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## Cost Functions in Freight Transport Models

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Freight transport models are used to estimate the expected impact of policy measures and are a necessary input for the justification of infrastructure investments. Seaport hinterland models can be used to forecast future hinterland traffic and modal split development. For the impact assessment, most freight transport models use a generalized cost approach for the purchasers' costs which amount the operators' costs passed on to the users of transport services and the actual users' costs (e.g. time costs). At present, no comprehensive model exists for the Port of Hamburg. Consequently, it is difficult to estimate the expected impacts of infrastructure measures for the Port of Hamburg's hinterland accessibility. The aim of this paper is to give an overview over the research field of freight transport modelling and to develop an approach for comparing the Port of Hamburg's hinterland connections taking into consideration different types of costs. Finally, the cost functions are applied to the use case "Port of Hamburg" on a macroscopic level.

**Keywords:** Freight Transport Modelling, Port of Hamburg, Hinterland Traffic, Container

## 1 Introduction

The international freight transport market grew almost steadily in the last decades, with a sharp decrease during the global financial crisis and stagnation at below crisis levels since then (OECD 2014). Nevertheless, different studies promise a positive outlook for future freight transport development. The current German sea traffic forecast forecasts an overall increase of volumes handled in the German seaports of 63 percent between 2010 and 2030 (MWP et al. 2014). Container handling volumes are expected to increase steeper in German seaports than conventional cargo volumes (MWP et al. 2014).

For foreign trade-oriented countries like Germany an internationally competitive maritime industry is of high economic significance. The maritime industry plays a key role in the competitiveness of the business location Germany and for securing growth and employment. Competitive seaports form the connector between seaside and landside transport modes and are indispensable for functioning international transport chains and foreign trade. However, their competitiveness depends on port efficiency. According to the Organisation for Economic Co-operation and Development (OECD) the doubling of port efficiency of two countries results in a 32 percent increase of their bilateral trade volume (Merk 2013). One factor influencing the efficiency of seaports is their landside accessibility and thus, the quality and number of available hinterland connections (Merk 2013). Consequently, future increase of freight on hinterland transport modes demands sufficient capacities of corresponding transport infrastructures (Ben-Akiva et al. 2013).

Freight transport models are used to estimate the expected impact of policy measures and are a necessary input for the justification of infrastructure investments. Seaport hinterland models can be used to forecast future hinterland traffic and modal split development. At present, no comprehensive model exists for the Port of Hamburg. Current forecasts are based on surveys, e.g. on the Container Traffic Model 'Port of Hamburg', by the Institute of Shipping Economics and Logistics (ISL). For that reason, it is difficult to estimate the expected impacts of infrastructure measures for the Port of Hamburg's hinterland accessibility.

The aim of this paper is to give an overview over the research field of freight transport modelling and to develop an approach for comparing the Port of Hamburg's hinterland connections taking into consideration different types of costs. Currently, a macroscopic freight transport model for the Port of Hamburg is under development. This work forms a first step within the development of a freight transport model for the Port of Hamburg.

In order to narrow the scope of transport modelling this paper focusses on freight transport models only. Cost functions will cover containerized cargo only. Finally, because most hinterland transport flows are long distance transport flows this paper will only take into consideration macroscopic freight transport models.

Section 2 gives a brief introduction to the fundamentals of freight transport modelling. A selection of existing freight transport models is presented in section 3. The differences between these freight transport models are highlighted by using differentiation criteria defined by the researcher. In section 4 the seaport hinterland model currently under development is described. Special focus is given on the underlying logic in order to highlight the role

of cost functions as part of the freight transport model. In section 5 cost functions for containerized seaport hinterland traffic are derived and also applied to the use case “Port of Hamburg”. Finally, a discussion and conclusion are provided in Sections 6 and 7. The chapter ends with a conclusion in section 8.

