the choice set. Such increases in welfare are often contrasted with prices and search costs. In the present case, the latter is not possible for two reasons. First equation (2) is deduced from equation (1) and thus prices are again relative. These relative prices also allow equation (2) to have a reasonable shape if real figures are entered. Taking absolute prices of shipments with a large spread in sizes, results would be misleading with just one estimated parameter α at hand for all shipments in the market. For small shipments $E\left(W_{Ch_{if}}\right)$ could become negative only after the addition of a second or third element to Ch_{if} whereas for large shipments the effect of additional choice set members would be negligible.

Thus the absolute value of $E\left(W_{Ch_{if}}\right)$ in equation (2) has not the meaning that allows it to contrast it with some search cost expression. However, differences between $E\left(W_{Ch_{if}}\right)$ and $E\left(W_{Ch_{if\cup k'}}\right)$ with k' being an additional carrier can be used to determine desired sizes of the choice set.

$$\Delta E\left(W_{Ch_{if}}\right) = E\left(W_{Ch_{if}}\right) - E\left(W_{Ch_{if\cup k'}}\right) \tag{3}$$

states the relative increase of welfare due to an increase in the variety to choose from. As the value of equation (3) is concave, a threshold value $\delta_{E\left(W_{Ch_{if}}\right)}$ can be defined. If $\Delta E\left(W_{Ch_{if}}\right) < \delta_{E\left(W_{Ch_{if}}\right)}$ for any increase of the cardinality of the choice set, the shipper can be considered as satisfied with the number of shippers at hand.

Choosing relative prices in equations (1) to (3) entails the same preference for variety for all shippers in the market. This assumption can be contested. If there were more detailed data at hand, group specific parameter values of α could be estimated.

3.2. The supply side of the transport market

In the transport market at hand, there is a set of carriers denoted by M and indexed by j. Carriers are endowed with production equipment that allows them to consolidate shipments that are not suitable to be transported directly in a single vehicle from the shipper to the recipient. For this purpose, they maintain hub facilities from which pickup and delivery tours as well as main runs between two hubs start. Each carrier j maintains a set H_j of hubs indexed with l. Each hub h_{jl} is limited in the volume of freight it can handle by its capacity $cap\left(h_{jl}\right)$. For the sake of simplicity, it is assumed that all hubs of all suppliers have the same capacity $cap\left(h_{jl}\right) = cap,\ \forall\, h_{jl} \in H_j\ ,\ \forall\, j \in$ M. Within or around each hub, several activities are defined:

- Tours in which shipments are collected from shippers in the catchment area of the hub (in the equations below referred to as “collect”).
- Tours in which shipments are distributed to recipients in the catchment area of the hub (referred to as “distribute”).
- Vehicle trips to other hubs in which shipments are sent in order to further distribute them to their recipients from there (referred to as “main run”).
- Reloading of shipments between two of the above mentioned tours (referred to as “reload”).

These activities can be combined in the following sequences:

- Collect – reload – distribute
- Collect – reload – main run
- Reload – distribute

Taking a closer look at these chains of activities, shows that the main run that connects two hubs is tied to the hub of origin. Moreover it shows that a two stop strategy is pursued unless both the shipper and the recipient are located in the catchment area of the same hub.

Selecting the start and end hub by taking the closest one to the shipper respective recipient together with the two stop strategy simplifies the path through the logistic network of the transport company. Along with the selection of the hubs, a capacity check is performed. If the shipment for which an offer is requested increases the payload of one of the involved hubs over the capacity limit, no offer is made. With the shipment being feasible for acceptance in the network and its path known, prices can be assigned to it. Prices depend on the weight of the shipment $q_{s_{if}}$, and the effort caused for transportation. To the shipper, prices have the shape $p_{h_{jo}h_{jd}}\left(q_{s_{if}}\right)$. With h_{jo} being the hub of origin and h_{jd} the hub of destination. This means that for all shipments on the same path the price is set by the same rule that only depends on the weight of the shipment. Prices can thus be looked up by the carrier from a tariff table.

In a market under monopolistic competition, suppliers seek to maximize their profit. Moreover they pretend that they can set the price for their service more or less independently from the other suppliers in the market as they have monopolistic power to a certain extent. Here, the consumer choice modelled by the logit model comes into effect. Shippers do not only choose according to the price, the decision is rather blurred by the parameter α in equation (1). The fuzziness brought into the decision thereby can be as resulting from the unique features of the carrier that his customers know and appreciate but that are hidden to the outside observer. Prices that allow for profits attract other carriers that enter the market in hope for also gaining a share of the willingness to pay. This movement into the market ends in a state where all active suppliers only break even and make no profit.

