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A multimodal transport chain choice model for container transport

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Abstract

A large part of freight transport movements are part of a multimodal transport chain, in particular for port-related containerized transport flows. Because data of multimodal transports are unavailable it is challenging to develop a multimodal transport chain models. This paper describes the development of a new module for multimodal transport chains for modelling container transport within the Dutch strategic freight transport model "BasGoed". The choice model distinguishes unimodal, bi-modal or tri-modal transport chains, depending on whether the transport chain is port-related. A direct road chain is available between each production and consumption combination; direct barge or rail transport is only available between seaports. A route enumeration module generates a choice set for each observed uni- or multimodal container transport. Since no directly observed PC data are available, a synthetic dataset was constructed with container flows between locations of production and consumption, using uni-modal observed transport data. Main assumption is that each container transported by rail or barge requires a road leg at the side of destination and/or origin, to complete the multimodal transport chain. Discrete choice models were estimated with different model structures. The best choice model that was found was a multinomial logit model, segmented by port dependency. The results show that a choice model can be estimated with significant parameters, and with plausible model sensitivities.

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Keywords: Freight transport demand models, multi modal freight transport, The Netherlands

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1. Introduction

A significant volume of containerized transports is part of multimodal transport chains, especially for port-related containerized transport chains. Since decision-making takes place at the level of transport chains, between the location of production and consumption, it is important to simulate decisions at the level of transport chains in forecasting freight transport demand. This paper addresses the development of a new module for multimodal transport chains for container transport for the Dutch strategic freight transport model “BasGoed”. The existing BasGoed model simulates the separate uni-modal transport legs in multimodal transport chains individually. But to improve the representation of multimodal transport chains for container transport, a choice model is specified that addresses multimodal transport chains and enables an analysis of the impacts of new multimodal terminals in a strategic freight transport model.

The development of this choice model is one of the steps in the incremental improvement strategy of the BasGoed model of the Dutch Ministry of Infrastructure and the Environment. This improvement strategy is laid out in the long term road map for R&D of freight transport models (Tavasszy et al., 2010; Berg et al., 2015). The multimodal transport choice model project was commissioned by Rijkswaterstaat WVL and executed by a consortium of organisations: Significance, TNO and Demis.

Models for multimodal container transport chains are mostly applied in the domain of port- and inland terminal network design. Different approaches can be applied: aggregate or disaggregate, for network design or forecasting, all depending on data availability and the scope of study. For instance, Jourquin and Beuthe (1996) model intermodal transport chains in Europe using assignment in a tri-modal supernetwork using EU freight transport statistics. Limbourg and Jourquin (2009) use aggregate data in an optimization approach which optimizes terminal location based on commodity flows. Zhang et al. (2015) developed aggregate, national level models for transport chain choice and inland terminal location. Yamada and Febri (2015) apply a multimodal transport supernetwork to develop a discrete optimisation model for transport network design, but this work is still based on a hypothetical network. Based on the availability of data, and the aggregate nature of the Basgoed model, the multimodal transport chain model for Basgoed applies an aggregate approach which builds on the work of Zhang (2013).

Existing multimodal transport chain models such as TransTools in Europe all apply synthesized databases for multimodal transport, as observations of end-to-end flows are not available (e.g. de Jong et al., 2016). Therefore, a dataset was constructed with container flows between the landside origins and destinations: the PC dataset. We assume that the transport chain is built up with the port as first point or origin or destination, disregarding possible influences of the maritime transport leg. In modelling terms we will call this the endpoint of the PC relation, or place of production or consumption. Since no directly observed PC data are available, a simple transport generation procedure was used to construct PC flows synthetically from uni-modal observed transport data (TNO, 2016). An important assumption for this data processing is that, if no direct rail or barge connection is available, container transport by rail or barge requires a road leg to complete the multimodal transport chain. Another assumption is that the road feeder transport of containers to and from hinterland multimodal terminals takes place over relatively short distances, mostly within the region of the terminal.

The choice model distinguishes different types of unimodal, bi-modal or tri-modal transport chains, depending on whether the transport chain is port-related. A direct road chain is available between each production and consumption combination; direct barge or rail chains are only available between seaports. A route enumeration module is applied to generate a choice set for each observed uni- or multimodal container transport.