## 2 Introduction to Freight Transport Modelling

There are a lot issues in freight policy that demand the modelling of freight flows, such as the increase of freight volumes, pricing, logistics performance, changes in vehicle types or external effects of transport. Amongst others the following modelling needs are linked to current key issues in freight policy: forecasting international freight growth, differentiating between goods with different logistic backgrounds, forecasting (cause and impacts of) choice of vehicle type, modelling critical global movements (containers, oil, dangerous goods, food) (Tavasszy 2006).

Transport modelling distinguishes between passenger transport modelling and freight transport modelling. Concerning methodology passenger transport models have achieved a high degree of specialization and are established as tools in strategic transport planning processes. In contrast to this freight transport models have evolved and methodologically developed only since the shorter past (Tavasszy 2006).

First of all, freight transport flows form a relatively small part of total transport flows. In addition, access to necessary data is difficult because of commercial interests of freight transport market actors that want as least transparency (of e.g. costs) as possible (de Jong et al. 2004). On the other

hand, due to the high number of different actors involved, such as consignors, shippers, freight forwarders, liner carriers and terminal operators, and their partly conflicting interests, the organization of international freight transport chains is very complex. As passenger transport models only have the passenger as decision maker, they are far less complex than freight transport models (Karafa 2010).

Nevertheless, in the early days of freight transport modelling the developers of these models used the scientific findings of passenger transport models and adopted the concepts, methods and tools to the specific requirements of freight transport. However, by now freight transport modelling has developed its own stream of methods and techniques inspired by disciplines such as economic geography and supply chain management (Tavasszy, de Jong 2014).

A widely spread model structure for passenger transport models is the 'Four-Step Model'. Other models like activity based models and land use models can also be used to fulfil functions similar to those of the Four-Step Model (Transport and Infrastructure Council 2014). The steps of the Four-Step-Model are illustrated in Figure 1.

Within the first step ‘Trip generation’ it is estimated how many person trips are produced within and attracted to each zone (incoming and outgoing passenger trips). The second step ‘Trip distribution’ determines the destinations and origins of the passenger trips. The result is an origin-destination matrix. The ‘Mode choice’ (step three) allocates the origin-destination-trips from step 2 to the available transport modes (mode-specific trip matrices). Finally, the mode-specific trip matrices are assigned to alternative routes or paths (step four, ‘Trip assignment’).

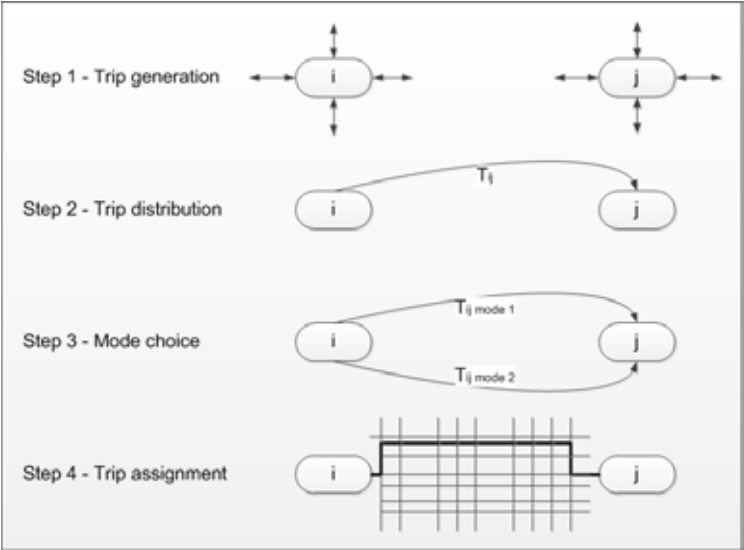


Figure 1 Steps of the Four-Step-Model (author based on Transport and Infrastructure Council 2014)



A significant feature of this model is the iterative feedback of costs arising from trip assignment to trip distribution and mode choice. The iteration between the last three steps enables the replication of impacts of congestion on travel costs (Transport and Infrastructure Council 2014). It is generally accepted that the Four-Step Model of passenger modelling can be applied to freight transport as well. However, due to the complexity of the freight transport system, the individual steps of the Four-Step Model need to be adapted to the requirements of the freight transport system (de Jong et al. 2004).

