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INTEGRATION OF TRANSPORT LOGISTICS HUBS IN FREIGHT TRANSPORT DEMAND MODELLING

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1. INTRODUCTION

Transport logistics hubs are important elements of freight transport and traffic is increasingly managed and handled by logistics hubs. They play a decisive role in transport processes. However, there is still little empirical knowledge about those hubs and they are considered insufficiently in most freight transport demand models. In order to understand the role of logistics hubs in the transport systems, empirical surveys and model-based calculations are important tools. They can help to determine the effects of measures regarding the transport system and answer the question for transport demand and the drivers behind it. The lack in empirical knowledge and the insufficient integration in freight transport demand models are determined by each other. This leads to the following research questions:

- What types of logistics hubs do exist and how could they be classified?
- Which characteristics and structures can be found for these different types of hubs?
- How do models in application integrate transport logistics hubs in freight transport demand modelling and what are proper methods?
- Which key values could be derived to describe logistics hubs in models?

The aim of this paper is to answer these research questions and, therefore, to provide a substantial contribution for the understanding of transport logistics hubs. In order to answer these research questions we will present the state-of-the-art in a first step. Therefore, we give a definition of logistics and logistics hubs and evaluate the integration of hubs in freight transport demand models consulting significant literature on the topic. In the subsequent chapter the research methods are explained. This mainly concerns literature research, the collection and analysis of secondary and primary data as well as the use of statistical methods to derive key values for modelling. The results will be presented in the following chapter. We will present a typological order of hubs and the results of the data analysis. Furthermore, we will show how the generated key values could be used for freight transport demand modelling in Germany. We will point out that the enhance data basis widens the possibilities for modelling and demonstrate this for the hub type of freight forwarding companies. The results are finally discussed in chapter five. An outlook and further research steps will be drawn in the conclusions at the end of the article.

2. STATE-OF-THE-ART

In the following chapter we will present how logistics and logistics hubs are currently integrated in freight transport demand modelling. In order to delimit the field of our research and to understand the hub integration some definitions about logistic and logistics hubs are given at first. The presentation of the state-of-the-art will point out the relevance of our research.

2.1. Logistics and Logistics Hubs

Logistics is defined as the process of planning, implementing, and controlling procedures for the efficient and effective transportation and storage of goods including services and related information conforming to customer requirements. It covers the whole transport chain from the point of origin to the point of consumption and includes inbound, outbound, internal, and external movements (Vitasek, 2013). Logistics hubs are intermediate points between the origin and the final destination of commodity flows. They provide the possibility to adjust flows both temporally and spatially. Logistics hubs represent the locations that determine the free flow of freight (Raimbault et al. 2011). In this context, logistics hubs can be defined as locations where goods are stored in warehouses or transhipped between different transport modes and vehicles. In the following, we will distinguish between transport logistics hubs and distribution logistics hubs. Transport logistics hubs mainly possess transhipment function as well as a buffer function as a time offset. In this context, transport logistics hubs are, for example, airports, seaports, terminals for intermodal transport as well as handling facilities of freight forwarders and courier, express and parcel service providers (cep service providers). In contrast, distribution logistics hubs are oriented towards storing goods for a longer time period. Examples for distribution logistics hubs can be found in central or regional warehouses. Within this research approach transport logistics hubs in Germany are considered.

The literature shows that research approaches have been developed, which investigate transport and transport networks. The state of the art is, however, very rare regarding logistics hubs in general and transport logistics hubs in particular. Only few approaches consider or study logistics hubs as fundamentals of the networks (Becker et al. 2003, Beuthe & Kreutzberger 2001).

There are different research approaches that examine the impact of logistics concepts or strategies on transport (see e.g. Drewes Nielsen et al. 2003, McKinnon & Woodburn 1996, Clausen & Iddink 2009) but there still has been no approach which describes logistics hubs in a comprehensive way. Other references have tried to develop a standardisation of logistics centres (Higgins et al. 2012) and to systemize their characteristics (Klaus & Krieger 2004). Although these approaches do not describe logistics hubs comprehensively, they could serve as a basis for systemising and specifying logistics hubs. Hesse and Rodrigue (2004) developed a systematization of logistics hubs and provide relevant characteristics of them. Glaser (1995) and Rimienė & Grundey (2007) describe and systemise other types of logistics hubs and extend their approach to a systematization of logistics. They consider hub-related criteria, characteristics and attributes of transport volume and performance as well as specific features of companies based on the logistics hubs and their customers. Sonntag et al. (1999) try to explain the effects of logistics hubs on urban transport. They analyse different types of hubs and derive diverse effects. Thereby, they present an approach to estimate outgoing flows of the origin hubs and calculate transport-specific effects of different hub combinations for specific cities. The results of this study can be used as a basis for assessing potential locations of logistics hubs. Transport-specific effects are describes per type of hub in detail on the basis of daily inflows per truck, distance classes per tour, transport volume on workdays, transport performance and daily traffic load curves. However, key values cannot be derived, which would reveal specific transport volume for a single hub. The reason is that the spatial scope of the study, which only describes transport effects of hubs on regional and urban level. Wagner (2009) also investigates transport effects of logistics hubs. This is done from the regional and transport planning point of view. She presents an approach to assess transport effects (e.g. transport volume, transport performance and transport consequences) of settlements of logistics service providers. Jünemann (1989) analyses logistics hubs on the basis of their corresponding storage organization. He focuses on hubs with storage function and investigates intra-logistical characteristics. His categories are static and dynamic key values for transshipment and commissioning performance (e.g. warehouse capacity, goods inflows per day). These approaches can be used as fundamentals in order to develop a theory-based typological order of logistics hubs.