Based on the ‘observed’ PC flows and route choice sets, discrete choice models were estimated with different model structures, and for different segments for port dependency: flows between sea ports, flows with origin or destination within a sea port and continental flows (not port related). The estimated model is implemented and tested in the corridor choice module.

The article presents the model structure, the data that was used, the model estimations and test results with the model, including elasticities.

2. BASGOED STRATEGIC FREIGHT TRANSPORT MODEL

The strategic freight transport model Basgoed was developed over the past years as a basic model, satisfying the basic needs of policy making, based on proven knowledge and available transport data. The structure of the simple freight model is based on the four step freight modeling approach, which includes (see e.g. Ortúzar and Willumsen, 2011):

- freight generation: the yearly volumes (weight) of freight produced and consumed;
- distribution: the transport flows between these regions;
- modal split, resulting in the flows between regions by mode;
- traffic conversion and assignment, describing the number of vehicles on the network.

Basgoed uses the existing economic module of the SMILE+ model (Bovenkerk, 2005; Tavasszy et al, 1998) for the freight generation. This module is based on an input-output framework, and translates economic scenarios in regional freight production and attraction forecasts (domestic and import/export). The same geographic level of detail was kept in the model, i.e. 40 regions within the Netherlands (NUTS3) and 29 in the rest of the world. International trade tables not including the Netherlands as origin or destination, are also produced by this model, however not using the same I/O framework but based on exogenous trade scenario.

The distribution and modal split models are estimated specifically for Basgoed (De Jong et al., 2011). The distribution model generates OD-commodity flows in tonnes, based on a double constrained gravity based model. The modal spit model predicts the market share of road, rail and inland waterway for each OD-pair, using a multinomial logit choice model. The modal split model is fed by the underlying assignment models to provide measures of transport costs and times between regions. The specification of these modules were kept simple (Tavasszy et al., 2010) as they were the main exponent of the move towards simplification of the Dutch freight model system.

Separate models are used for the assignment stages. The traffic conversion and assignment stage is covered by the existing assignment models for passenger transport (the National Model System of Rijkswaterstaat), rail (the Nemo model of ProRail, the Dutch railway infrastructure provider) and inland waterways (BIVAS, of Rijkswaterstaat). The commodity classification used is NSTR-level1 (10 commodity groups).

As the assignment models have substantially more detailed zoning systems, baseline flow tables are matched at the aggregate (NUTS3) level. For prediction purposes, a growth factor method (pivot point analysis) is used. The model is run for a baseline and a future situation. Growth factors are derived for the O/D tables by mode, expressed in tons moved yearly. These growth factors are applied to the observed vehicle, ship and train matrices that are input for the detailed assignment models; after this, assignment of new flows can be done.

This model works quite well for unimodal transport chains. But multimodal chains, and especially containerized chains, are less accurately described by this classical approach. Therefore we will extend the BasGoed model with a specialised container module, replacing the distribution and modal split module for containerized transport only.

3. MULTIMODAL TRANSPORT CHAIN CHOICE MODEL

3.1. Introduction

Based on the aggregate geography of the Basgoed model (NUTS3) and availability of data, the specification of the multimodal transport chain model for Basgoed applies an aggregate approach (TNO and Significance, 2016). The multimodal transport chain choice model distinguishes between maritime and continental container flows. Maritime flows are transport chains via deep sea ports. Since no data is available on the maritime leg of container transports, the model assumes the port as a final origin or destination location. In other words, the model simulates transport chain choice for the hinterland transports via deep sea ports. The deep sea ports currently considered in the area to be relevant for Basgoed include Rotterdam, Amsterdam and Antwerp. In addition to the port related flows, the model includes all continental container flows: multimodal- and direct transports.

3.2. Description of multimodal choice alternatives

The model describes multimodal transport chains in the continental study area of Basgoed, which comprises of 40 Dutch and roughly 300 international regions. Locations of transshipment are regions with multimodal terminals available. The deep sea ports in the study area of Basgoed are main production- and consumption regions for continental and hinterland container flows in the study area.

The choice model distinguishes between different types of unimodal, bi-modal or tri-modal transport chains, depending on whether the transport chain is port-related. A direct road chain is available between each production and consumption combination; direct barge or rail chains are only available between seaports. Tri- or bi-modal transport chains have barge or rail as main mode. Table 1 gives an overview of the multimodal chain types and composition of choice sets in the model.