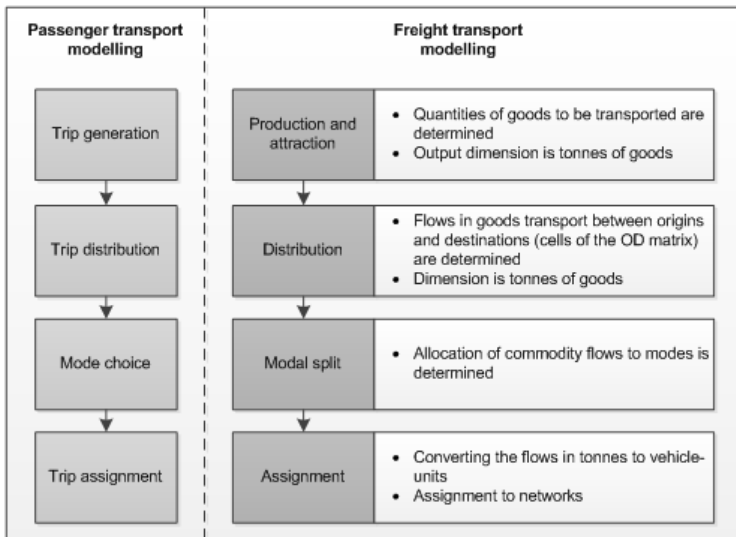


Figure 2 Comparison of Four-Step Models  
(author based on de Jong et al. 2004)

A number of transformation modules are usually required (de Jong et al. 2004). An example for this is the converting of trade flows in monetary units into physical flows in tons for the first step of the Four-Step Model. As trade forms the basis for freight transport flows this is an inevitable step. For this Tavasszy (2006) enhances the Four-Step Model by a fifth step ‘Trade’ after the first step that includes the conversion of monetary units into tons. As passenger transport does not relate back to monetary units no such translation has to be carried out in passenger modelling. The following elements of freight transport models are necessary to carry out the illustrated model:

Table 1 Components of freight transport models (author)

Model Component	Description
Demand model	Different regional areas; Origin-destination data for different commodity groups as well as vehicle types
Network model	Different networks for transport modes; Terminals for transfer between transport modes or the integration of logistics processes
Cost model	Fixed and variable costs related to transport modes, vehicle types and commodity groups (or loading units)

The cost model is an essential component of freight transport models. In most models the costs are linked to the network as part of a resistance function. Freight transport models use costs in order to differentiate between different transport modes (and vehicle types) as well as commodity groups (Müller et al. 2012). Costs occur at different stages of the transport chain and can be found as resistors for the mode and route choice during freight transport modelling. As part of common freight transport models the transport mode, transport chain (incl. changes of transport modes) as well as transport route are selected under the principle of minimization of total costs of transport. The cost model is therefore a deterministic model of cost minimization. Consequently, for freight transport models to be as exact and realistic as possible, it is of special importance that the overall costs of possible elements of logistical alternatives are calculated with sufficient accuracy.

### 3 Macroscopic Freight Transport Models

Existing freight transport models do not only differ in terms of their international, national or regional perspective but also in relation to the data used and their depth of aggregation, corresponding measurement variables used, or their scale of analysis named as aggregated or disaggregated. Examples for macroscopic freight transport models are e.g. the Swedish National Model System for Goods Transport (SAMGODS) and the Swiss National Freight Transport Model (NGVM). Both models cover different transport modes and commodity groups and consider all processes of traditional freight transport chains (transport, handling, storage). SAMGODS

and NGVM are selected for further analysis because they can be considered to belong to the best documented freight transport models. Table 2 compares the two models with each other.

