INTEGRATED SIMULATION OF TOUR PATTERNS AND TRANSPORT TARIFFS

Li Zhang, Institute for Economic Policy Research (IWW), Karlsruhe Institute of Technology, Germany, Email: li.zhang@kit.edu

Gernot Liedtke, Institute for Economic Policy Research (IWW), Karlsruhe Institute of Technology, Germany, Email: gernot.liedtke@kit.edu

ABSTRACT

The long-distance truckload general freight trucking market is an important market segment of freight transportation. The market price on each lane (interregional transportation relation) is dependent on the demand and supply of transportation service not only on that transportation relation (economies of scale), but also on the related lanes (economies of scope), as carriers drive round tours. On the demand side, the shippers (or 3PL providers) try to find the most cost-efficient service provider in the market. On the supply side, the carriers maximize their profit by increasing the operational efficiency. This coordination process in the market leads to efficient tours and the transportation demands are fulfilled. However, market opacity and transaction costs have a negative impact on the allocation process. Our paper addresses this problem and proposes a computational model simulating the interactions between carriers and shippers in the transport service procurement process. The individual optimization behaviours and the market mechanism are taken into account in the simulation. As results, a price matrix and tour patterns are derived.

Keywords: long-distance truckload general freight trucking market, supply and demand, shippers and carriers, efficient tours, individual optimization behaviour, market mechanism, monopolistic competition, interregional price matrix

INTRODUCTION

The long-distance truckload (TL) general freight trucking market is one of the important market segments in the trucking industry. The name contains its three important attributes: long-distance, truckload and general freight, which need to be understood before investigating this market segment. Long-distance (or long-haul) indicates interregional transportation services, in contrast with urban logistics. The destination of the shipment is more than 150 km from the home base (Federal Office for Goods Transport, 2011). In a truckload shipment, a truck is dedicated to a single shipment moving from an origin to a destination, in contrast with less-than-truckload (LTL) and parcel service, which consolidate many small shipments on a single truck. General freight relates to a wide range of commodities, generally palletized and transported in a container or van trailer. It doesn't need special transportation vehicles or handling equipment, in contrast with special freight or dangerous freight. In general, the long-distance TL general freight trucking market handles the interregional TL transportation of general commodities (Liedtke 2004; Babani 2011).

Contractual agreement is the most popular governance structure in the service procurement process of this market segment. Auction is widely used by the shippers to find the most cost-efficient service provider, which leads to an annual contract between the shipper and the winning carrier at the end of the auction. Besides price, level of service is also an important decision factor for the shipper. On the other hand, carriers try to sell their transportation capabilities through bidding. Due to product differentiation (expressed by spatial differences in transportation service and differences in level of service) and free market entrance/exit, the market form of the long-distance truckload sector could be considered as monopolistic competition. In such a market, the optimal bid price of a carrier should correspond to the real cost of serving the specified lane. The cost of serving a lane is dependent on the distribution of other lanes in the carrier's network, as the transportation service is provided through driving a closed loop tour by the carrier. The carrier, which can combine the newly offered business with its existing business to create favourable tour patterns, can submit a lower bid price and thus win the lane. The carrier, which has a high repositioning cost when executing the additional newly offered business, can only submit a relatively high bid price and probably lose the lane. The price mechanism and the market competition ensure that carriers win the lanes that fit their network and thus avoid misallocation. In the end, each carrier has a relatively balanced network and an efficient resource allocation is achieved. The fact that the portion of empty movements accounts for only 10% of the total transport performance in the long-haul sector (Federal Office for Goods Transport, 2011), complies with our conclusion. We should point out that this carrier allocation problem is solved in practice through the market, where self-interested shippers and carriers are doing their business and optimizing their operations.

To simulate the market price in equilibrium on interregional lanes and the resulting long-distance freight movements, we could simulate the individual decision makings of all the market participants and their interactions in the transportation procurement process. However, this approach is infeasible due to the lack of data and the complexity of solving numerous optimization problems. Our paper addresses the market equilibrium problem and suggests a simplified simulation procedure, which simulates tour construction, price calculation and bidding in an integrative way. Our model takes account of the interactions between shippers and carriers in the transport service procurement process, their optimization behaviours and the market mechanism. We have tested our model on the interregional transportation lanes in Germany. As results, a price matrix in equilibrium reflecting the interregional price difference serves as reference price for both shippers and carriers. And the resulting tour patterns help us to understand the long-haul vehicle movements.

