A strategic network choice model for global container flows: specification, estimation, and application

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ABSTRACT

Container flows have been booming for decades. Expectations for the 21st century are less certain due to changes in climate and energy policy, increasing congestion and increased mobility of production factors. This paper presents a strategic model for the movement of containers on a global scale in order to analyse possible shifts in future container transport demand and the impacts of transport policies thereon. The model predicts yearly container flows over the world’s shipping routes and passing through 437 container ports around the world, based on trade information to and from all countries, taking into account more than 800 maritime container liner services. The model includes import, export and transhipment flows of containers at ports, as well as hinterland flows. The model was calibrated against observed data and is able to reproduce port throughput statistics rather accurately. The paper also introduces a scenario analysis to understand the impact of future, uncertain developments in container flows on port throughput. The scenarios include the effects of slow steaming, an increase in land based shipping costs and an increased use of large scale infrastructures such as the Trans-Siberian rail line and the opening of Arctic shipping routes. These scenarios provide an indication of the uncertainty on the expected port throughputs, with a particular focus on the port of Rotterdam in the Netherlands.

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1. Introduction

International trade has increased rapidly during recent decades (see Fig. 1). Between 1948 and 1992, world trade grew from 57.5 billion USD to 3600 billion USD. Since the beginning of the 1960s, the share of containerized cargo in the world’s total dry cargo movements has increased significantly. The major growth poles for maritime transshipment shifted to Asia (Borrone, 2005) and contributed to a recent surge in cargo throughput in all European ports (Ruijgrok and Tavasszy, 2008) which lasted till the start of the Asian and African continents, together with the Central and Eastern European countries are expected to attract an increasing share of world trade. For port and hinterland infrastructure, uncertainties in future flows not only originate from unknowns in the total volume that is traded worldwide but also from spatial shifts in transport chains and between ports within the same container system. These spatial shifts may occur as hinterlands change, but also depend on the availability, user price and quality of the port and hinterland infrastructures. For example, the rail land bridge between China and Europe, the enlargement of the Panama Canal and the development of European freight corridors are expected to have an influence on the spatial patterns of global freight flows. Finally, production systems and logistics services become more sophisticated, thereby contributing to increasingly complex
logistics networks that are spatially re-organized at a worldwide scale (Tavasszy et al., 2003; Notteboom and Rodrigue, 2008). To better cope with these uncertainties, a model-based analysis is needed to inform policy makers about future freight flows under different scenarios.

The objective of this paper, therefore, is to develop a worldwide freight model that analyzes freight transport chains over long distances, chains that span large parts of the world where routing alternatives may lead over different continents. The challenge is to test whether this simplified model can be made consistent both with basic principles of shipper and carrier behavior, confirmed by in-depth research on the one hand, and with publically available data on worldwide freight trade and transport on the other. With these capabilities, a worldwide container model is a basis for answering strategic policy questions, such as the impact of increased transport costs or the impact of new sea or land routes becoming available.

In the next three sections of the paper we describe the mathematical formulation of the model and the data used to build the model (Section 2), the estimation approach and results (Section 3) and some applications on policy questions at the global level (Section 4). We conclude the paper in Section 5 with a brief summary of the results and some recommendations for further research.

2. Model specification and data

2.1. A brief literature review on port selection and cargo routing through ports

Academic literature on port choice identifies a multitude of service-related and cost factors that influence the decisions made by shipping lines and shippers. These factors relate primarily to port infrastructure, the accessibility over land and via the sea, the geographical location vis-à-vis the immediate and extended hinterland and the main shipping lanes (centrality and intermediacy), port efficiency, port connectivity, reliability, capacity, frequency and costs of inland transport services, quality and costs of auxiliary services (such as pilotage, towage, customs, etc.), efficiency and costs of port management and administration (e.g. port dues), the availability, quality and costs of logistic value-added activities (e.g. warehousing) and the availability, quality and costs of port community systems, see e.g. Murphy et al. (1992), Murphy and Daley (1994), Malchow and Kanafani (2001), Tiwari et al. (2003), Nir et al. (2003), Song and Yeo (2004), Lirn et al. (2004) and Guy and Urli (2006).