The model anticipates this state and thus the suppliers charge prices that correspond to their expected marginal costs. Cost components in the model correspond to the activities in and between the hub facilities as outlined above. Every additional shipment is charged for the costs that the activities necessary to handle it cause. In this sense, an activity based costing scheme is applied (see Baykasoglu and Kaplanoglu (2008)). As the acceptance of a shipment also has an effect on the costs for the orders already at hand, the activity based costs can be seen as the marginal costs for the whole set of orders.

The cost components for a single shipment s_{if} are:

- Loading and unloading of shipments at the shippers or recipients premises:

$$c_{handle}\left(q_{s_{if}}\right) \tag{4}$$

With $c_{handle}\left(q_{s_{if}}\right)$ an arbitrary function stating the itemized costs for loading a shipment of size q_{is} on or from a vehicle.

- Reloading a shipment between two transport legs in a hub:

$$c_{reload}\left(q_{s_{if}}\right) = 2 \cdot c_{handle}\left(q_{s_{if}}\right) + \frac{c_{fix,h_{jl}}}{\sum_{s_{kf} \in S_{h_{jl}}} q_{s_{kf}}} q_{s_{if}} \tag{5}$$

With $S_{h_{jl}}$ the set of all shipments running through hub h_{jl}. The second summand in equation (5) assigns the fixed costs for running the hub to the single shipments. Costs and hence prices are depending on the payload of the hub and thus unknown to the supplier at the time of making an offer. This problem will occur at several cost components.

- Collection and distribution of shipments in vehicle tours:

$$c_{collect}\left(q_{s_{if}}\right) = c_{fix\ collect}\left(q_{s_{if}}\right) + c_{approach\ collect}\left(q_{s_{if}}\right) + c_{inter\ collect}\left(q_{s_{if}}\right) \tag{6}$$

$$c_{fix\ collect}\left(q_{s_{if}}\right) = E\left(r_{collect,h_{jl}}\right) \cdot c_{fix,veh_{collect}} \cdot \frac{q_{s_{if}}}{\sum_{s_{kf} \in S_{collect,h_{jl}}} q_{s_{kf}}} \tag{7}$$

$$c_{\ approach\ collect}\left(q_{s_{if}}\right) = E\left(r_{collect,h_{jl}}\right) \cdot E\left(d_{approach,collect,h_{jl}}\right) \cdot c_{dist,veh_{collect}} \cdot \left(\frac{q_{s_{if}}}{\sum_{s_{kf} \in S_{collect,h_{jl}}} q_{s_{kf}}}\right) \tag{8}$$

$$c_{inter\ collect}\left(q_{s_{if}}\right) = \frac{E\left(r_{collect,h_{jl}}\right) \cdot E\left(d_{inter,collect,h_{jl}}\right) \cdot c_{dist,veh_{collect}}}{E\left(\left|S_{collect,h_{jl}}\right|\right)} \tag{9}$$

Equations (6) to (9) hold for both collection and distribution runs. In the latter case, the subscript $collect$ is simply replaced by the subscript $distribute$. The costs are composed of fixed vehicle costs that are assigned to each shipment according to its share of the payload. $S_{collect,h_{jl}}$ is the set of all shipments collected at the corresponding hub in the observed period. The same holds for the trips between the hub and the first respective last customer of the tour. This distance is denoted by its expected value $E\left(d_{approach,collect,h_{jl}}\right)$. To account for the case of vehicles that are only filled to a small part, the assignment is made over all runs from the hub in the observed period. The expected number of collection tours is $E\left(r_{collect,h_{jl}}\right)$.