Table 2 Comparison of SAMGODS and the NGVM (author based on Vierth et al. 2009 and ARE 2011)

Criteria	SAMGODS	NGVM
Development period	2004-2009	2009-2011
Number of regions	290 in Sweden; 174 outside Sweden	2.945 in Switzerland; 156 outside Switzerland
Level of aggregation	Aggregated and Dis-aggregated	Aggregated and Dis-aggregated
Transport modes	Road, rail, sea, air	Road, rail
Logistics processes	Transport, handling, storage	Transport, handling, storage
Number of freight categories	35	118
Software	Own programming	Visum

Both freight transport models are similar concerning the considered criteria. Nevertheless, they differ from each other in their level of detail in terms of the number of freight categories as well as the geographical coverage. The level of aggregation of the NGVM is named as 'Aggregated' and 'Disaggregated'. Aggregated freight transport models do not take into consideration flows between individual firms and logistics decisions but between regions or zones. Disaggregated means, that logistics decisions (e.g. use of consolidation and distribution centers, shipments sizes or loading units) are included. For this, the NGVM includes so called logistics systems (e.g. full truck load, pallets) (ARE 2011). Due to the fact that the information per shipment is finally aggregated to origin-destination flows for the network assignment the NGVM can be described as an aggregate-disaggregate-aggregate (ADA) freight model system.

SAMGODS can also be understood as an ADA freight model system as illustrated in Figure 3.

Thus, ADA freight model systems model the generation of trade flows and assignment to networks in an aggregate way and simulate logistics decisions at the level of individual firm-to-firm flows (Ben-Akiva, de Jong 2013). According to Ben-Akiva, de Jong (2013) the different logistics decisions could be:

- Frequency/shipment size (incl. inventory decisions)
- Choice of loading unit (e.g., containerized)
- Use of distribution centers, terminals and the related consolidation and distribution of shipments
- Mode/vehicle type used for each leg of the transport chain

These logistics decisions are made with the overall objective of minimizing total logistics costs. ADA freight model systems also have been developed for Norway and Flanders and are currently under development in Denmark and for the European Union (Ben-Akiva, de Jong 2013).

The development of a seaport hinterland model for the Port of Hamburg will follow the underlying logic of the ADA freight model system.

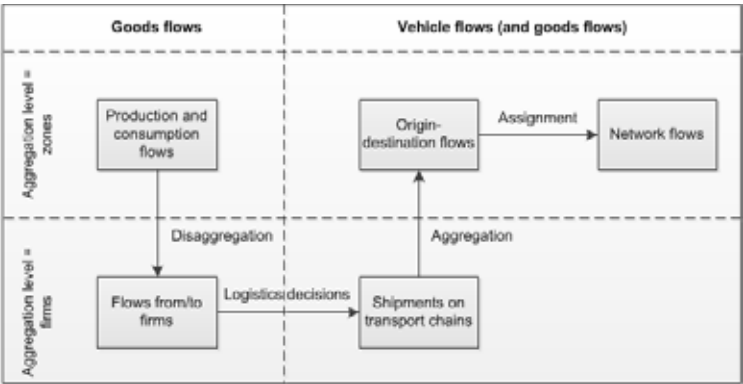


Figure 3 Structure of SAMGODS model (author based on Karlsson et al. 2012)

#### 4 Development of a Seaport Hinterland Model for the Port of Hamburg

The macroscopic freight transport model currently under development is funded by the Ministry of Science and Research of the City of Hamburg. The model follows the logic visualized in Figure 4.

In step 1, the transport networks as well as origin-destination matrices for different commodity groups (according to value and density) are created in

the software environment Visum. This step comprises the first two steps of the Four-Step Model as illustrated in Figure 2. The model includes road, rail and inland waterway networks. These networks connect in total 380 demand zones and 237 terminal zones across the whole of Europe. As part of this first step, origin-destination, distance and time matrices between the demand as well as terminal zones are calculated. These matrices form the input for the second step.