RELATED LITERATURE

Holguín-Veras (2000) points out that to model the freight movements the transportation market should be first understood, as the freight transportation involves many firms, which play different roles in the market. He suggests a bi-level approach to understand the urban freight movements. In the top level the transportation performance (including loaded and empty kilemeters) of each carrier consistent with a Cournot equilibrium is estimated. And then, the bottom level focuses on the construction of tours that satisfy the Cournot solution and the remaining system constraints. The especial contribution of this paper lies in the application of market mechanism in the research of freight movements. Liedtke (2009) provides a bottom-up approach to freight modelling, in which logistics structures are created endogenously by simulation, in contrast with traditional freight models, in which logistics structures are deduced from aggregate statistics. In the sub module transport market simulation, the author differentiates the contract awarding at the tactical decision level and the tour planning at the operational decision level and models them sequentially. However, the bid price calculation in contract awarding and the "en-route pickup and delivery" in tour planning are both very complex.

Another strand of research addresses the auction mechanism design and the application of internet-based platform in the procurement of transportation service. An intensively study area is the combinatorial auction. Sheffi (2004) depicts the procedure, the status quo and benefits of using combinatorial auctions in the procurement of transportation services. Combinatorial auction prevents complementary lanes from being assigned to different carriers and exploits the economies of scope inherent in the carrier's TL operations. Especially large shippers are more likely to use combinatorial auctions. These shippers can save 3 to 15 percent of transportation costs, while improving and maintaining their service levels. Song and Regan (2003) examine the benefits of combinatorial auctions primarily from the carrier's perspective. The two problems implied in combinatorial auction, bid generation and winner determination are formulated as set partitioning problems and then solved using an approximation method. On the basis of a simple simulation model consisting only one shipper and two carriers, carriers can achieve a cost reduction of empty movements from 2% to 14%, in comparison with sequential single item auction. The paper by Caplice and Sheffi (2003) addresses the problem, how shippers should procure TL motor carrier transportation services. It explains the advantages of conditional bidding and optimization-based procurement to the shipper in theory and practice. In theoretical formulation, the optimization function of a shipper is to minimize the summed cost of all contracted carriers. An important message is that, the shipper should take the carrier's economies of scope into account in the auction design and bid analysis. Song and Regan (2001) examine the benefits and drawbacks of online transportation intermediaries to the carriers, shippers and traditional 3PL providers. This strand of studies focuses on how the purchasing of transportation service is carried out nowadays or should be done in future. Both sophisticated auction design and application of advanced information technology have improved the information transparency and facilitated an efficient resource allocation. We can conclude that, with this advanced mechanism and technology carriers can have a more balanced network and shippers reduced their transport expenditure.

TRANSPORT MARKET SIMULATION

Service procurement process

Caplice (1996) summarizes three governance structures used by shippers and carriers to realize a procurement process: private fleet, spot market and contractual agreement. In the case of private fleet, the shipper has the direct control of the operations of carriers. Private fleet are usually less efficient than on-hire carriers. In spot market, shipper and carriers can exchange additional loads and excessive capacity. A drawback of spot market is the high planning and transaction cost, since the shipper needs additional efforts to evaluate carriers' reliability and performance for each deal (Caplice 1996). As a result, it is limited to match irregular loads and excessive capacity. The focus of our paper is contractual agreement, which is the most popular governance structure in the procurement process of transport service. In this case, shippers use annual auctions to procure transportation service, leading to annual contract. Through a contract, a stable relationship between shipper and carrier exists for a year (or two years) and a reliable transportation service can be guaranteed compared with spot market. In the rest of this subsection, the procurement process of the contract market is illustrated microscopically.

In the microscopic level, a numerous number of shippers (also 3PL providers) and carriers are the actors in the market. Shippers procure transportation services on a single or multiple lanes annually in the market. They try to find the most cost-efficient service provider in the market using annual auctions (including auction for a single lane or combinatorial auction for a package of lanes). Besides the price, the service level (non-price parameters) is also a factor in the decision making process. Carriers, as service providers, sell their transport capabilities by bidding. They should submit a relatively low bid price in order to win the auction. However, the bid price should not be too low to cause a deficit. Therefore, the optimal bid price should correspond to the real cost of providing the specified transportation service.