Most quantitative research on port selection (see e.g. Tongzon, 2009; De Langen, 2007; Malchow and Kanafani, 2004) uses disaggregate behavioral analysis, which limits the geographical scope of application of models, due to the high costs of data acquisition involved. Aggregate models could in principle be applied at a global level, if the specification of the model is such that data needs do not become prohibitive. Transportation literature presents a limited number of aggregate models for the routing of seaborne freight (Tang et al., 2008; Giannopoulos et al., 2007; Leachman, 2006; Aversa et al., 2005; Frémont, 2005; Veldman and Buckman, 2003). None of these, however, have been shown to be operable or valid at a global scale and suffer from additional shortcomings, such as:

- A lack of route assignment using actual container liner service networks as offered by international seaborne carriers: models using a link and node based network do not allow service lines to be distinguished and assume that link performance is independent of the membership of such a link of service lines.
- An absence of elements describing aggregate choice behavior of shippers and preferences related to the generalized costs of freight and the value of time of goods. Here, again, models suffer from one or more shortcomings. Routing models are deterministic (applying all-or-nothing techniques) without accounting for heterogeneity in choices, do not include the value of time going beyond time as a factor cost (see Blauwens and Van de Voorde, 1988) or are not estimated to replicate observed flows.
- A problematic model specification is one where port attractiveness depends directly on port throughput (and vice versa). This is the case in the Veldman model (Veldman and Buckman, 2003), where port attractiveness is found to be a significant factor in explaining port choice, and later regressed against trans-shipment volume, the reasoning in the model becomes circular.
• Assuming stochastic independence between alternative routes, implicitly, by using the basic multinomial logit approach to discrete choice modeling. Due to this assumption of independence between routes, choices will be heavily biased towards groups of routes that overlap, unless the choice model is adapted for use in a network situation. All specifications cited above, including the disaggregate logit-based models, suffer from this problem.

The limitations of our model for the purpose of strategic forecasting of worldwide container flows are twofold. Firstly, we assume that congestion does not significantly affect the routing of freight flows. Short-term congestion can be caused by cycles/seasonality in the traffic volumes or temporary situations such as strikes or bad weather conditions. Structural congestion is caused by a chronic underinvestment in ports and terminals. High port congestion levels enhance terminal developments in the affected ports. If such developments are impeded by environmental and land availability issues, congestion can lead to the emergence of new container terminal facilities in the vicinity of established but congested load centers as described in 'challenge of the periphery' phase in port system development (see also (Hayuth, 1981; Slack and Wang, 2002; Notteboom, 2005 and Frémont and Soppé, 2007). In some cases, new ports emerge far away from existing (congested) ports in combination with the development of new corridors to serve the hinterland market (e.g. Prince Rupert in Canada as a new gateway port on the West Coast of North America far away from existing gateways). However, given that many ports' capacity extensions are above the mean growth scenarios, partly as a result of the economic crisis of 2008/2009, we simplify our model by assuming that congestion levels are too small to significantly affect medium-term forecasts on the routing of goods through port systems. For long-term scenarios (e.g. 2040) congestion is expected to influence the use of shipping routes and we would recommend extension of the model. Such an extension would require a major modeling effort, as aggregated congestion functions for port complexes are not available and would need to be developed anew. Challenges in this process include data acquisition and data aggregation; their detailed treatment is beyond the scope of our paper. The degree to which congestion affects flows in the base year will implicitly be included in the model, as the estimated parameters include a representation of the shadow price of congestion, as experienced in the base year. We recommend that future expected congestion levels are entered into the model exogenously by increasing the transshipment times, according to current practice in other aggregate models.

Secondly, our model is limited to routing issues and does not include impacts on trade itself. Again, for medium-term forecasts we believe this is not problematic. For long-term forecasts, especially if we want to look at major shifts in overall transport costs (e.g. resulting in a doubling of trade costs), integration with a global trade model would be desirable.

In the remainder of this section we describe the choice model in detail, in particular the choice criteria used, the behavioral assumptions behind the model and its mathematical specification.

2.2. Choice criteria and choice function

The choice of shipping route for unitised goods is a complex process involving many attributes of different actors and services. Port selection factors typically relate to the geographical location of origins and destinations of freight, the costs of transport (inland and overseas), the forwarding organization's preferences (e.g. merchant or carrier haulage), the logistics characteristics of the goods (e.g. perishability, sensitivity and unit value), the available facilities and services (e.g. ports and inland infrastructure) and the decision agent's characteristics and strategies (forwarders, shippers or shipping lines).