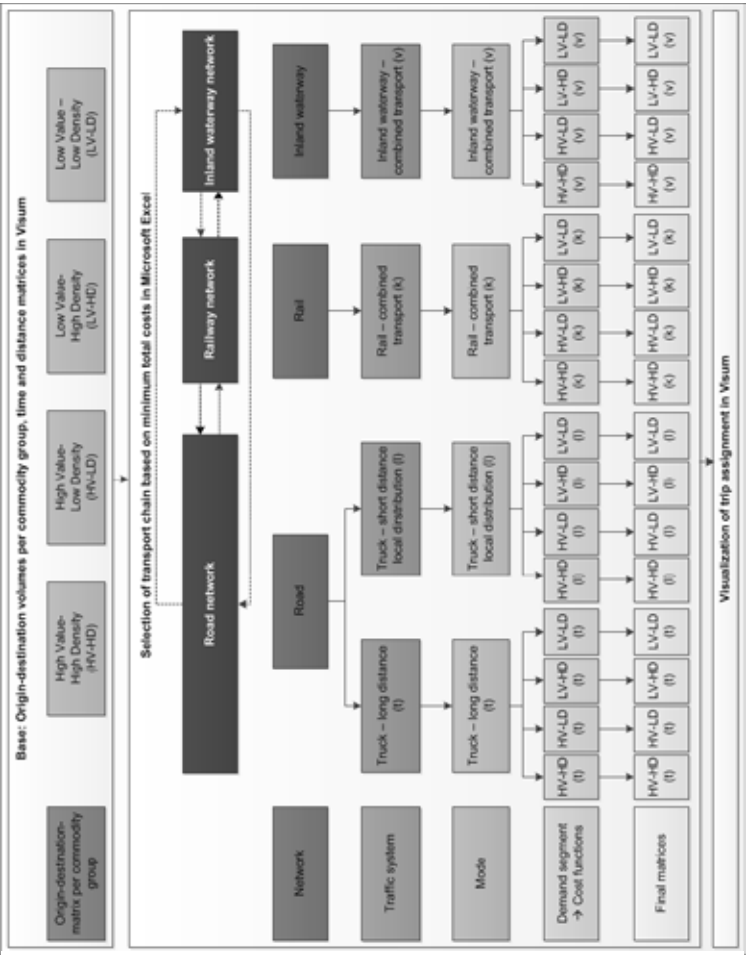


Figure 4 Traffic systems, modes, demand segments and demand matrices of the freight transport model under development (author)



The second step is carried out outside of the Visum environment by using a Visual Basic for Applications (VBA) macro in Microsoft Excel. In this step the least expensive transport chain for each origin-destination relation is chosen by passing the following process:

1. Select the cheapest path between origin and destination without transshipment.
2. Is there a cheaper path between origin and destination with one transshipment move? If yes, select this path - If no, select path between origin and destination without transshipment.
3. Is there a cheaper path between origin and destination with two transshipment moves? If yes, select this path - If no, select path between origin and destination with one transshipment.

The total number of transshipments is limited to two transshipments and distinction is made between different traffic systems (vehicle types). The step complies with the third step of the Four-Step Model (modal split). The result of this step is a certain path with a fixed modal split for each origin-destination relation and commodity group.

The final step consists of the transfer of goods flows in tons into vehicle flows and the assignment to the network. This step is again carried out inside the software Visum and complies with the fourth step of the Four-Step Modal (assignment).

As described, especially the second step of the new model logic bases on cost functions taking into consideration different transport modes, vehicle types as well as commodity groups.

## 5 Derivation of Cost Functions

In this section cost functions are derived and also applied to the use case of the Port of Hamburg. For this, characteristics of the Port of Hamburg's hinterland connections are presented first. Afterwards, cost functions implemented in the ADA freight model system are analyzed and adapted to the requirements of the model under development. Finally, the cost functions are tested taking into account a transport chain significant for the Port of Hamburg.