- Main run between two hubs:

$$c_{main\,run,h_{jo}h_{jd}}\left(q_{s_{if}}\right) = c_{fix\,main\,run,h_{jo}h_{jd}}\left(q_{s_{if}}\right) + c_{dist\,main\,run,h_{jo}h_{jd}}\left(q_{s_{if}}\right) \tag{10}$$

$$c_{fix\,main\,run,h_{jo}h_{jd}}\left(q_{s_{if}}\right) = E\left(r_{main\,run,h_{jo}h_{jd}}\right) \cdot c_{fix,veh_{main\,run}} \cdot \frac{q_{s_{if}}}{\sum_{q_{s_{kf}} \in S_{main\,run,h_{jo}h_{jd}}} q_{s_{kf}}} \tag{11}$$

$$c_{dist\,main\,run,h_{jo}h_{jd}}\left(q_{s_{if}}\right) = E\left(r_{main\,run,h_{jo}h_{jd}}\right) E\left(d_{main\,run,h_{jo}h_{jd}}\right) c_{dist,veh_{main\,run}} \frac{q_{s_{if}}}{\sum_{q_{s_{kf}} \in S_{main\,run,h_{jo}h_{jd}}} q_{s_{kf}}} \tag{12}$$

The values $E\left(r_{collect,h_{jl}}\right)$, $E\left(d_{approach,collect,h_{jl}}\right)$, $E\left(d_{inter,collect,h_{jl}}\right)$, $E\left(r_{main\,run,h_{jo}h_{jd}}\right)$ and $E\left(d_{main\,run,h_{jo}h_{jd}}\right)$ have to be calculated by solving instances of a vehicle routing problem with more or less restrictions.

Several difficulties occur when trying to do this. First, numbers and distances of tours are depending on the number, location and shipment size of the customers as well as on the competition with other suppliers. The more suppliers are active in a region, the more sparsely are one's own customers likely to be distributed and the longer the tours are likely to be. This leads to ever changing cost functions that make the determination of prices difficult. This is mainly due to the fact that resource utilizations like $\sum_{s_{kf} \in S_{collect,h_{jl}}} q_{s_{kf}}$ or $\sum_{q_{s_{kf}} \in S_{main\,run,h_{jo}h_{jd}}} q_{s_{kf}}$ are not known in advance and have to be deduced from former periods. Second, in every iteration two instances of a vehicle routing problem have to be solved for each hub, one for collection and one for distribution. In a market with a set M of suppliers, $2\sum_{j \in M}\left|H_j\right|$ instances of such a problem have to be solved in each iteration. Furthermore, even if the paths taken on the main runs between two hubs remain unchanged, a bin packing problem has to be solved to determine the number of vehicles that is necessary to transport all shipments.

In comparable situations, approximate solutions for the number and distance of tours have been used in the past. These solutions have in common that they regress these figures from samples of the customers (e.g. Figliozzi (2009)). In the present case, tour lengths are approximated by the expected values of the tour components. Route planning is only performed, if the concerned carrier has reason to believe that noticeable changes in the tour patterns happen. This can be the entry of a further carrier in the market, so that the relative density of customers decreases or a considerable change in the number or volume of the shipments that were handed over occurred.

The number of vehicles that is needed is supposed to change more frequently than characteristics of vehicle tours do. Note that the capacity of a carrier is only fixed as far as the facilities are concerned. The number of vehicles, in contrast, is flexible. Otherwise a capacity check had to be performed for each shipment at the time an offer is requested.

The number of vehicles needed for the main run, can be approximated if one assumes that the carrier has already gained experience to a certain extent. In this case, a linear regression is made (c.f. Figliozzi (2009)) with the scaling factor $\tilde{\beta}_{main}$ known and constant:

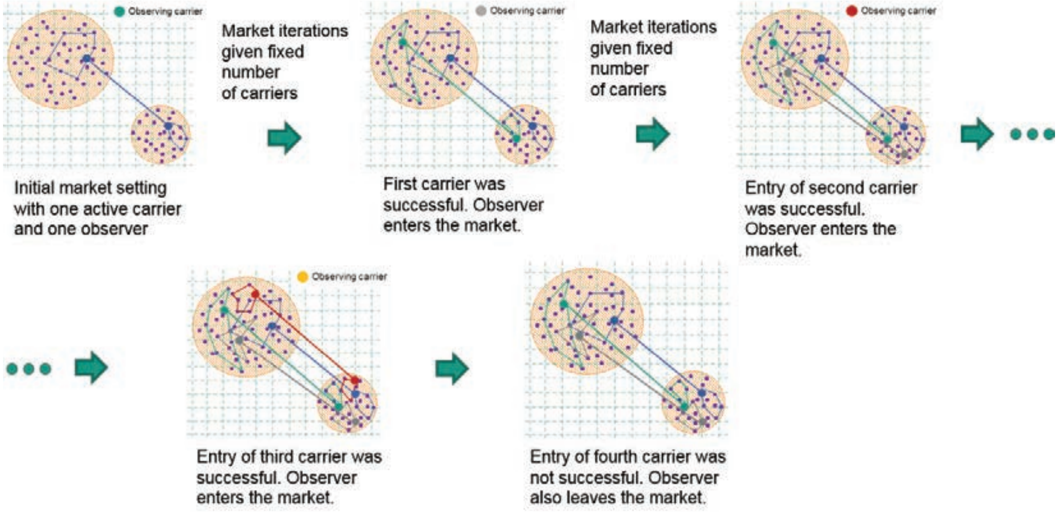
$$E\left(r_{main\,run,h_{jo}h_{jd}}\right) \approx \left\lceil \tilde{\beta}_{main} \frac{\sum_{q_{s_{if}} \in S_{main\,run,h_{jo}h_{jd}}} q_{s_{if}}}{cap_{\ veh_{main\,run}}} \right\rceil \tag{13}$$