2.2. Logistics and Logistics Hubs in Transport Demand Models

In the past there were several attempts to integrate logistics aspects into freight transport demand models. The article from Bergman (1987), which was presented at the International Meeting on Freight, Logistics and Information Technology, is widely recognized as the starting point in the process of integrating logistics aspects into transport modelling. In his paper he proposes a more comprehensive representation of logistics processes in freight models. In the early 1990s the introduction of basic aspects of logistics decision-making in freight models was boosted in the Netherlands. Since then it has taken years before comparable approaches were adopted elsewhere (Tavasszy 2006; Tavasszy et al. 2010; de Jong et al. 2012).

Even though logistical aspects were considered in freight transport demand modelling to a greater extend in last decades, there are currently only a few different models in application, which incorporate logistical aspects actually (Liedtke 2009). New methodical possibilities and the availability of new surveyed data allowed the integration of logistics into freight modelling, which resulted in greater realism of some models. Almost all models in use operate in different countries and across borders, to some extent. The British EUNET, the Dutch SMILE or in the Spatial Logistics Appended Module (SLAM) realized in the European model SCENES can be named as some examples in this manner. Furthermore, SAMGODS and NEMO, which represent the national transport models implemented in Sweden and Norway, represent exemplars in this domain (Tavasszy et al. 2010). However, the differing initial situation regarding data availability and model characteristics did lead to different methods of integrating logistics in general, and logistics hubs in particular.

There are different articles dealing with integrating logistics into freight transport modelling (see. e.g. de Jong et al. 2004, 2012 or Tavasszy 2006, Tavasszy et al. 2012). Although these reviews treat of the integration of logistics excellently, they do not centre on the integration of transport logistics hubs specifically. Nearly every paper reviews international models and the integration of logistics in a more general way. There are no articles that focus specifically on the integration of transport logistics hubs regarding models in application.

Approaches that focusing on the determination of freight transport demand for Germany are lacking integration of logistics hubs. Existing models like the trip chain model of Machledt-Michael (2000), InterLOG (Liedtke 2006, Rothengatter & Liedtke 2006) or the WIVER model (Sonntag 1996) are not applicable to consider transport logistics hubs. The WIVER model from Sonntag (1996), for instance, was originally consulted to estimate effects of distribution logistics hubs in cities and their hinterland. However, a comprehensive integration of transport logistics hubs and their integration in logistics structures are not achieved. The exact picturing of this special type of hub is crucial for modelling transport demand and trips generated at these hubs. Nevertheless, freight transport demand models in Germany are not able to capture transport logistics hubs in their calculations.

Investigating international models, a proper integration of logistics hubs can mostly be found in models, which implement logistics modules. Based on cost minimization these modules consider logistics decisions and build origin-destination-matrices that contain different distribution channels passing logistics hubs. Predefined transport chains are then selected and commodity flows are directed over distribution centres within the transport chain, for instance. Crucial influences on the consideration of hubs are the characteristics of commodities and shipments (e.g. type of good and shipment size). According to the characteristics of hubs there are certain limits in handling specific goods or shipments. If hubs are not suitable to handle specific commodities, the probability of transportation passing these hubs will be reduced. In this way, the combination of the characteristics of hubs with the characteristics of shipments determines the utilization of hubs and, therefore, the impact of hubs on transport demand (e.g. de Jong & Ben-Akiva 2007 or de Jong et al. 2010).

An interesting aspect, which goes beyond the integration of logistics hubs corresponding to, for example, modal connectivity or different types of commodities handled at hubs, is the inclusion of detailed hub characteristics like differences in technologies used at hubs, if the technologies used vary significantly (see e.g. SAMGODS). However, the integration of logistics hubs in transport demand models is mostly achieved by considering commodity characteristics and hub attributes.

It has to be kept in mind that, although logistics hubs are currently taken into account in models, considered hubs are mainly distribution logistics hubs. Accordingly, hubs serve as distribution and consolidation centres in most cases and are, therefore, integrated as sources and sinks in the models. In addition, hubs are considered as so-called special generators or singular traffic generators in a more simple way with externally defined input and output regarding their transport volume.

Table 1 gives an overview of relevant freight transport demand models according the identified topic. The table reveals that transport logistics hubs are considered in much less cases than distribution logistics hubs and that only some models in application integrate transport logistics hubs in a proper way. There seems to be a very obvious and evident reason in this context: data availability. Although it is not always evident where the used data come from and what they contain in detail, they obviously allow an adequate consideration of these hubs. For this reason it seems to be apparent that the capability of models to consider transport logistics hubs varies with the available data.