Academic literature on port selection factors is abundant (see earlier section and Magala and Sammons (2008) for a recent literature review). Our intention is not so much to study these factors, but rather to apply the existing insights at an aggregated level. For strategic forecasting and planning purposes with a long-term focus on worldwide developments, it is neither necessary nor possible to take all factors into account. Instead, we are looking for an aggregate description of the system, capturing the main flows and replicating the behavior of groups of actors, for forecasts of worldwide container flows and port throughput for the next 10–20 years.

We assume that route choices are made by profit maximizing shippers who have knowledge of the main routing alternatives over land and sea, for goods traded between two countries. The basis for the route choice model is a simple logit route choice model using path enumeration (Florendo-Catalano, 2007) where choice probabilities depend on the route specific generalized costs:

\[ P_r = \frac{e^{-jC_r}}{\sum_{h \in C} e^{-jC_h}} \] (1)

where \( P_r \), the choice probability of route \( r \); \( C \), generalized costs; \( C_h \), the choice set; \( h \), path indicator; \( \mu \), logit scale parameter.

As the logit model assumes stochastic independence of alternatives (due to the assumption of independent error terms), the application of the model for networks with overlapping routes is problematic. When applied for route choice problems, the share of routes that are part of a bundle, i.e. those routes that overlap will be overestimated (see e.g. Hoogendoorn-Lanser et al., 2005). Therefore the basic logit model was extended to a path size logit model (see e.g. Cascetta et al., 1996 and Ben-Akiva and Bierlaire, 1999):

\[ P_r = \frac{e^{-j(C_r + \ln S_r)}}{\sum_{h \in C} e^{-j(C_h + \ln S_h)}} \] (2)

With the path size overlap variable defined as

\[ S_r = \sum_{a \in \mathcal{L}} \frac{z_a}{Z} \frac{1}{N_{ah}} \]

where \( a \), link in route \( r \); \( S_r \), degree of path overlap; \( \mathcal{L} \), set of links in route \( r \); \( z_a \), length of link \( a \); \( Z \), length of route \( r \); \( N_{ah} \), number of times link \( a \) is found in alternative routes.

The generalized cost function is given by the following equation:

\[ C_r = \sum_{p \in \mathcal{L}} A_p + \sum_{l \in \mathcal{L}} c_l + z_r \left( \sum_{p \in \mathcal{L}} T_p + \sum_{l \in \mathcal{L}} t_l \right) \] (3)

where \( C_r \), costs of route \( r \); \( p \), ports used by the route; \( l \), links used by the route; \( A_p \), total cost of transhipment at port \( p \); \( c_l \), total cost of transportation over link \( l \); \( T_p \), time spent during transhipment at port \( p \); \( t_l \), time spent during transportation over link \( l \); \( z_r \), value of transport time (USD/day/ton).

Note that the mode of transport (sea or land modes) is embedded in the network attributes and does not appear in the cost formula. This mode-abstract formulation allows to use a more detailed underlying multimodal network; the aggregate result will be a level of service expressed in times and costs. The value of the attractiveness parameter \( A_p \) and the scaling parameter \( \mu \) are unknown and need to be estimated. The scaling parameter \( \mu \) captures the phenomenon that, although individual shippers and carriers may decide to use one port or another, their aggregate behavior results in the use of more than one alternative route and that their joint response to policies is a smooth one. The parameter \( A_p \)
includes all relevant, measurable and hidden service characteristics of ports, such as fuel costs, handling costs, congestion costs, etc. The use of such a parameter as an alternative specific constant is not uncommon in transport modelling. In order to allow this parameter to be estimated, we made sure that:

- The model is not too rich in parameters relative to the data available for estimation. This was done by keeping the number of parameters limited to one constant per port.
- We did not introduce circular relations, by keeping this cost parameter exogeneous and not allowing it to be a function of volume.
- Parameters would not fully overlap in the estimation with observed cost attributes of the same alternatives (which would renders these observations useless).