Table 1: Overview of multimodal chain types in choice sets (rd= road; rl= rail; iww= barge; T=multimodal terminal).

Segment	Chain type	Description	# alts.	Choice set size
Continental	rd	direct road	1	11
	rd-T-rl-T-rd	IM rail	5	
	rd-T-iww-T-rd	IM IWW	5	
From deep sea port	rd	direct road	1	11
	rl-T-rd	IM rail w. direct access in port	5	
	iww-T-rd	IM iww w. direct access in port	5	
To deep sea port	rd	direct road	1	11
	rd-T-rl	IM rail w. direct access in port	5	
	rd-T-iww	IM iww w. direct access in port	5	
Between deep sea ports	rd	Weg direct	1	3
	rl	Spoor direct	1	
	iww	Binnenvaart direct	1	

A route enumeration module is applied to generate a choice set for each observed container transport. This module generates a stratified choice set comprising of a distinct number of uni- bi- or tri-modal transport chain alternatives with main transport mode road, barge or rail. The composition of the choice set depends on the availability of direct access at the production or consumption side. For each type of multimodal transport chain, a fixed number of alternatives were selected with lowest transport costs. Since the spatial configuration of multimodal terminals is rather coarse, we selected a maximum of 5 multimodal transport chains with the lowest transport costs, to include enough multi modal chains that are likely alternatives.

3.3. Cost functions

The costs for each transport chain are described with a generalized transport cost function, with similar distance- and unit costs that are used in the modal split model. The generalized cost function for multimodal transport chain r between production region p and consumption region c is described by:

$$G_{pcr} = \sum_{l \in r}\left(c_v^d \cdot D_{ijl} \; + \; c_v^t \; \cdot T_{ijl}\right) + \sum_{t \in r}\left(c_v^{ove}\right) \tag{1}$$

With:

G : generalized transport costs
r : multi modal transport chain
l : transport leg in multi modal transport chain
p,c,I,j : region of production, consumption, intermediate origin, destination
t : multimodal terminal
v : main mode

c_v^d : distance unit costs (Euro/tonkm)
D : distance (km)
c_v^t : time unit costs (Euro/ton/h)
T : transport time (h)
c_v^{ove} : transfer costs (Euro/ton)

Transport costs are the main determinant in the systematic part of the utility function. In addition to a parameter for generalized transport costs, a time parameter for capital costs (interest costs, depreciation, and insurance for time in transport) and chain specific dummy parameters. In addition, separate models were estimated for each segment: port export, port import, continental and inter-port segments:

$$V_{pcr}^S = \beta_{gcost}^S \cdot G_{pcr} + \beta_{time}^S \cdot T_{pcr} + CSC_v^S \tag{2}$$

With:

β_{gcost} : parameter for generalized costs;
β_{time} : parameter for capital costs during transport;
CSC : constant for each type of multi modal transport chain;
S : segment.

4. DESCRIPTION OF SYNTHETIC PC DATA

The Production Consumption (PC) flow data describe the physical flow of goods between the region where the goods are produced to the region where the goods are consumed, but since this data is not directly observed, in practice synthetic or modelled data is used (e.g. see de Jong et al., 2016). Also for Basgoed, a PC data set is constructed synthetically. In this section we describe a data driven construction method for the PC data. The approach is based on transport flows observed and reported through the Dutch statistics office and infrastructure network operators. For a more elaborate description of the approach we refer to TNO (2016).

4.1. From uni-modal observed transport data to PC flow data

As the input to the PC flow construction procedure the following container transport data sets have been used.

1. Wegvervoerdata (CBS, 2014): Road transport flow data
2. Spoorvervoerdata (ProRail, 2015): Rail transport flow data
3. Binnenvaartdata (RWS Water, Verkeer en Leefomgeving, 2014): Inland waterways transport flow data

These datasets are “observed” datasets, which are generated through survey samples or directly registered data. Per mode each data set indicates annual container loading and unloading NUTS3 region and ton volume transported. These unimodal transport flow data form the input for the construction of multimodal PC flow data. Construction of the multimodal PC flow data distinguishes four types of transport chains

1. Maritime flows by train and IWW
   i) From deep sea port to the hinterland (sea port production)
   ii) From hinterland to the deep sea port (sea port consumption)