Total volumes handled in the Port of Hamburg amount to 145.7 million tons in 2014. This means an overall increase of 4.8 percent compared to 2013. Containers form about 70 percent of total throughput (9.7 million TEU (Twenty-foot Equivalent Unit) in 2014, +5.1 percent compared to 2013 (HHM 2015a). According to the current German sea traffic forecast the relatively high degree of containerization in the Port of Hamburg relates back to the NST-2007 commodity group 'not identifiable goods', which amounts to 20 percent of all hinterland volumes. Relevant hinterland regions for this commodity group are especially Bavaria, the Czech Republic, Baden Württemberg, Bremen as well as North Rhine-Westphalia (MWP et al. 2014). However, the relevant hinterland regions for all freight categories handled in the Port of Hamburg are different to that. Around 59.8 percent (5.8 million TEU) of all containers handled in the Port of Hamburg are transported into hinterland regions, most of them via the transport modes road (59.4 percent, 3.4 million TEU) and rail (38.6 percent, 2.2 million TEU) (HHM 2015b). Hinterland transport of containerized cargo via inland waterways forms a negligible low part of all containerized hinterland transports (only 2.0 percent).

Due to the Port of Hamburg's high degree of containerization and the significance of the transport modes road and rail the development of cost functions for transport chains in the hinterland of the Port of Hamburg will focus on containerized cargo into relevant hinterland regions and road only as well as rail-road transport chains.

ADA freight model systems include freight flows between zones or regions as well as individual firms. The basic model for decision-making on the disaggregated level (logistics decisions at the level of individual firm-to-firm flows) is the minimization of total logistics costs. According to Ben-Akiva, de Jong (2013) the disaggregated level consists of shipments of goods in number of shipments, tons, ton-kilometers, vehicle-kilometers and vehicle/vessels per year, by

- $k$ , commodity type
- $l$ , transport chain type (number of legs, mode and vehicle/vessel type used for each leg, terminals used, loading unit used)
- $m$ , sending firm (located in zone  $r$ )
- $n$ , receiving firm (located in zone  $s$ )
- $q$ , shipment size

As stated by Ben-Akiva, de Jong (2013) and Vierth et al. (2009) the total annual logistics costs  $G$  of commodity  $k$  transported between firm  $m$  in production zone  $r$  and firm  $n$  in consumption zone  $s$  of shipment size  $q$  with transport chain  $l$  (including number of legs, modes, vehicle types, loading units, transshipment locations) are:

$$G_{rskmnl} = D_k + I_{kq} + K_{kq} + O_{kq} + T_{rskql} + Y_{rskl} + Z_{rskq} \quad (1)$$

Where

*D*: Cost of deterioration and damage during transit

*G*: Total annual logistics costs

*I*: Inventory costs (storage costs)

*K*: Capital costs of inventory

*O*: Order costs

*T*: Transport, consolidation and distribution costs

*Y*: Capital costs of goods during transit

*Z*: Stockout costs

As can be taken from equation 1 the cost functions of ADA freight model systems take into account the costs of all transport, handling and storage processes within a transport chain (logistics costs). The cost function includes operators' as well as so-called senders' costs. According to Vierth et al. (2009) senders' costs include costs that are related to the transported good itself, as well as a certain risk (e.g. risk of delay or damage) cost. These costs are represented by the capital costs of the goods and the cost of deterioration and damage that are included in the equation above.

However, this equation is not focusing on containers as loading unit only. Some characteristics of container transports allow a reduction of the complexity of equation 1: First, goods are not likely to change loading units in long-distance hinterland transport chains. According to the definition of intermodal transport it is even forbidden (Tsamboulas et al. 2007). Most transport chains end in a logistics center. Second, once loaded on trucks it is unlikely that containers switch from road to other transport modes. Finally, transshipment terminals (rail-road) aim at reducing the dwell-time of

containers in order not to lose too much time and to increase the competitiveness of intermodal transport compared to road container transport.

A possible cost function representing containerized cargo is developed by Jourquin, Tavasszy (2014). According to Jourquin, Tavasszy (2014) intermodal container transport is an alternative to road container transport when the internal costs of the intermodal trip are competitive in comparison to the internal costs of trucking. Internal costs of moving a container cover the sum of costs incurred by the various parties responsible for the movement of the container (Black et al. 2003).