Port costs (e.g. port dues and terminal costs) are not included explicitly in the model specification, as it is included in parameter $A_p$. There are two main considerations behind this choice. First of all, it is difficult if not impossible to obtain suitable aggregate averages for these costs, given the difficulty to observe the rates charged in – often complex or even confidential – arrangements between ports and carriers and the lack of insight in the exact composition of freight flows and ship types, needed to construct such averages. One of the discussions in this field relates to the question whether the port-specific terminal handling charges (THC), a surcharge fee which shippers pay to the shipping lines, are a good proxy for the real terminal costs incurred by shipping lines calling at a port (see also Dynamar, 2003). Secondly, port choice literature does not offer convincing evidence that cargo handling costs as a part of port costs play an equally important role as transport costs. Some studies even point in the opposite direction (Malchow and Kanafani, 2001).

The value of time parameter denotes the average preference of decision makers for either faster (and thus more expensive) or cheaper (and thus slower) transport options. It summarizes all the characteristics of the goods, e.g. perishability and value, and the logistics environment in which the goods transport takes place (e.g. time window for delivery) into one parameter. Even in a network such as used here, with carriers offering similar services in terms of the time/cost trade-off, this parameter is of importance to distribute freight between ports that involve shorter and longer hinterland legs. A higher value of time may lead to an earlier port call in the network, with a relatively long inland haul left than otherwise.

2.3. Choice set generation

The choice set routes are determined by a shortest path algorithm for each port-port segment of the service, in the port-call order specified in the published service tables of container shipping lines worldwide. Given the physical network and the networks of services, choice sets are generated for every O/D pair. A route between an origin country O and destination country D, starting at an origin port S and a destination port E is defined by one or more maritime services between S and E, with intermediate transhipment at ports where a change of service can be carried out. For each (outgoing) port S to the (incoming) port E the shortest path is added to the choice set of this combination O–S–E–D (see Fig. 2).

2.4. Assignment

Each country has a fixed number of ports which may be used for import or export of containers, and may include ports located in neighboring countries. When the different possible routes are generated (equal to the number of accessible ports at origin country multiplied by the number of accessible ports at destination country), the logit route choice probabilities are calculated for the alternatives within the choice set and applied directly on the O/D flow for the distribution over the alternative ports and links in the network.

2.5. Data

2.5.1. Origin/destination matrix

The input data for the model on freight flows were obtained from three sources: international trade statistics and two European statistics sources to allow conversion into containers. The Comtrade database of exchanges between countries in the world, measured in USD and tonnes provides the basis for the model. As the flows in tonnes need to be converted in containers (in 20 Foot Equivalent Units – TEUs), the Eurostat database was used

![Fig. 2. Example of routes between an OD-country pair.](image-url)
(Eurostat, 2007). The area coverage is less complete than the trade database, as it covers only transports between Europe and the rest of the world, but information on the exchanges is available in tonnes, unitised tonnes and TEUs. This database allows to calculate ratios of unitisation (total cargo tonnes potentially unitised divided by the total cargo tonnes) and ratios of density (unitised tonnes divided by TEU). These two ratios were calculated per type of goods and OD pair. The ratios were applied to the trade database. In case some ratios were lacking, the averaged ratio per OD and/or type of goods were used. In order to include empty containers in the input data, another database of Eurostat was used which made it possible to extract the number of empty and full TEU for each OD-pair. A return percentage of empty containers could thus be obtained. As before, the percentage was applied per OD-pair and type of goods.

Table 1 provides an overview of the data used and their spatial and functional coverage.

<table>
<thead>
<tr>
<th>Source</th>
<th>Database 1</th>
<th>Database 2</th>
<th>Database 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Area</td>
<td>Comtrade</td>
<td>Eurostat</td>
<td>Eurostat</td>
</tr>
<tr>
<td>Type</td>
<td>World</td>
<td>Europe-world</td>
<td>Europe-world</td>
</tr>
<tr>
<td>Units</td>
<td>Trade</td>
<td>Trade</td>
<td>Maritime</td>
</tr>
<tr>
<td>Goods</td>
<td>Tonne, USD</td>
<td>Tonne, unitised tonnes, TEU</td>
<td>TEU</td>
</tr>
<tr>
<td>classification</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Empties included</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
</tr>
</tbody>
</table>

2.5.2. The transport network

The network description includes the physical network and the network of maritime and inland transport services. The model predicts the routing of container flows between an origin and destination country, using weekly container liner service routes as provided by container shipping lines. More than 800 maritime services involving 437 ports were included in the database through the use of public sources such as published liner schedules and transport fee schemes. We applied a super-network approach for network coding (see Sheffi, 1985). Supernetworks are networks that allow a simultaneous choice of mode of transport and route, including transhipment points (see Fig. 3).