Equation (13) also holds for the number of vehicles necessary for collection and distribution, though with different subscripts.

3.3. Endogenous formation of the market supply

As mentioned, the essential feature of monopolistic competition is the endogenous determination of the number of active suppliers. This number is obtained during the course of market interactions. From Fig. 3, it can be seen that the market interactions take place in rounds during which the carriers enter the scene one by one. The set of carriers in each iteration is divided into three different subsets: Incumbent carriers that have been active on the market already in previous rounds, a newcomer carrier that just entered the market at the beginning of the current market round and an observing carrier that decides whether to enter the market in the next round or not. Between two subsequent entries, shippers ask the active carriers for offers and choose them according to the rule stated in equation (1). Thus, two nested loops of market iterations are necessary to determine the supply structure in the market. The iterations, in which a new carrier enters the market are denoted by the superscript ω (see also Fig.4.). Between two iterations ω and $\omega + 1$, demand distributes over the available carriers. This takes several market rounds that are denoted by the superscript $\nu = 1, \cdots, N^{\omega}$. During these market rounds, carriers adjust their costs and hence prices. The first carrier that enters the market in $\omega = 1$ does not know much about the market. Being the first supplier, the assumption that his facilities will be used to capacity is reasonable. For all further cost components $c_{j\,a}^{\omega=1\,\nu=1}$ educated guesses are made. The subscript a denotes the activity that serves as cost driver. Each carrier j is endowed with a set A_j of activities that entail costs. In the course of the iterations cost components are updated according to an exponential smoothing, so that the costs after iteration ν are updated for the following market round:

$$c_{j\,a}^{\omega\,\nu+1} = \lambda c_{j\,a}^{\omega\,\nu} + (1-\lambda)\lambda c_{j\,a}^{\omega\,\nu-1} \tag{14}$$



Initial market setting with one active carrier and one observer

First carrier was successful. Observer enters the market.

Entry of second carrier was successful. Observer enters the market.

Entry of third carrier was successful. Observer enters the market.

Entry of fourth carrier was not successful. Observer also leaves the market.

Fig. 2. Carriers enter the market one by one

The iterations of the inner loop will stop, if the total number of transport orders that are handed over to the active carrier/s does not change beyond a small tolerance. This stop criterion is motivated by the by the variety in shipment sizes which makes changes in total utilization a criterion that can probably inhibit convergence of the market interactions. This criterion is also in line with the master equation model that was outlined in 3.1.

The newcomer in iteration $\omega + 1$ was the observer in iteration ω. Thus he can reasonably be assumed to have examined the market to some extent. This can be seen in Fig. 3., where an observing carrier is placed in the top right corner. The observer from iteration ω enters the market in $\omega + 1$, if the newcomer in iteration was successful, i.e. he did not have to leave the market again. After having decided to enter the market, the newcomer charges the average price that the incumbent carriers did in iteration N^{ω} of loop ω. More formal:

$$p_{new}^{\omega+1\;1} = \bar{p}_{M^{\omega}}^{\omega\;N^{\omega}}\left(q_{s_{if}}\right) \tag{15}$$

All incumbent carriers keep their prices at the same level that they had in iteration $N^{\omega}$of loop ω. As mentioned, the decision of the observer to enter the market in the following round $\omega + 1$ depends on the success of the newcomer in round ω. Success depends on the choices of the shippers, who ask carriers for offers until $\Delta E\left(W_{Ch_{if}}\right)$ does not increase considerably anymore. Shippers distinguish between established carriers and the newcomer. Among the established carriers they ask the one that was in charge for the transport in the previous iteration and some arbitrarily selected others for an offer. If the choice set obtained by the offers from the established carriers is not large enough, the newcomer is also asked for an offer. At the beginning of the interactions, capacities of carriers are small compared with total demand so that some shippers do not find any carrier with free capacity anymore. As the number of active carriers increases, the tendency to ask the newcomer decreases as more and more shippers are satisfied with the choice at hand. As the carriers call cost based prices, the newcomer will become unattractive at some point, as he is too expensive because of the lower total utilization. If his utilization undercuts a threshold value $Q_{t\,min}$ he leaves the market again. The observer sees this and also decides not to enter the market, a decision that ends the interactions.