In difference with general goods and services, the provision of transportation service of a carrier is not based on a one-way movement, but on driving a round tour. Due to this special characteristic, the cost of carrier is more influenced by the economies of scope than the economies of scale (Sheffi, 2004). The cost of a lane is thus not only dependent on the number of shipments on that lane (economies of scale), but more influenced by the number of shipments on the related lanes in the carrier's network (economies of scope). In other words, if the carrier can find a load in the opposite direction or can balance its network, it should submit a lower bid price. If it is difficult to find a return load and the load just exacerbate the carrier's resource utilization, it should submit a higher bid price. Through this price mechanism in the auction, a lane is always allocated to a cost-efficient carrier, and hence optimal resource utilization is achieved. In the long-haul trucking sector, the empty kilometer accounts for only 10% of the total transport performance and thus the resource allocation is especially efficient (Federal Office for Goods Transport, 2011). In contrast with urban transport, the tour patterns in long-distance TL sector are relatively simple. And this gives us incentives to simulate bidding and (potential) tour construction in a combined way.

Market form

The market form of long-distance TL general freight market is monopolistic competition. According the annual report of Federal Office of Goods Transport (2012) there are 49,676 registered transportation service providers in the market and 53% of them operate with less than 4 vehicles. It's not oligopoly, because die decision of a single carrier hat negligible effects on the decisions of other carriers and thus on the overall market price. It is also not perfect competition, because each carrier differentiates its service provision with its competitors. The spatial heterogeneity of transportation service and the level of service are two forms of product differentiation. Sheffi (2004) points out that on-time performance (both transportation time and response time), familiarity with the shipper's operations, availability of the right equipment, assessorial services, pick-up performance and ease of doing business are indicators for level of service.

Besides product differentiation, another typical characteristic of monopolistic competition, free market entrance and exit for carriers, can also be identified. Due to the existence of the truck leasing market, the market entry and exit for a carrier is relatively free. When the market is profitable, more carriers enter the market and the market price drops down. When the market price is low, some carriers can not operate with cost recovery and must exit the market, and then the market price rises up. In the end of the process, a market price in equilibrium and each carrier operates in a just cost-recovery manner and has a very thin profit margin (Federal Office for Goods Transport, 2011).

As a result, the TL carriers have a certain freedom to set the price but not much. They must also compete for the same shipper in the market. It should be pointed out that large carrier and smaller carriers have different positions in the market competition. Large carriers have nationwide network coverage and modern IT systems and thus are able to provide high service level. As a result, they can charge the shipper with a higher price. However, the small carriers normally concentrate on local areas and compete with each other more on price.

Mathematical formulation of the carrier allocation problem

Traditionally, the carrier allocation problem is formulated as a minimization problem, whose objective function is to minimize the total transportation cost in the TL sector. Through competitive mechanism of the market and the internal optimization behaviours of shippers and carriers, a lane or a bundle of lanes is allocated to a carrier, which can operate it in a most efficient way. A lane and its opposite direction are more likely allocated to the same carrier, which can combine the two lanes in a shuttle tour, than to two different carriers, each of which has an empty backhaul potentially. As a result, the carrier allocation problem can be formulated as an optimization problem as follows:

$$\min \sum_{k} C^k(X^k)$$

Subject to

$$\sum_k X^k = D \qquad (1)$$

$$X^k \in F^k \qquad (2)$$

Where:

X^k: $n \times n$ matrix of truckloads for each lane assigned to carrier k, each item in the matrix denoted as x_{ij}^k representing the amount of truckloads for the lane from i to j,

$C^k(X^k)$: Cost function for carrier k to serve the matrix of lanes X^k,

D: $n \times n$ matrix of truckloads for each lane demanded by all the shippers in the market,

F^k: The set of feasible lane allocation and truckload assignment of the carrier k.

Constraint (1) ensures that each lane is served by a carrier. Constraint (2) specifies the volume allocation of lanes is feasible for the carrier. This feasibility relates to the capacity (including equipment and driver), the operational feasibility (each TL for each lane is included in a tour) and the preferred service area of a carrier.
In praxis, this optimization problem is solved by various carriers and shippers in a distributed way. The competitive mechanism in the market and the internal optimization of self-interested firms ensures that a suboptimal allocation would be found. Only the carriers, which build efficient tours and have a relatively balanced network, could exist in the market. However, market opacity and transaction costs have a negative impact on optimum finding process. As a result, a suboptimal solution containing latent excess capacity is achieved through the real market coordination process. This suboptimal solution is in fact not the most efficient resource allocation, but approximates to the optimal solution. We can image, if there is only one carrier in the market, the optimal mathematical solution is identical with the solution found by the market in a distributed way. Our simulation procedure, which will be introduced in the following section, models this optimum finding process as a market equilibrium problem.

