September 25th — 26th, 2017 | Darmstadt, Germany
Interdisciplinary Conference on Production, Logistics and Traffic
www.icplt.org

A macroscopic freight transport demand model to analyse effects of transport planning in Germany

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Abstract: DLR has developed a macroscopic freight transport demand model. Its feature is its consistency in all steps of demand modelling. The Freight Generation generates traffic based on gross value added, trade volumes and value densities first and uses its results of domestic and international traffic as input to distribute traffic with a gravity model, adjusted by iterative proportional fitting. Distribution and Modal Split are nested based on generalised costs and their expected maximum utilities. The model provides independent advices from a research perspective on matters of transport planning by examining new technologies and innovations of the current traffic system. The model is sensitive to policy measures that affect transport costs, and transport times, and vehicle utilisation. Besides that trade relations can be analysed and predicted. Model versions have been used in several projects analysing scenarios for freight traffic development in the coming decades and the connection to environmental and economic indicators.

1 Introduction

This paper describes a macroscopic transport demand model of surface freight transport. It is part of the "Transport model for Germany", DEMO, which has been developed at the German Aerospace Center (DLR), Institute of Transport Research [8]. DEMO is the only nation-wide transport demand model for Germany, which includes synthetic variables in their submodules of private and commercial transport demand and presents an assignment of the final demand to surface transport networks. The introduced module for freight transport demand analysis follows the steps freight generation, freight distribution, choice of mode and trip conversion and is coupled to the assignment model of DEMO to obtain network related data like travel times and distances as well as to consider route choice and congestion effects.

The tool is used to analyse the effects of transport planning and policy measures on freight transport in a differentiated way for specific commodity groups, distance bands and modes. The model is sensitive to measures that affect interaction of commercial corridors, transport costs, transport times and vehicle utilisation. Therefore it is suited to analyse effects of new technologies and innovations in transport. Model versions have been used in several projects analysing scenarios for freight traffic development in the upcoming decades and the connection to environmental and economic indicators.

2 Model specification

2.1 Freight Generation and Distribution

Based on a regression analysis between gross value added in different sectors (NACE divisions) and transport statistics for different commodities (NST sub-chapters/divisions), the amount of goods produced and attracted in currently more than 400 traffic zones in Germany is calculated. The approach uses external structural data forecasts [2,7] as economic input as well as supply and use tables to provide the weighting of different sectors for specific products [5].

Import, export and transit are derived from the Regionalised Structural Data Forecast computed for the Federal Transport Infrastructure Plan (BVWP) [2]. Using trade data and value densities of foreign trade statistics, foreign trade volume is converted into transport volume, thus ensuring a consistent model for all freight traffic touching German territory.

This approach results in indicators of domestic and international traffic. The calculation of inland traffic indicators is explained in detail in Müller/Wolfermann [5]. The indicator of the international trade generation is calculated as:

$$T_{i,commodity} = \frac{EI_{i,s}}{v_c} \quad \textbf{(1)}$$

The individual components (for any individual commodity) are given by:

- $T_{i,c}$: tons of commodity *c* generated in zone *i* (tons/year).
- $EI_{i,s,}$: economic indicator in form of gross value added of zone *i* in economic sector *s* (€/year).
- v_c: value density of commodity *c* (€/t).

Freight is subsequently distributed by an attraction constrained gravity model that uses composite generalised cost of the three surface modes rail, road and inland waterways as a distance measure (impedance). Generalised costs comprise travel times and transport costs. The same generalised costs are used in the modal choice to assign the freight flows to the modes. In the next step the result of this attraction constrained gravity model is used as the start value in an iterative proportional fitting algorithm (IPF).

These considerations lead to the following expression of the freight distribution:

$$T_{ij} = \frac{P_i A_j BC(C_{ij}) K_{ij}}{\sum BC(C_{ij}) K_{ij}} \quad \textbf{(2)}$$

The individual components (for any individual commodity) are given by:

- T_{ij}: tons from zone *i* to zone *j* (ton/year).
- P_i: tons produced in zone *i*, according to generation analysis (ton/year).
- A_j: tons attracted to zone *j*, according to generation analysis (ton/year).
- $BC(C_{ij})$: Box-Cox-transformed generalized costs.
- K_{ij}: calibration parameter.

2.2 Mode choice

The freight flows from origins to destinations by commodity are assigned to the surface transport modes railway, road and inland waterways by a multinomial logit model. A substantial stated preference study among shippers has been conducted as part of the German Transport Forecast 2030 [1]. This survey derived sensitivities for transport costs, transport times and reliability measures among others for ten distinct market segments. The model parameters for the logit model are derived from this SP experiment and enable the use of commodity groups according to the classification of the European transport statistics (NST 2007) while taking account of peculiarities of market segments (e.g. different kinds of bulk goods, general cargo, combined transport).

Transport costs for the three modes are determined from detailed components (e.g. commodity dependent vehicle costs, tolls, energy costs [4]). The determination of relation specific costs is coupled to the vehicle model (see 2.3) which ensures the consideration of commodity specific vehicle utilisation. The modal split module is calibrated to modal freight flow matrices computed for the German Transport Forecast 2030 [3].

Particularly for bulk cargo, single transport sources with individual characteristics have a major impact on freight flows and mode choice. The smaller the geographic scale the more the calibrated modal split tends to extreme values (all freight transported by one mode only) which renders the logit model inelastic to changes in transport costs and travel times. In order to cope with this challenge, the modal split model uses a pivot approach on state level (NUTS 1). Thus, average values per state are obtained and the model elasticities become more realistic. Changes in the tons transported per mode are pivoted on the NUTS 3 matrices.