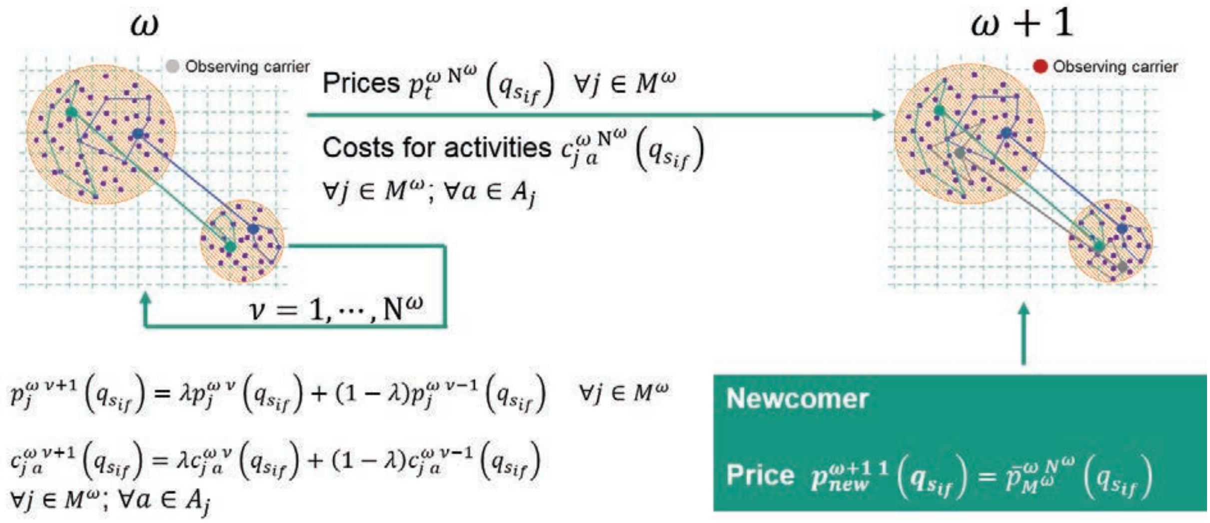


Fig. 3. Iterations of shippers and carriers in detail

Charging cost covering prices and increasing the number of carriers sequentially entails an increase in prices. This is on first sight contradicting to economic concepts as prices usually are supposed do decrease when further suppliers are entering the market. However, the final price $p_t^{\Omega\,N^{\Omega}}\left(q_{s_{if}}\right)$ for any shipment can be seen as a measure of willingness to pay of the shippers. This price reflects the amount that shippers want to spend on transport services given the choice set at hand. Thus the preference for variety is already factored in. This means that the first active carrier could charge a price higher than $p_{t=1}^{\omega=1\,\nu}\left(q_{s_{if}}\right)$ as he has monopolistic power but lower than $p_t^{\Omega\,N^{\Omega}}\left(q_{s_{if}}\right)$ as there is no variety from which the shippers can profit.

This has implications for policy measures, that usually are positioned on the level of the traffic operations, and their assessment. Given a market under monopolistic competition, the level of supply can be determined for which the shippers are willing to pay. After having implemented the policy measure, it can be tested if adaptations of supply can prevent their results from reaching the shippers whose behavior is the actual target.

3.4. Extension to multiple regions

This setting can be extended to multiple regions. In this case, two further aspects have to be addressed.

1.) Traffic now takes place in both directions.

2.) Multiple lanes can start and end at each hub facility.

When shipments are travelling in both directions, imbalanced flows are likely to occur. This can have implications on the number of vehicles that have to be held available in both regions. It is determined by the stronger one of the two flows. If in a lane that connects two regions o and d the flow from o to d is the stronger one, the number of vehicles needed in the two regions is $E\left(r_{collect\ h_{jo}}\right)$ and $E\left(r_{distribute\ h_{jd}}\right)$. This results from the assumption that the shipments are collected and distributed in both regions at the same time. For the sake of simplicity, it is assumed that there is only one vehicle type (indexed by veh in equation 16) in use.