Following the authors argumentation the attractiveness of the intermodal chain depends on the level of transshipment costs and on the length of the pre- and post-haulages to and from the intermodal terminals. The authors define the cost functions for road (Equation 2) and intermodal container transport (Equation 3) as follows:

$$C_g^{road} = a_{road} * \left( \frac{h_{road}}{f_{road}} + e_{road} \right) \quad (2)$$

$$\begin{aligned} C_g^{rail-road} = & a_{rail} \left( \frac{h_{rail}}{f_{rail}} + e_{rail} \right) + b_{rail-road} \left( \frac{h_{road}}{f_{road}} + g \right) \\ & + d_{rail-road} + h_{rail} C_{rail-road} \end{aligned} \quad (3)$$

Where

$C_g^{road}$ and $C_g^{rail-road}$ :	Generalized costs for road and rail-road transport, per loaded ton
$a_{road}$ and $a_{rail}$ :	Truck-only and rail-only distances
$b_{rail-road}$ :	Post-haulage distances for rail-road transport
$c_{rail-road}$ :	Transshipment times for rail-road transport
$d_{rail-road}$ :	Transshipment costs for rail-road transport
$e_{road}$ and $e_{rail}$ :	Transport costs for road and rail-road transport
$f_{road}$ and $f_{rail}$ :	Transport speeds for road and rail-road transport
$g$ :	Post-haulage cost
$h_{road}$ and $h_{rail}$ :	Value of time

Again, these equations integrate the purchase costs of the goods inside the containers by introducing the variable  $h$  (value of time). Due to the fact that this approach fits better to the specific characteristics of containerized sea-port hinterland traffic it will be used to calculate the costs of selected hinterland transport chains of the Port of Hamburg. The following transport chains are analyzed:

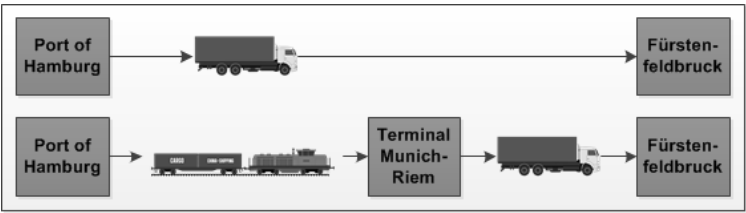


Figure 5 Analyzed transport chains (author)

As illustrated in Figure 5 the above described cost functions are applied to two possibilities to transport containers from the Port of Hamburg into its hinterland zone Fürstenfeldbruck (logistics center): First, as a unimodal transport chain by truck or second, as a multimodal transport chain by rail and truck.

Fürstenfeldbruck was selected as hinterland zone because Bavaria is the Port of Hamburg's most important hinterland region for containerized cargo (HHM 2013). Further, it is located within a radius of about 50km around the intermodal terminal Munich-Riem which is the most important intermodal terminal for containers in the Port of Hamburg's hinterland region Bavaria (HHM 2013). The radius of 50 km relates back to the assumption that the catchment area of intermodal terminals can be described as an ellipse around the terminal with a radius of at maximum 50 km (HHM 2013). In the analyzed intermodal transport chain, the transport mode rail is used for the main haulage. Road transport is only used for post-haulage. Hence, it can also be described as a combined intermodal transport chain (Destatis 2013).

Table 3 Input used in the cost functions for the transport of a 40-foot container (author based on Jourquin, Tavasszy 2014 and HHM 2012)

Variables	Road	Intermodal
<i>a</i> : Main distance (km)	798	$r = a - b$
<i>b</i> : Post-haulage distance (km)	n.a.	50
<i>c</i> : Transshipment time (hours)	n.a.	2
<i>d</i> : Transshipment costs (€/Cont.)	n.a.	22.50
<i>e</i> : Transport tariff (€/Cont.km)	1.17	0.53
<i>f</i> : Transport speed (km/hour)	50	40
<i>g</i> : Post-haulage tariff (€/Cont.km)	0.000	5.33
<i>h</i> : Value of time (€/Cont./hour)	1	1