Integrative simulation of tour construction, profit calculation and bidding

As noted before, the optimal carrier allocation problem is solved in the practice through the interactions of numerous shippers and carriers in the market. In this paper, we propose a simplified simulation model to build tour construction, profit calculation and bidding in an integrated way. The strategies of shippers and carriers are specified as follows.

Strategies of the shippers:

- Each shipper has a given and fixed transport demand (fixed shipment sizes, fixed frequencies) on one up to several transport relations.
- For each regular shipment, shippers conclude a transport contract with a carrier.
- If a transport contract expires, the tariff is beaten down by 10%.
- If the carrier accepts the new tariff, the contract is prolonged. Otherwise, the willingness to pay is incremented step by step until a transport company accepts the contract.

Strategies of the carriers:

- In each region, there is a potential carrier.
- Using random drawing, the carrier constructs tours (shuttle tours, triangle tours, simple quadrangular tours) bundling several shipment cases that are currently on

the market (all transport contracts that will expire soon). The carriers ask the responsible shippers for their willingness-to-pay. A tour is constructed, if the tariffs for all transport cases on that tour allow for recovering the full tour cost.

- Cost coverage of the existing tours is continuously monitored. If the revenues do not allow for the full-cost coverage, the tour is closed down (special termination of the transport contracts).

In this approach, the carrier constructs an initial tour from the open queries of the shippers in the transport market. The decision criterion of bidding is the profitability by calculating the revenue of all shipments in the tour subtracted by the total cost. If a tour is profitable, the carrier bids all the shipments in the tour and wins the bid. Otherwise, it gives the turn to the next carrier who carries out the same procedure, until all the open queries are allocated. In a round of each carrier, the tour construction, profit calculation and bidding are carried out simultaneously. For this reason we call our approach as integrative simulation of tour construction, profit calculation and bidding. This integrative approach guarantees that each carrier has a balanced network and thus high resource utilization. It also ensures that each shipment is allocated to a tour of a carrier and each tour is profitable. In the course of the iterations, the rate of a lane approaches to the carrier's costs operating that lane, as the carrier submits a bid based on its cost calculation. The cost comprises not only the direct cost operating that lane but also the cost for a possible deadhead for the carrier to return to the home base. As a result, a carrier's cost to serve a single lane is also affected by the other traffic movings throughout its network (economies of scope).
The market price of each lane stabilizes through two counter forces: the shipper beating the tariff for transport cost reduction and the carrier executing only tours with full cost recovery.
To simulate the market price on a lane, we have considered the tour construction and cost calculation of the individual carriers in the market. In our model, market price on a lane is not only dependent on the number of TL shipments (loads) on that lane in the market (economies of scale). To a much greater extent, it is influenced by the number of loads on other, related lanes (economies of scope) due to the integration of tour construction, profit calculation and bidding.

IMPLEMENTATION

Algorithm

An evolutionary algorithm is developed to get the market price in equilibrium. The algorithm is realized through two nested iteration. The outer iteration iterates on all the shippers whereas the inner one on all the carriers. In the first outer iteration, the shippers start with a high willingness to pay for all their shipments. This starting willingness to pay can be interpreted as the initial market prices which need to be justified through iterations. In the following iterations, the shipper beats the prices by 10% on the basis of the last iteration. When the market price of all lanes varies within in a defined threshold iteration by iteration, the simulation can be shut down and we obtain the market price of the lanes.
The task of inner iteration is the allocation of the open queries to tours (Figure 1). Open queries come from two sources. The first is the shipments that have never planed in a tour of any carrier. The second results from that the shippers beat the prices and the related unprofitable tours are dissolved by the carrier. As a consequence of that, the shippers must then put the shipments back to the transport market and find another carrier willing to make

the deal. After finding out all the open inquiries, the algorithms then iterates on all the carries. A carrier is randomly selected and plans a tour from open queries in the market. We assume that the historically executed but due to cost dissolved tours have a higher priority. If a tour is profitable, the carrier bids all the related shipments in the tour and wins the bid. These shipments must then removed from open inquiries and transferred to a confirmed tour of the carrier. Otherwise, it gives the turn to the next carrier who carries out the same procedure, until all the open queries are allocated. If there are still open queries in the market and no carrier is willing to bid, the related shipper is informed to raise the willingness-to-pay for a successful allocation. The market price is updated after each tour acquisition. In the end, no open inquiries remain and the market demand is fully satisfied.