These considerations lead to the following expression of the generalised costs U and the mode shares p:

$$U_i = \alpha_i + \beta_c BC(C_i, \lambda_c) + \beta_T BC(T_i, \lambda_T) + \beta_V BC(D_i, \lambda_V) \quad \textbf{(3)}$$

$$p_{disaggregate,i} = \frac{exp(U_{disaggregate,i})}{\sum_j exp(U_{disaggregate,j})} \quad \textbf{(4)}$$

$$p_{aggregate,i} = \frac{\sum_j p_{disaggregate,i}}{n} \quad \textbf{(5)}$$

$$cp_{aggregate,i,scenario} = \frac{p_{aggregate,scenario} - p_{aggregate,base\ scenario}}{p_{ggregate\ cell,base\ scenario}} \quad \textbf{(6)}$$

$$p_{disaggregate,i,scenario} = p_{disaggregate,i,base\ scenario} * (1 + cp_{aggregate,i,scenario}) \quad \textbf{(7)}$$

The individual components (for any individual commodity) are given by:

- U_i: utility of alternative *i*.
- $p_{disaggregate,i}$: selection probability of alternative *i on disaggregate cell level.*
- $p_{aggregate,i}$: averaged selection probability on aggregate level of states.
- n: number of disaggregated cells in the aggregated state.
- cp_i: changed selection probability of alternative *i on aggregate level of states.*
- α_i: alternative specific constant (ASC) of alternative *i*
- C_i: transport cost of alternative *i* (€).
- T_i: transport time of alternative *i* (min).
- P_i: punctuality of alternative *i* (percent).
- D_i: delay time of alternative *i* (min).
- BC: BoxCox-transformation.
- $\lambda_C, \lambda_T, \lambda_V$: parameter of BoxCox-transformation.
- $\beta_c, \beta_T, \beta_P, \beta_V$: MNL parameters.

2.3 Conversion of freight flows to origin-destination trips

Commodity flows are converted by factor approaches into vehicle trips by rail, road and inland shipping. The conversion differs slightly between the three modes.

Road vehicle trips are computed according to trip distance in subsequent steps: weighting the share of lorry size in five weight categories; deriving vehicle utilisation; generating the share of empty trips. The trip conversion is calibrated on national level to transport statistics. For railway transport a certain share of wagonload traffic is assumed depending on commodity. Costs are calculated separately for combined transport, trainload, and wagonload. A similar but more aggregate approach is followed for vessels. Combined and conventional transport is distinguished between two vessel sizes each, which depend on the waterway class used (larger vessels for River Rhine and similarly large waterways). Thus, size, utilisation, and empty trips are defined.

The trip flow matrices per traffic relation and year can be converted to daily trip matrices using time variation curves. However, as the variation particularly for road traffic differs between locations this conversion is only significant for aggregated evaluations. Trip matrices are passed to a traffic assignment tool for the computation of accurate travel times and trip distances which feed back into the freight model [8].

3 Example of application

The model is particularly well suited to policy and technology assessments on large scale. Changes to tolls and fuel taxes, the introduction of new vehicle types with specific vehicle costs and sizes or the impact of new handling technologies can be analyzed for their effect on modal split and overall freight rates. Furthermore, different scenarios of economic development in specific sectors and regions and the impact on freight generation and freight distribution can be modelled.

A new technology, currently discussed in the context of fighting climate change, is the electric lorry equipped with pantographs obtaining electricity from overhead contact lines. The suggestion is to furnish important motorways with the overhead lines so that long distance lorries can drive electrically. While this technology would reduce the carbon footprint of long distance road freight transport, it might well lead to a modal shift from rail to road, thus diminishing the positive effect. Hence, the overall effect of introducing this technology on GHG emissions is of major interest for policy makers.

To estimate these effects, assumptions and results are contributed by a project, named Renewbility, which is coordinated by the DLR and finished in 2015 [6]. Concerning lorries infrastructure costs are derived from existing studies. Relating to a desired increase of attractiveness of railway a further scenario is created, which includes the reduced time of train composition and cargo handling, caused by automatic vehicle monitoring and improved combined transport technologies.

A combined railway and lorries scenario can shift 3%-points to rail transport. A single railway scenario results in a shift of up to 5%-points to 23% modal share of railway considered transported tons-kilometers [6]. Hence, it is shown, that the traffic system needs to be considered completely concerning competition between transport modes and improvement of efficiency of railway can be minimized by the same in road transport. Furthermore a single improvement of the rail system, as it currently exists, does not cause a significant shift.

4 Outlook

The example of application highlights the strength of DEMO by its applicability to large geographical areas (Europe) without excessive need for disaggregated data and its plausible sensitivity to changes in transport costs and transport times. With its strengths DEMO is able to provide independent advice from a research perspective on matters of general relevance in the context of freight transport and further helps to improve transport planning by examining new technologies and innovations of the current traffic system.

Till now the model does not adequately represent logistics (lot sizes, transport chains, terminal location etc.), and effects on the underlying decision makers, namely logistics service providers. But the modular structure of the model allows a successive improvement of its parts. Hence the next major step will be the incorporation of logistics in the model, namely consideration of lot sizes and transport chains and, thus, also an improvement to the modelling of intermodal transport.

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