   To the deep sea ports belong the ports of Amsterdam, Antwerp and Rotterdam. To the hinterland locations belong all relevant NUTS3 regions except NUTS3 regions of the aforementioned ports.
2. Continental Multimodal (IM) flows: the flows from a hinterland location to a hinterland location by train or inland waterways.
3. Direct flows by road transport. These flows do not involve multimodal transport, as the goods are transported directly from the production to consumption locations.
4. Direct rail and inland waterways flows between two deep sea port regions

The PC flow generation procedure essentially looks at the hinterland multimodal terminals. It is known that the majority of the transshipped containers will stay in the transshipment region, or will be transported by road to the surrounding regions over relatively short distances. Therefore, for the construction the PC dataset, the following assumptions and procedures have been used:

1. ***For the*** regions ***within the Netherlands***. The production region of a non-seaport produced container is located in the same NUTS3 hinterland region where the container is loaded onto a ship or train under the condition that there are sufficient intra-regional road transport volumes to transport containers within the region from the place of production to the multimodal terminal. If more multimodal containers leave the region by train or barge than transported by road within the region, it is assumed that containers from the surrounding regions are brought to the terminal. The volume of this transport is limited to the maximum of traffic flow from those surrounding regions to the terminal region. The surrounding regions are defined as 5 nearby most important in terms of road transport volume to the terminal region. The deep sea port regions are excluded. If the intra-regional volumes together with the volumes of surrounding regions are not sufficient to bring the departing containers to the terminal, it is assumed that those containers have not been brought to the terminal by road, but originate directly at the terminal. The same assumption in a mirrored form is used for the containers consumed at the region.
2. ***For foreign locations, outside of the Netherlands***. The production region of a non-seaport produced container is located in the NUTS2 hinterland region where the container is loaded onto a ship or train. The same assumption in a mirrored form is used for the containers consumed at the region.

The total multimodal transport PC flow matrix is the sum of all four types of transport chain related PC flow components.

4.2. Descriptive statistics

The resulting PC flow matrix describes the flow of 106,8 MTon of containerized goods in 4828 production-consumption relations. Table 2 and Table 3 present descriptive statistics with respect to the type and direction of flow correspondingly.

Table 2: Descriptive statistics per type of flow

Flow Type	**N**	**Volume (Mton)**	**Share (%)**
Deep sea port production IM	326	21.8	20%
Deep sea port consumption IM	310	30.6	29%
Continental IM	2527	3.5	3%
Direct Road Unimodal	1652	43.9	41%
Direct Rail and IWW between deep sea ports	13	7.0	7%
Total	**4828**	**106,8**	**100%**

Table 3: Descriptive statistics per direction of flow with respect to the sea ports

Direction of Flow	**N**	**Volume (Mton)**	**Share (%)**
Continental	3736	10.3	10%
From deep sea ports	543	34.0	32%
To deep sea ports	527	42.2	40%
Between deep sea ports	22	20.3	19%
Total	**4828**	**106.8**	**100%**

5. ESTIMATION RESULTS

Based on the specifications and data described above, different choice models were estimated. The optimal model specification was a MNL logit model with coefficients for generalized transport costs (GCost), capital costs (KCost) for continental transport, and chain type specific constants for multimodal rail- (CSC_IMsp) and barge transport chain (CSC_IMiw). The estimation results are presented in Table 4.

The models show significant coefficients with the expected sign (negative) for generalized transport costs (GCost). The CSC's are significant and negative for multimodal chain types. Indicating, apart from clear cost differences, a significant advantage of road transport (reference type). This seems plausible given the higher flexibility (and perhaps reliability) of direct road transport compared to multi modal transport chains. The estimated parameters for multimodal transport using inland waterways (CSC_IMiw) show a slight preference over using multimodal rail transport (CSC_IMsp). Most likely this this the result of the high service level of the dispersed inland waterways network in the hinterland of the deep sea port of Rotterdam.

The time parameter for capital costs is only significant for continental transports. In case of transports between sea ports the number of observations is too low to derive significant estimates, and for container flows from the hinterland back to the sea ports mainly concern low value return flows, or often empty containers.