The assignment of collection and distribution costs thus changes in comparison with equation (6). For the shipments from o to d the share of fixed costs is:

$$c_{fix\ collect\ h_{jo}}\left(q_{s_{if}}\right) = c_{fix,veh} \cdot \frac{2 \cdot \left[E\left(r_{collect\ h_{jo}}\right) - E\left(r_{distribute\ h_{jo}}\right)\right] + E\left(r_{distribute\ h_{jo}}\right)}{2 \cdot E\left(r_{collect\ h_{jo}}\right)} \tag{16}$$

and for the opposite direction:

$$c_{fix\ distribute\ h_{jo}}\left(q_{s_{if}}\right) = c_{fix,veh} \cdot \frac{E\left(r_{distribute\ h_{jo}}\right)}{2 \cdot E\left(r_{collect\ h_{jo}}\right)} \tag{17}$$

For the allocation of fixed costs in facility h_{td} the same allocation formulas hold so that the flow in the stronger direction has to cover the full fixed costs for the additional vehicles that are needed.

For the main run it is assumed that the two regions o and d are too far apart so that only the main run in one direction can be performed within the given time window. Such a time window could for example be the result from the requirement for overnight delivery. Thus the number of vehicles needed for the main run is $2 \cdot E\left(r_{main\ run,h_{jo}h_{jd}}\right)$ that is twice the number of vehicles needed to serve the stronger flow. Cost allocation is the same than in equations (16) and (17).

If one assumes that shipments are collected at the same time in both regions (e.g. in the late afternoon or early evening) and distributed some hours later (for example in the case of overnight delivery), the capacities of hub facilities do not have to be extended as the flows of each direction use space that would otherwise be idle. Nevertheless, additional staff has to be hired for a second shift in each of the facilities, so that $c_{fix,h_{jl}}$ from equation (5) increases for every hub facility. Costs are assigned to each direction based on the share of overall weight.

The behavior of shippers in a setting with multiple regions does not change remarkably. Despite the complete spatial setting, they only choose carriers from the region in which they are located. This is necessary to retain the notion of a lane as a market. All other things remain the same, especially the rules for the formation of the choice set.

Carriers can now serve lanes between all pairs of regions. As before, the lanes start and end in hub facilities. Each carrier maintains at most one hub h_{jl} in each region l at which all lanes start and end. If only one lane starts and ends in h_{jl}, its capacity is cap, as in the case with only two regions. For each additional lane, a capacity increment Δcap is added that causes fixed costs $c_{fix\ \Delta cap,h_{jl}}$. Cost allocation in the case of multiple regions considers again fixed hub costs and the number of vehicles that are necessary for collection and distribution. In the case of fixed hub costs each lane has to cover $c_{fix\ \Delta cap,h_{jl}}$. Assignment to both lanes is also done according to the weight share.

The number of vehicles that are needed for collection and distribution is determined by the sum of the stronger flows of all lanes that are incident to a hub facility. Every lane then has to cover the costs that correspond to their weight share. Within each lane, costs are assigned again according to equations (16) and (17).

Looking at both sides of the market, it can now be said that the lanes can be seen as own market segments of which some are connected by common cost functions for collection and distribution tours. This has implications on the entry of new carriers, which now happens on the basis of single lanes. As before, there are again established carriers, the newcomer and an observer present in each iteration ω (see Fig. 4.). In $\omega = 1$ the first carrier enters all lanes. During the following iterations of ω later entrants also enter all lanes until the entry on the lane with the lowest demand or preference for variety is not successful anymore. In this case, the newcomer only leaves this lane again and the observer only enters the remaining lanes. The lane is now seen to be closed for further entries by the carriers. This goes on until all lanes are closed.