A maritime network was created using country nodes (origin/destination centroids), port nodes and maritime nodes. Maritime links were created between the maritime nodes. A shortest path algorithm based on distance was used to identify the routes taken by the different container liner services between the ports in the maritime network, given the order of port callings in the liner service. Note that this does not yet include the assignment of freight flows to these alternative routes. Fig. 4 shows the maritime networks used.

The origin/destination tables of transport flows, as presented above, include flows that have inland shipping alternatives as well. Therefore these alternatives needed to be identified and added to the list of shipping alternatives for each O/D pair. A simplified inland network of links was created in order to capture container flows between neighboring countries that may use inland routes without using a port. We applied a number of simplifications. First of all, the network is connected to every country of origin or destination by one single centroid. Hereby we assume that this location captures the weighted average location of all freight moving to, or from the country. Second, the main network attributes are times and costs for transhipment and transportation. Average levels of shipping costs and speeds (for the services without enough information) are the same over the whole network, without making a distinction between alternative modes of transport. For the purpose of our model, this assumption is not problematic as differences between shipping rates per unit of distance will be limited on competing routes. The speeds and tariffs used in the model are presented in Table 2.

3. Estimation of the model

As described above, the port-specific parameter $A_p$ was introduced for calibration purposes as an overall parameter for all cost factors. The observed levels of inland transport costs allow for a normalization of the cost levels of this parameter to real cost levels. By making modifications of this value and the scale parameter $\mu$, the distance between observed and calculated flows is minimized by means of an iterative process. Transhipment and transport
times and costs were taken from published timetables. The distribution of values of time for freight was inferred from an earlier study on international maritime shipments (Tavasszy, 1996) with a global average value near 100 USD per TEU per day. Note that the route choice sets needed to be generated at each iteration step in the calibration process. As the routes are created with a shortest path algorithm based on generalized costs (in order to be able to take transhipment into account), we had to regenerate them when costs are modified. For the purpose of model calibration, the assignment was done by OD pair and no distinction was made between types of goods.

Using a simple Newton-based greedy search method, the model converged quickly and resulted in an excellent fit with available observations. Container throughput data were available for about one hundred ports worldwide, and for these ports the model is able to explain over 96% of the amount of variation between ports’ throughput volumes. The sum of the absolute differences for all the ports divided by the total flow is below 10%. The ports with the highest difference between observed and predicted flows are the Asian ones, probably because of the lack of geographical detailed input OD flows.

We obtained an optimal value of 0.0045 for the spread factor $\mu$. This value multiplied by the average route’s global cost is a unit figure. The response curve for this parameter is smooth and shows a global minimum, which indicates that the assumption of minimization of probabilistic ‘generalized’ cost minimization is superior to random distribution (for larger values of $\mu$) or deterministic choice (for $\mu$ approaching zero). Institute of Transport and Maritime Management Antwerp, 2007.

The European Sea Ports Organisation (cf. Bovy, 1990) provides total figures of the number of TEU handled in 2005, which we used for an additional validation of the model. These figures were compared with the model output as illustrated in Table 3.

We conclude that the TEU flows observed (and used for the calibration) are in line with the ESPO data. The input flows of the model are higher than the ESPO data (empty and full), but they also include some inland container flows. For the output, the total number of TEU handled is correct. There is an overestimation of TEU transhipped which means that the model could benefit from an additional degree of freedom in terms of a choice between direct and indirect transport. This could be introduced using a nesting of choice sets, and will be subject to further research.

4. Scenario analysis

Fig. 5 shows a snapshot of the model output. The lines are proportional to the volume of maritime traffic. Although the US has the largest absolute import and export flows, the container flows are larger near Asian and European coasts, particularly along the so-called Suez Canal route stretching from northeast Asia to northern Europe (Hamburg being the most northern main port). This route not only accommodates direct intercontinental container flows on a large set of OD pairs, it is also home to a large number of sea–sea transhipment hubs which act as turntables in extensive regionally-based hub-feeder networks. Hubs have emerged since the mid-1990s within many global port systems: Freeport (Bahamas), Salalaha (Oman), Tanjung Pelepas (Malaysia), Gioia Tauro, Algeciras, Taranto, Cagliari, Damietta and Malta in the Mediterranean, to name but a few (see, for instance, Fagerholt, 2004; Guy, 2003; McCalla et al., 2005). In the US, many impediments in American shipping regulations gravitating around the Jones Act have favoured a process of port system development with limited (feeder) services between American ports and the absence of US-based transhipment hubs (Brooks, 2009). Transhipment hubs multiply shipping options and are the points of convergence of regional shipping, essentially linking separate hierarchies and interfacing global and regional freight distribution systems.