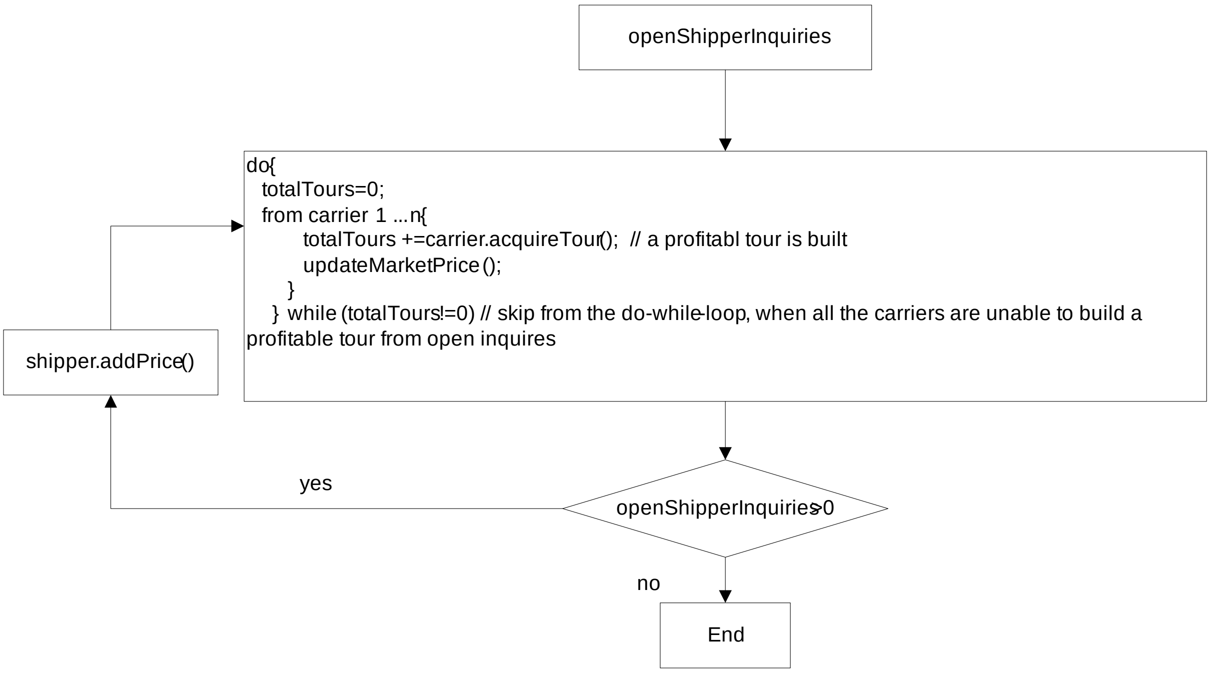

Figure 1 - flow diagram of inner iteration

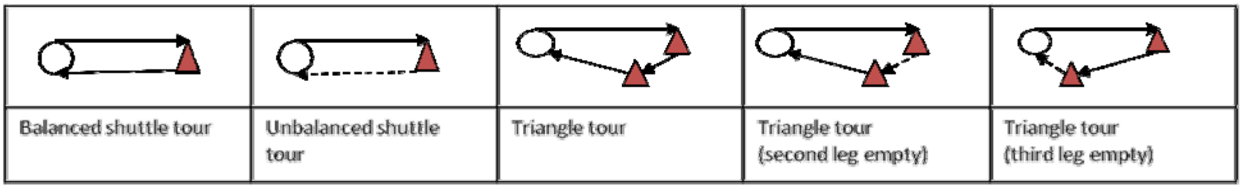

Figure 2 - tour types

Implementation

We have implemented the aforementioned algorithms in Java. The Figure 3 shows the class carrier and its associated classes. Tour construction (class TourConstructor) and profit calculation (class ProfitCalculator) are two important tasks for a carrier. Class MarketObserver and MarketUpdater are for the communication interface between the market and the carrier.