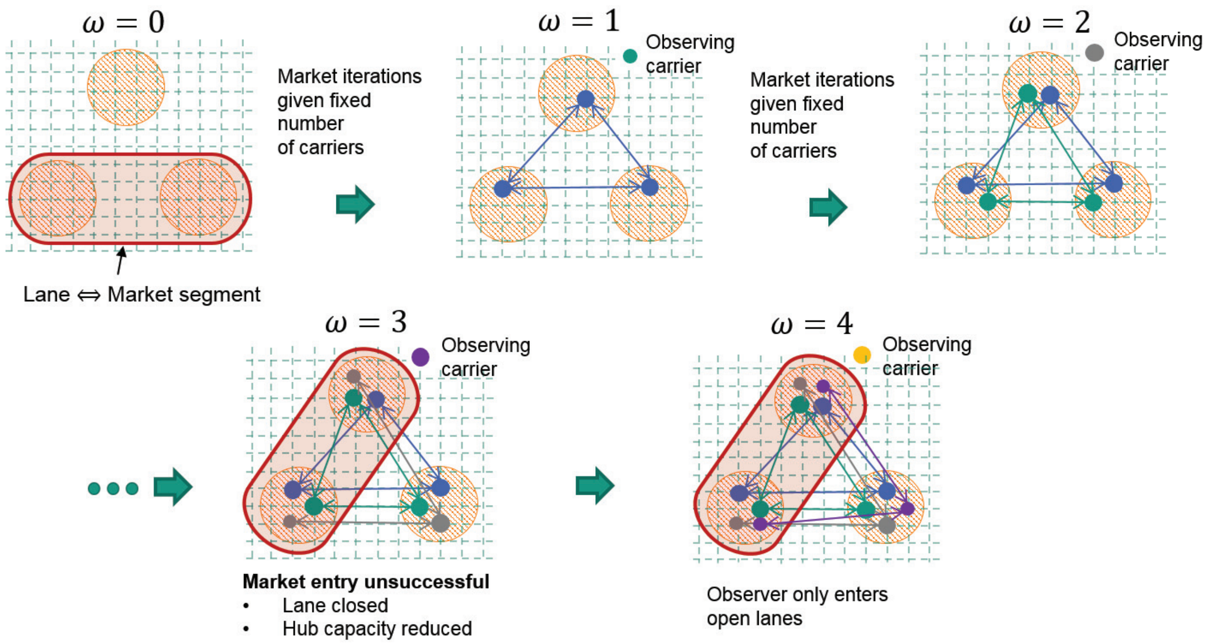


Fig. 4. Sequential entry of carriers in multiple lanes

4. Conclusions

A framework on how to incorporate market interactions that allow for the explanation of supply structures in urban freight transport has been set up. Supply and demand agents have some capabilities to act autonomously. When applying the model to the market segment of general cargo, spatial meso structures of transport supply could be derived. First, the base scenario in situations where the transport market consists of unregulated private companies can be described. If a policy measure is applied that is reflected in a change of the cost structure of transport companies, their number and capacity utilization will change. Thus, a model in which fiscal effects of policy measures not only are handed on to the shippers but in which also the supply structure changes in a way that is visible to the observer, can be set up.

The model uses existing concepts from transport economy and transport modeling and combines them to gain a closed model of a transport market with emergence phenomena. Some aspects that are less relevant are addressed by approximation, such as the characteristics of vehicle tours. Emergence results on the level of aggregated demand to which the single shippers contribute according to their preferences. As single shippers are assumed to send small shipments compared to the size of a vehicle, transport companies base their decision to enter or leave them market only on aggregate demand figures. This procedure aims for the maximization of the overall welfare on the market, although single shippers have to accept welfare losses.

However, previous knowledge on the area of operation and the demand there are assumed on the side of the transport companies in order to shorten calculation time and keep the model simple. A gradual decrease in the use of such assumptions in favor of more autonomy of the agents would add to the touch of the model with reality. Also, steps have to be taken towards an empirical foundation of the model, so that it can be applied to a real urban scenario. Demand representations of some urban areas have been developed in the past (e.g. Wisetjindawat et. al. (2007), Gentile and Vigo (2013)). However, data on the supply side in the transport market is still scarce and the various competing companies are expected to be very heterogeneous.

Further extensions are the application in a model covering a seamless world. Moreover, monopolistic competition actually incorporates profit maximization on the side of the suppliers. This quest for profit takes place in an environment where each supplier does not have a direct opponent nor is completely independent from others. Thus suitable methods have to be found that enable the carriers with the capability to explore their environment and react to actions of the collective of competitors without addressing single opponents.

References

Adler, N., 2005. Hub-Spoke Network Choice Under Competition with an Application to Western Europe, Transportation Science, 39 (1), 58–72

Anderson, S.P., De Palma, A., Thisse, J.-F., 1992. Discrete choice theory of product differentiation, MIT Press, Cambridge

Baindur, D., Viegas. J.M., 2011. An agent based model concept for assessing modal share in inter-regional freight transport markets, Journal of Transport Geography, 19, 1093–1105.