Table 4: Estimation results multimodal transport chain model

	Deep sea port related:			**Continental**
	From	**To**	**Between**	
Observations	543	527	22	3736
Final log (L)	-804,7	-1067,5	-117,4	-130,3
D.O.F.	3	3	2	4
Rho²(0)	0,382	0,339	0,67	0,67
Estimated	7-nov-16	7-nov-16	7-nov-16	7-nov-16
CSC_road (ref.)	0 (*)	0 (*)	0 (*)	0 (*)
CSC_IMiw	-2.715 (-20.1)	-2.133 (-18.3)	-1.871 (-14.0)	-0.616 (-0.9)
CSC_IMsp	-3.509 (-20.9)	-3.338 (-21.4)	-8.177 (-3.7)	-7.546 (-7.1)
GCost	-0.356 (-16.7)	-0.375 (-18.8)	-0.356 (*)	-0.268 (-6.7)
KCost	0 (*)	0 (*)	0 (*)	-0.097 (-3.8)

Each segment clearly has distinctive parameters for costs, either chain specific constants, therefore we choose to implement the same segmentation of choice models into Basgoed.

The resulting multinomial model (MNL) assumes equal substitution between all transport chain types. In addition, nested logit models (NL) were estimated but the estimates nest coefficients were in an implausible range. We tested nest coefficients for clusters per region of transshipment: assuming higher competition between barge and rail chains that have the same region of transshipment. And we tested a nesting structure for clusters of transport chain with similar main mode of transport (barge or rail), assuming higher competition within the mode segment. None of the models was preferable over the standard MNL model, which most likely is the result of the lack of detail in simulating multi modal transport chains with a regional geography.

After model implementation, we derived time- and costs elasticities for tonnes transported, that we will discuss here to validate the sensitivity of the model. Table 5 presents the elasticities that are derived from a series of runs with cost- and time scenarios. When compared to international literature, the cost elasticity for road transport, -0.34, seems to fall in a plausible range: Jourquin et al. (2016) report -0.14; de Jong et al. (2010) report -0.40, and Jensen et. al. (2016) report a range of -0.43 to -0.21. The cost elasticity for rail, -1.25, is high compared to the other modes but this is in line with results found in literature: de Jong et al. (2011) report -0.87 on data for the Netherlands in previous Basgoed estimations; VTI and Significance (2010) report a range of -0.8 to -1.6 based on a literature review.

The cost elasticity for inland waterways, -0.50, falls within the range of previous results: de Jong et al. (2011) report -0.28 on data for the Netherlands in previous Basgoed estimations; while the EXPEDITE consortium (2002) reported a cost sensitivity for IWW of -0.76.

Table 5: Elasticities from the multimodal transport chain model

	Road	**Rail**	**IWW**
Road: time	**-0.15**	0.62	0.69
Rail: time	0.13	**-0.92**	0.41
IWW: time	0.16	0.79	**-0.96**
Road costs	**-0.34**	0.99	1.10
Rail costs	0.14	**-1.25**	0.51
IWW costs	0.83	0.50	**-0.50**

6. CONCLUSION AND DISCUSSION

This paper presents a multimodal transport chain choice model for container transport for a strategic freight transport demand model. The model contains a route enumeration module that constructs a set of plausible multimodal transport chains. The market shares for each transport chain are derived from a discrete choice model, using generalized transport time and chain type specific constants are main explanatory variables. The results with test runs show plausible model sensitivities. Most importantly, the module adds the functionality to the strategic model, to explicitly simulate the impact of new multimodal container terminals on transport market shares.

Main disclaimer with the presented approach is the use of constructed data. Since no observed data exists from multimodal transport chains between location of production and consumption, multimodal PC data was constructed, by linking uni-modal transport statistics. However, results are still valuable: the constructed data and results are consistent with the uni-modal freight statistics for The Netherlands, which also form the basis for any policy analysis. The results show that a choice model can be estimated with significant parameters, and with plausible model sensitivities. Implementation of this module in Basgoed is currently taking place and allows the analysis of the impact of new container terminals on container transport flows. However, we do emphasize that data collection, in this case multimodal transport data, remains a challenge. Therefore, to develop more advanced multimodal transport models data collection is one of the key issues on the long term improvement strategy of the BasGoed model (Tavasszy et al., 2010; Berg et al., 2015).

In the presented specification the location of transshipment in multimodal transport chains is modelled at the level of NUTS 3 regions. To improve the level of detail of modelled transport chains, the granularity of the network should be refined to allow the formation of transport chains through individual terminals.

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