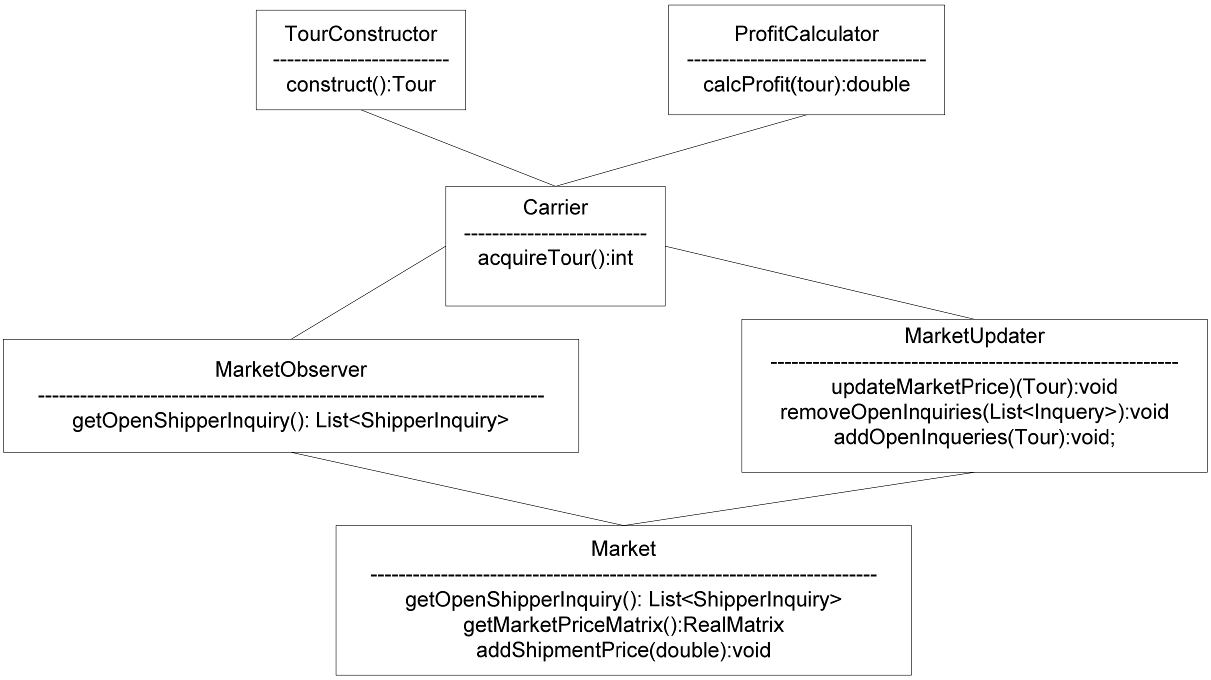

Figure 3 part of class diagram

We should note that the tourConstructor in our implementation is not for solving a vehicle routing problem, where the demands for all customers must be satisfied through tours. In our case, a carrier can decide to build a tour or not. The carrier does not need to satisfy all the demands in the market. It just builds a profitable tour and gives the control to the next carrier.
Carriers can apply different strategies in the tour construction. The first aspect of a strategy is the time of decision making. A carrier can confirm the first profitable tour during the searching process (ProfitFirst) or the most profitable tour after a complete searching process (ProfitMax). The second aspect is the preference. A carrier would have a preference to construct tours from some dedicated shippers (ShipperPreference). So a tour containing shipments from these shippers is better evaluated in the decision process. Or a carrier prefers to build tours only within a certain region, so only the shipments in that region are of interest (RegionPreference). Or the carrier has a memory of the executed tours in the history. These tours are preferred to rebuild for the next time (HistoryPreference). In our implementation we have chosen the ProfitFirst+HistoryPreference strategy to reach the equilibrium (stable market price and number of tours) in relatively short execution time. We have also introduced parameters indicating the extent of market transparency or transaction cost, for example, the percentage of dissolved well-structitours for the next interaction and the matching restrictions in the tour construction.
In the current version, a carrier builds only one tour and then the next carrier has the control. In future, this can be replaced with thread technologies. Each carrier has a thread. And all

threads (representing all carriers in the market) compete on the transportation market. And the synchronized object is the open inquires in the market. Two carriers cannot include the same open inquiries and the capacities of carriers should also be considered when a carrier makes a tour. Furthermore, carrier can have different market visibility. Only a part of the open inquiries in the market are visible for the carrier, which reflects the business connectivity of the carrier.