By changing the circumstances under which flows are routed we can test the sensitivity of the container throughput of individual ports or the sensitivity of services provided by container shipping lines. A number of scenarios were tested in order to evaluate the impacts of changes in the transport system. These include:

1. Opening of shipping routes along the Northern polar cap.
2. Landbridge railway connection between China and Europe.
3. Strong increase in inland transportation costs.
4. Decrease of transhipment costs in the port of Antwerp.
5. A strong overall increase of transhipment costs.
6. A decrease in shipping speed.

In the following sections we elaborate on these cases and highlight in particular the results for European ports.

4.1. Scenario 1 – polar cap shortcut

A first scenario which may become reality in the near future is the opening of shipping routes along the Northern polar cap. The Arctic Ocean has been affected by climate change and this evolution is creating opportunities for maritime transportation. Liu and Kronbak (2009) demonstrate that shipping through the Arctic Ocean via the Northern Sea Route (NSR) could save about 40% of the sailing distance from Asia (Yokohama) to Europe (Rotterdam) compared to the traditional route via the Suez Canal. However, this reduction in distance does not lead to similar cost saving as ship-

### Table 2

<table>
<thead>
<tr>
<th>Description of the characteristics of the services used.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Speed (km/day)</td>
</tr>
<tr>
<td>----------------</td>
</tr>
<tr>
<td>Calculated*</td>
</tr>
</tbody>
</table>

* Calculated separately for each service or a default value of 1000 km/day.

b Mean, actual depending on continent.

### Table 3

Comparison of ESPO data and modelled container flows (in million TEU).

<table>
<thead>
<tr>
<th>Total handling</th>
<th>Port to port</th>
<th>Port to port</th>
<th>Transhipment</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Full containers</td>
<td>Empty containers</td>
<td></td>
</tr>
<tr>
<td>ESPO</td>
<td>399</td>
<td>231</td>
<td>59</td>
</tr>
<tr>
<td>Observed flowsa</td>
<td>407</td>
<td>360</td>
<td>66</td>
</tr>
<tr>
<td>Input datab</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Output data model</td>
<td>400</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

a Sum of the number of TEU handled by all the ports in the dataset in 2005/2006.
b Mean, actual depending on continent.
c Also includes empty containers transhipped.
ping lines on the route incur higher building costs for ice-classed ships, non-regularity of services, slower speeds, navigation difficulties and greater risks, as well as the need for expensive ice breaker services (see Fig. 6).

The model results show that from West to East, about 2.12 million TEU might use this link and from East to West only around 1.15 million TEU in comparison. The estimated container shifts towards the polar cap path represent around 1.5% of the total container flows. Ten services out of the 849 available services are estimated to use this shortcut, accounting for 1.1% of the total number of services. Container throughput handled by each port does not change significantly. Very slight variations are observed which account for a total of 4 million TEU. Rotterdam, Pusan and Yantian are the ports which are estimated to gain most traffic with respectively 0.65, 1.2 and 0.76 million TEU. Singapore, Shanghai and Bremen are the ports which are expected to lose most traffic with traffic losses of respectively 0.50, 0.54 and 0.49 million TEU.

4.2. Scenario 2 – land bridge railway connection between Europe and China

In the model a new container service line was added to represent the Trans-Siberian land-bridge, a set of long-distance railway connections. The Trans-Siberian Railway connects St. Petersburg with the port of Vladivostok via cities like Moscow, Omsk, Novosibirsk and Irkutsk (see Liliopoulou et al., 2005 for an overview of the railway’s history). Other primary rail connections are the Trans-Manchurian Railway, the Trans–Mongolian Railway and the Baikal Amur Mainline (BAM – opened in 1991) which all coincide with the Trans-Siberian in the western sections but diverge north of Mongolia just before or after Lake Baikal (see Fig. 7). Total TEU volumes on the Trans-Siberian railway reached 948,000 TEU in the first nine month of 2008 of which 519,000 TEU were Russian domestic traffic and 429,000 TEU international container traffic (figures TransContainer). The service runs between Shanghai and Moscow, but in our study we extend it to Hamburg, a distance of about 8500 km, also passing through other countries that can use the line to ship goods over land.