Baykasoglu, A., Kaplanoglu, V., 2008. Application of activity-based costing to a land transportation company: A case study, International Journal of Production Economics, 116, 308–324.

Carrillo, D.G., 2011. Demand and supply interactions in transport models: The case of hinterland transportation, Karlsruher Beiträge zur Wirtschaftspolitischen Forschung, 31, Nomos, Baden-Baden

Carrillo, 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

Catullo, E., 2013. An Agent Based Model of Monopolistic Competition in International Trade with Emerging Firm Heterogeneity, Journal of Artificial Societies and Social Simulation, 16 (2), 7

Cavalcante, R. A., 2013. Freight Market Interactions Simulation (FREMIS): An Agent-Based Modelling Framework, Phd- thesis, Graduate Department of Civil Engineering, University of Toronto

Dimitriou, L., Stathopoulos, A., 2009. Optimal Co-evolutionary Strategies for the Competitive Maritime Network Design Problem, In M. Giacobini et al. (Eds.): EvoWorkshops 2009, LNCS 5484, pp. 818–827

Dixit, A., K., Stiglitz, J. E. (1977). Monopolistic Competition and Optimum Product Diversity, American Economic Review, 67 (3), 297-308

Figliozzi, M. A., 2004. Performance and Analysis of Spot Truck-Load Markets using sequential auctions, Phd- thesis, Faculty of the Graduate School, University of Maryland

Figliozzi, M., A., 2009. Practical Approximations to Quantify the Impact of Time Windows and Delivery Sizes on VMT Multi-stop Tours, Civil and Environmental Engineering Faculty Publications and Presentations, Paper 99, *http://pdxscholar.library.pdx.edu/cengin_fac/99* accessed on 08 Dec 2014

Gentile, G., Vigo, D., 2013. Movement generation and trip distribution for freight demand modelling applied to city logistics, European Transport \ Trasporti Europei, 54(6), Paper n° 6

Helbing, D., 2010. Quantitative Sociodynamics, Stochastic Methods and Models of Social Interaction Processes, Springer-Verlag, Berlin, Heidelberg

Holguin- Veras, J., 2000. A Framework for an Integrative Freight Market Simulation, 2000 IEEE Intelligent Transportation Systems Conference, 1-3 October 2000, Dearborn (MI), USA

Krajewska, M.A., Kopfer, H., 2009. Transportation planning in freight forwarding companies, Tabu search algorithm for the integrated operational transportation planning problem, European Journal of Operational Research, 197(2), 741-751.

Lee, H., Boile, M., Theofanis, S., Choo, S., Lee, K.-D., 2014. A freight network planning model in oligopolistic shipping markets, Cluster Computing, 17 (3), 835-847

Mes, M., 2008. Sequential Auctions for Full Truckload Allocation, Phd- Thesis, University of Twente, Enschede.

Nagurney, A., 2010. Supply Chain Network Design Under Profit Maximization and Oligopolistic Competition, Transportation Research Part E: Logistics and Transportation Review, 46 (3), 281-294

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, 18-31

Schoemaker, J., Allen, J., Huschebeck, M., Monigl, J., (2006). Best Urban Freight Solutions II, Quantification of Urban Freight Transport Effects, *http://www.bestufs.net/download/BESTUFS_II/key_issuesII/BESTUF_Quantification_of_effects.pdf*, accessed on 23 May 2014

Tesfatsion, L., 2006. Agent-Based Computational Economics: A Constructive Approach to Economic Theory, In: Tesfatsion, L., Judd, K.L. (Eds.) Handbook of Computational Economics, Volume 2 Agent- Based Computational Economics, pp. 831-880, North-Holland

Weidlich, W., 2006. Sociodynamics, A Systematic Approach to Mathematical Modelling in the Social Sciences, Dover Publications, Mineola

Wisetjindawat, W., Sano, K., Matsumoto, S. and Raothanachonkun, P., 2007. Micro-Simulation Model for Modeling Freight Agents Interactions in Urban Freight Movement, 86th Annual Meeting of the Transportation Research Board, January 21-25, 2007. Washington D.C.

Wooldridge, M., Jennings, N.R., 1995. Agent theories, architectures, and languages: A survey, In Wooldridge, M., Jennings, N.R. (Eds.), Intelligent Agents, ECAI-94 Workshop on Agent Theories, Architectures, and Languages Amsterdam, The Netherlands August 8–9, 1994 Proceedings