APPLICATION

Data

The German office for freight traffic (KBA) records all trips of a randomly chosen lorry for an observation period of a half week. In the year of 2002, 1.7 millions empty and loaded vehicle-trips are traced. According to the characteristics of logistical operations, 11 tour types are considered to be representative. Each trip or tour is assigned to a unique tour type with a fuzzy clustering algorithm (Liedtke 2006, Babani 2011). Then, the trips for the long-distance TL general freight market are extracted (using criteria such as the aforementioned tour type, commodity type, vehicle style, package form) and the transport demand for the submarket is built with a 40*40 matrix (40 NUTS2[1] regions in Germany). The detailed description of data preparation can be found in Babani (2005) and Hannemann (2007). The Table 1 presents a part of transport demand matrix, in which each item presents the number of long-distance TL trips between 2 NUT2 regions in a half week. Our opinion is that the length of considered time horizon doesn't influence the resulting price matrix. In future, we plan to change the considered time horizon and show the corresponding sensibility of the price matrix.

Table 1 - Interregional demand matrix

sum of flows	destination									
origin	DE11	DE14	DE21	DE22	DE23	DE24	DE25	DE26	DE27	DE40
DE11		261	107	32	28	31	45	35	46	7
DE14	261		48	14	13	14	20	16	21	3
DE21	94	42		199	174	190	277	218	285	38
DE22	28	12	199		52	57	83	66	86	12
DE23	25	11	174	52		50	73	57	75	10
DE24	27	12	190	57	50		80	63	82	11
DE25	39	17	277	83	73	80		91	119	16
DE26	31	14	218	66	57	63	91		94	13
DE27	40	18	285	86	75	82	119	94		17
DE40	36	16	37	11	10	11	15	12	16	

We define the InOutRatio of a region i as the total number of trips ending in the region I divided by the total number of trips starting from the same region.

$$InOutRatio_i = \frac{\sum_j \varphi_{ji}}{\sum_j \varphi_{ij}}$$

where,

φ_{ij}: the number of trips between NUTS2 regions i und j.

The value of $InOutRatio_i$ has the following meanings:

- $InOutRatio_i > 1$: the region is a sink.
- $InOutRatio_i \approx 1$: the region has balanced inbound and outbound freight traffic.

[1] NUTS stands for Nomenclature of Territorial Units for Statistics, see http://en.wikipedia.org/wiki/Nomenclature_of_Territorial_Units_for_Statistics

- $InOutRatio_i > 1$: the region is a source.

The Figure 4 shows the InOutRatio for NUTS2 regions. We can see several NUTS 2 regions can be identified as strong sinks or sources concerning the long-distance cargo flow. Our price matrix in the following subsection will show how the imbalanced freight flow influences on the transport price on the related lanes.