The results of the research carried out in terms of the quantification of the internal costs are summarized in Table 3. The costs for the transport chains have been determined and quantified empirically by carrying out desk research as well as interviews with freight forwarders in 2015. Different origin-destination relations have been taken into account. Accordingly, the values listed in Table 3 are average figures for the analyzed transport chains. The variable transport tariff includes time-dependent (e.g. capital costs of the vehicle, administrative costs and personnel costs) and distant-dependent costs (e.g. operating and maintenance costs or energy costs) for the chosen



transport modes. Using the input data the costs for the different transport chains are

- 949.62 €/40-foot container for road only container transport and
- 707.14 €/40-foot container for intermodal container transport.

The transport costs of a 40-foot container with an average load capacity of 30.40 tons from Hamburg to the logistics center in Fürstenfeldbrück amount to 0.039 €/t.km for the road only transport and 0.029 €/tkm for the intermodal transport. The intermodal option turns out to be significantly cheaper than the road only alternative. This corresponds to observations made by Ricci (2003) or Black et al. (2003).

## 6 Discussion and Further Research

The chosen transport tariff for road transport is based on the assumption, that the average cost of movement by road amounts to 1.19 €/km for a 40-foot container. This value corresponds to the figures published in Black et al. (2003). As reported by them the value for moving a 40-foot container in Germany is 1.14 €/km. According to HHM (2012) the cost of moving a 40-foot container between Hamburg and Bavaria amounts to 1.17 €/km.

For intermodal transport it is assumed that the average cost for moving a 40-foot container amounts to 0.89 €/km. Again, this figure lies within a range that can be found in different studies. Within the project Hafen Hamburg 62+ systematic comparisons of costs have been carried out for different transport chains between Bavaria and Hamburg. Within the project, rail haul unit costs of roughly 0.79 €/km per 40-foot container were identified for container transports between Hamburg and Munich (HHM 2012).

Following this argumentation, the achieved results are in conformity with the current state of practice. However, several aspects have been neglected so far:

1. Different vehicle types. The calculation does just take into consideration one vehicle type (long-distance truck). But, operational costs can be different for different vehicle types.
2. Different commodity groups with different logistics backgrounds. The variable 'value of time' has not been quantified so far. Consequently, the purchaser's costs of the content of containers are not integrated. Neither are the specific requirements of different commodity groups, e.g. urgency of transport.
3. Different network types. The cost function calculates with average speeds and considers only one possible route.
4. Capacity restrictions. The interdependencies of different transport chains as well as capacity restrictions have been neglected so far. The attractiveness of a transport chain is dependent on the degree of utilization. The more containers are assigned to a transport chain (and route) the less attractive it will be because of an increasing probability of congestion.

Consequently, the described cost function can only be seen as a first approach towards the development of a cost function usable in the model under development.

## 7 Conclusion

Freight transport models are a useful tool for estimating the expected impacts of policy measures and are a necessary input for the justification of infrastructure measures. Based on cost functions transport demand is assigned to the transport network and different transport modes.

When intermodal transport competes with road transport, trucks are used in two different ways: Either they are used as a substitute for or as a complement for the rail. Nevertheless, for the analyzed Origin-Destination relation (Hamburg-Munich) the intermodal option turns out to be significantly cheaper than the road only alternative (707.14 €/Cont. for intermodal container transport compared to 949.62 €/Cont. for road only container transport).

The described cost function can be seen as a first approach to calculate the total costs of the Port of Hamburg's containerized hinterland transport chains. It needs to be extended by a quality variable that integrates the interdependencies of different transport chains as well as the probability of congestion in order to describe the transport market in a more realistic way. The sensitivity to cost changes or situational responses because of interdependencies as well as the differentiation between goods with different logistics backgrounds are challenges that need to be integrated into cost functions of an appropriate seaport hinterland model for the Port of Hamburg.

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