The average speed of the service was set at 500 km per day. In principle, container trains can reach an average speed of 900 km a day (80 km/h), allowing freight to cross Eurasia in about 12 days, making the overland route much shorter than container ships taking the Suez route. Russian railway company RZD and its subsidiary TransContainer have plans to introduce block trains operating on even tighter schedules. In practice, however, these speeds are not reached due to border crossings, rail equipment issues and stops underway. Similar to the maritime container services, a weekly service is assumed.
In the case study, containers can also be transhipped at Hamburg or Shanghai and then use the long distance railway connection. Different cost scenarios were tested, varying from a level of the inland cost applied in Asia to half the cost applied in Europe. In general, the costs linked to the routes using the railway link are higher than on the all-water routes. However, the transit time is lower.

It was found that the utilization of the link is relatively price-sensitive, and that the flows are larger in the direction from Asia to Europe. Using the same price level as in Europe, it was found that 12.3% of the container flows between Germany and China would use the new service (Table 4). However, from the Netherlands a negligible percentage would use the link, because of transhipment at Hamburg and a limited cost advantage due to the same price level compared to alternative services. It was also observed that empty flows would use the railway link relatively less compared to other routes. The explanation for this observation lies in the value of time, which is far lower in case of empty containers. The results are somewhat in line with the analysis of Vernya and Grigentinc (2009) who adopted a model schedule between Shanghai and Hamburg to analyze the relative costs of various axes in the Asia–Europe transport network. Their results show that shipping through the Suez Canal is still the cheapest option. The North Sea Route and the Trans-Siberian Railway appear to be roughly equivalent second-tier alternatives. Volumes on the landbridge are thus expected to remain fairly small compared to shipping via the Suez route.

4.3. Scenario 3 – strong increase in inland transportation costs

Under this scenario, the inland transport costs were doubled and the changes in the number of TEU handled by different ports were analyzed. Increases in inland transport costs can lead to a transfer of costs to final consumer and not a modal shift, but it can also lead to changes in routing behavior and modal choice. It was found that this measure resulted in a higher number of TEU handled by ports (plus 33 million TEU), with a total of 435 million TEU. This increase is mainly due to more transshipment and short sea shipping, with 31 million TEU movements created. The other additional 2 million TEU are the result of a modal shift from inland to maritime transport. The total increase (transshipment and modal shift) for empty containers amounts to 4 million TEU and to 29 million TEU for full ones. For the European ports we see that overall transhipment volumes increase, as flows are routed to the nearest port and transhipped to the main container lines. Hamburg gains relatively most within its competitive range (Table 5).

4.4. Scenario 4 – reduction of Antwerp’s cost to the level of the port of Rotterdam

The port of Antwerp is the main competitor of Rotterdam, although a certain level of complementarity exists among the two main ports (Notteboom, 2009). In fourth scenario, the impact of a reduction in Antwerp’s generalized cost parameter to the same level as the port of Rotterdam was investigated. The results are provided in Table 6. The increased attractiveness of Antwerp causes a reduction in container flows in all the other ports in the region, but particularly in Rotterdam, Hamburg and Bremen. This clearly shows that these ports are in the same competitive range.

4.5. Scenario 5 – strong increase of transhipment costs

In this case study, port costs for transhipped containers were doubled. As a result, European ports encounter a huge reduction

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**Table 4**

<table>
<thead>
<tr>
<th>Region</th>
<th>Share of flow (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Germany</td>
<td>12</td>
</tr>
<tr>
<td>France</td>
<td>0.04</td>
</tr>
<tr>
<td>Belgium</td>
<td>1.7</td>
</tr>
<tr>
<td>Netherlands</td>
<td>0</td>
</tr>
<tr>
<td>Poland</td>
<td>24</td>
</tr>
<tr>
<td>Luxembourg</td>
<td>2.0</td>
</tr>
<tr>
<td>Austria</td>
<td>15</td>
</tr>
</tbody>
</table>