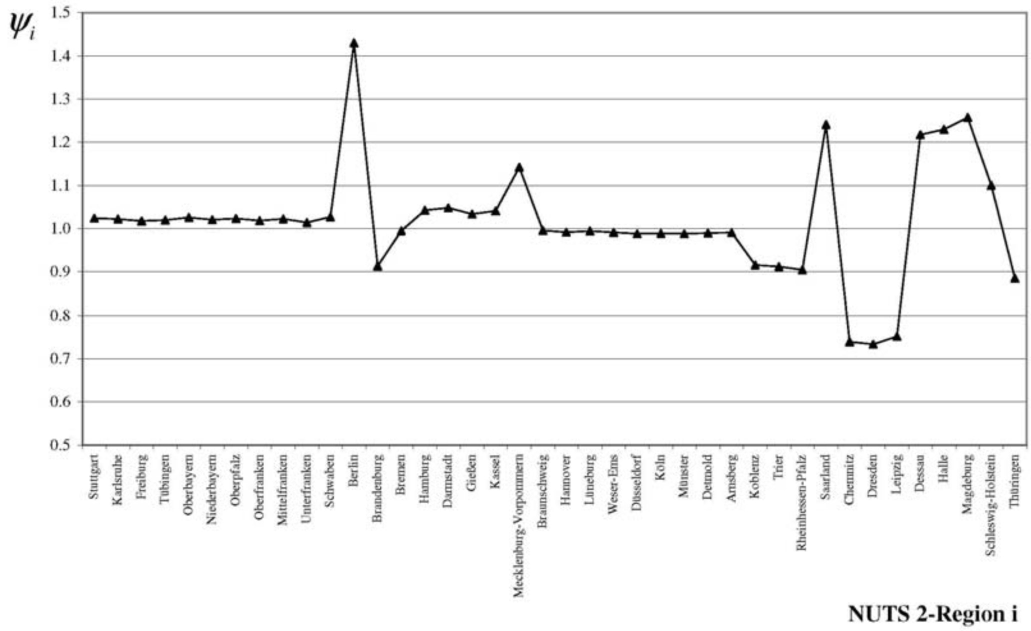

Figure 4 - InOutRatio of NUTS2 regions

Simulation results

The resulting price matrix indicates the average transport price between any two NUTS2 regions and serves as a reference price on the German long-haul trucking market. It also shows a significant regional price difference.

Table II – Interregional transportation market price

Price (€/km)	destination									
origin	DE11	DE14	DE21	DE22	DE23	DE24	DE25	DE26	DE27	DE40
DE11	0	1,23	1,27	1,26	1,18	1,1	1,12	1,15	1,14	1,02
DE14	1,17	0	1,21	1,12	1,26	1,09	1,06	1,16	0,94	0,2
DE21	1,16	1,09	0	1,2	1,19	1,18	1,16	1,22	1,17	1,18
DE22	1,21	1,06	1,21	0	1,12	1,2	1,19	1,23	1,18	1,14
DE23	1,12	1,24	1,24	1,21	0	1,14	1,17	1,19	1,24	1,19
DE24	1,27	1,22	1,27	1,26	1,22	0	1,14	1,26	1,3	1,05
DE25	1,12	1,33	1,27	1,29	1,23	1,1	0	1,14	1,27	1,18
DE26	1,16	1,46	1,24	1,23	1,22	1,11	1,21	0	1,22	1,08
DE27	1,02	0,96	1,21	1,25	1,17	1,19	1,19	1,2	0	1,2
DE40	1,35	1,35	1,31	1,28	1,26	1,44	1,27	1,45	1,23	0

Figure 5 shows the number of tours during the iterations. The number of tours illustrated by the blue line is stabilized in the range between 19800 und 20200. We should note that the number of tours found by our algorithms is in fact not the optimal solution from the view of efficient resource utilization. It contains some extent of inefficiencies, which is a typical characteristic of monopolistic competition. In contrast, in the case of monopoly, the solution is illustrated by the green line.

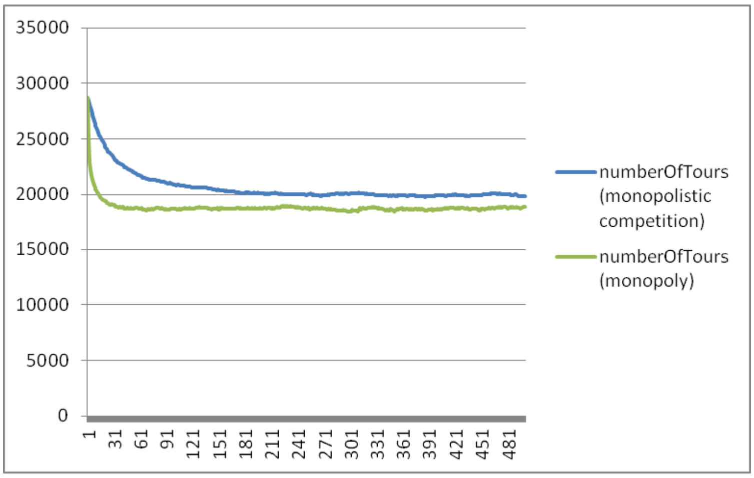

Figure 5 - Number of tours during the iterations

CONCLUSION AND OUTLOOK

Our focus on a specific submarket overcomes the difficulties considering the heterogeneous entire market. By picking up only a market segment, we can better understand the behaviours of carriers and shippers in the transport service procurement process of the submarket, which is a foundation for the further modelling. By the simultaneous treatment of the planning decisions of various actors, the "market price" is the result of many interdependent individual decisions, which overcomes the problems that arise in an isolated view of several individual transport demands.

The resulting market price matrix helps not only the shipper with the evaluation of the suggested transport price of carriers, but also the carrier to assess the empty trip probability on certain transport relations. Moreover, it contributes to the optimal design of transportation networks for procurement or distribution with consideration of regional price differences in transportation service. In future, we would extend our model or change the model parameters to study how the other market interaction forms affect the behaviours of carriers and shipper and the resulting market price.

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