**Table 5**

<table>
<thead>
<tr>
<th>Port</th>
<th>Change (mln. TEU/year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rotterdam</td>
<td>0.54</td>
</tr>
<tr>
<td>Le Havre</td>
<td>0.28</td>
</tr>
<tr>
<td>Hamburg</td>
<td>1.49</td>
</tr>
<tr>
<td>Gioia Tauro</td>
<td>0.11</td>
</tr>
<tr>
<td>Bremen</td>
<td>0.46</td>
</tr>
<tr>
<td>Antwerp</td>
<td>0.45</td>
</tr>
</tbody>
</table>

**Legend**

- a = Trans-Siberian Railway
- b = Trans-Manchurian Railway
- c = Trans-Mongolian Railway
- d = Baikal Amur Mainline (BAM)
- e = New Asia-Europe Land-Bridge

**Fig. 7.** The TSR route and east–west rail corridors as routing alternatives between East Asia and Northern Europe.
in sea–sea transhipment flows. In the Northern port range, only Hamburg gains container traffic and even transhipment traffic. Hamburg’s pivotal position vis-à-vis the Baltic Sea might make it less vulnerable to losses in feeder traffic. Overall, global container traffic decreases by 13 million TEU, caused by reductions in transshipment flows (see Table 7).

### 4.6. Scenario 6 – slow steaming

Changing the operational speed of the vessel is one way of modifying the operational characteristics of a container liner service. A reduction in vessel speed or ‘slow steaming’ is becoming common practice among shipping lines in order to cut fuel costs (Notteboom and Vernimmen, 2009). Quite a number of shipping lines are now examining the possibilities of making cost savings by further slowing down ships to about half their usual speeds. A service speed of 14 knots is considered by some as the possible future norm for container ships, in contrast to speeds of up to 22–23 knots before slow steaming was introduced. While some container carriers such as Maersk Line and CMA CGM are moving to super slow steaming, others continue to run their services at full speed despite the high fuel price. Some shippers who have managed to defer new-building deliveries are taking advantage of the extra time to modify designs and specify smaller, more fuel-efficient propulsion systems with lower service speeds. Many owners are however still reluctant to commit to smaller engines as they fear that at some stage higher speeds will be viable again. This scenario investigates a case of a drastic reduction of the operational speed of vessels to super slow-steaming (i.e. 14–15 knots instead of a normal 22–24 knots). Super slow-steaming does not significantly affect container throughputs in ports. However, worldwide 1.3 million TEU are handled a second time in order to use other services. In other words, super slow-steaming encourages sea–sea transhipment operations at intermediate hubs. In particular, shifts in container flows can be observed towards hubs that are being served in a slow-steaming configuration. At the European continent, however, the effects remain limited: Rotterdam is the most affected port with a reduction of 95,000 TEU/year. The tendency towards more hub-and-spoke using bigger vessels does not imply that there is no longer room for smaller liner services with smaller vessels in specific niche markets.

### 5. Conclusions

This paper introduced a new strategic choice model for container shipping routes which explicitly takes into account port selection criteria. The model is unique as it combines a worldwide coverage and a description of route selection made within the network based on shippers’ preferences and a comprehensive network of maritime services.

The calibration shows that the model is able to predict quite well the yearly container flows to and from all countries using major and minor container ports around the world. The model can be applied to assess the impacts of various future changes in the container transport market. The results of the case studies provide us with interesting insights into port choice dynamics triggered by changes such as a polar cap shortcut and a long distance railway connection between Europe and China. The model also allows a comparison of the impacts of different policies or evolutions in the market environment. Table 8 summarizes the consequences of different modifications in the port environment on total container throughput in the port of Rotterdam. In this context, the relative differences are more relevant than the absolute figures.

The model gives ample possibilities for future research on a number of themes. First of all, there is room for the introduction of measurable indicators for ports’ economic and physical attractiveness in view of increasing the explanatory value of the model. Second, the nesting of choices between direct and indirect services might be useful as to take into account the relative attractiveness of sea–sea transshipment versus direct liner services. Third, more research is needed to estimate the value of time along with the presented parameters.

A new direction of research which now becomes possible to explore, involves the linking of this global transport network model with a model of worldwide logistics networks, trade and production. This will allow us to study the influence of major transport cost changes on worldwide supply chain structures and economic growth.

### References


of the 13th International Symposium on Transportation and Traffic Theory, Lyon, France.