Table 1: Overview of identified freight transport demand models

Model	Resolution	Scale of analysis	Depth of aggregation	Type of considered hubs
SAMGODS / NEMO	national	macro	aggr. / disaggr.	DLH, TLH
SMILE	national	macro	aggr.	DLH
SLAM	international	macro	aggr.	DLH
EUNET	national	macro	aggr.	DLH
LAMTA	urban / regional	macro	aggr.	DLH, TLH
CMAP	urban / regional	macro / meso	aggr. / disaggr.	DLH, TLH
FAME	national	macro	aggr.	DLH, TLH
GoodTrip	urban	macro	aggr.	DLH
WIVER	regional	macro	aggr.	DLH

Own illustration according to (Boerskamps & Binsbergen 1999, de Jong et al. 2010, Donnelly et al. 2006, Fischer et al. 2005, Jin et al. 2005, Liedtke 2006, Outwater et al. 2012, Pourabdollahi & Mohammadian 2011, Samimi et al. 2010, Sonntag & Meimbresse 1999, Tavasszy 2010, Urban & Beagan 2011, Urban et al. 2012)

Due to the reason that modelling approaches as well as the availability of data varies significantly (for instance comparing European countries) a transfer of modelling approaches from one country to another can hardly be achieved. Models in Germany for example are not able to capture the freight transport demand of transport logistics hubs. Additionally it is not possible to transfer established approaches from other countries because specific data, which are needed for a proper transfer, are missing.

The potentially major barrier is that there are no high quality data available concerning commodity flows or trips generated by transport logistics hubs. The mostly aggregated data, which are published by national statistic agencies, do not offer comprehensive information (e.g. on the level of individual shipments, their description of origin and destination or spatial information on transport logistics hubs). Even if there is high quality data available, it is commonly for certain areas or economic branches. Due to the fact that there are no comprehensive high quality data, standardized data have to be used. This prevents hub-specific forecasts because these data can only provide a basis for a more general overview.

Evidently, there are additional data requirements to realise a sufficient integration of transport logistics hubs. For Germany the lack of hub-specific data illustrates that it is unavoidable to survey supplementary data. Such data should contain information about hub characteristics as well as data regarding the transport process itself. The correlation between hub characteristics and trip generation, for instance, could be used to estimate hub specific transport volumes. A similar approach was realised by Davydenko et al. (2011) in their work for distributions centres in the Netherlands. However, there is currently no approach determining transport volume dependent on characteristics of transport logistics hubs. This supplementary information would enable an improved integration of transport logistics hubs in freight transport demand models in Germany.

3. METHODS

The following sections will present the different methods that were applied to answer our research questions.

In order to develop a typology of logistics hubs a methodological characterisation of logistics hubs is carried out. The theoretical typology of logistics hubs is derived from a literature analysis (see chapter 2). This analysis enables to investigate selected approaches for systemizing logistics hubs and to transfer them in a comprehensive typology. In this context, logistics hubs are divided into distribution logistics hubs (storage function) and transport logistics hubs (transhipment function). The relevant hub-related aspects as well as transport-related and business-specific characteristics of the logistics hubs are selected and a typological order is designed. Furthermore, an overview of the different logistics hub types is worked out..

To gather data for this project we collected secondary data for different kinds of transport logistics hubs in Germany. Aim of the data collection was to define all characters of the considered hubs. In detail we considered seaports, inland navigation ports, airports, terminals of combined transport and hubs of logistics service providers as forwarding agencies and courier, express and parcel services. As mentioned before in this paper will we demonstrated our approach and our results for freight forwarding companies.

First step of the secondary data collection was the identification of all locations of transport logistics hubs in Germany. For most of the considered kinds of hubs list of locations in Germany were available. This is true for seaports, inland navigation ports, airports, and terminals of combined transport but not for hubs of forwarding agencies. Thus locations of these hubs must be gathered by the analysis of networks of logistics service providers and match with data on the number of such companies in Germany. Second step of the secondary data collection was to bring together as many as possible information on the characters of the hubs analysed. The framework for the characters was set by the aforementioned characterisation of logistics hubs.

To gather much more detailed data than public available and to complete and evaluate the secondary data collection a primary data collection for transport logistics hubs in Germany was done. For this 2012 a standardized, web-based and written survey was carried out. The target groups were companies located at logistics hubs and operators of logistics hubs. They were contacted by post and e-mail. The questionnaire contains mainly closed questions, which align with the characteristic categories of the typological order developed.

In order to examine the data from the survey we used univariate as well as multivariate statistical methods. Univariate methods are applied to get an overview of the distribution of our data, whereas multivariate methods are used for testing and discovering connection between variables. To describe the data we used frequency distributions and measures of location scales (arithmetic mean, median) as well as dispersion measures (standard deviation). Regression analysis is applied for the multivariate analysis. For the statistical analyses we used the statistical analysis software SPSS.

The aim of the regression method is to describe the functional relationship between a dependent and one or more independent variables. The variables considered in the regression analysis are: company size, revenue, size of the total area, size of the transhipment area, size of the storage area, number of ramps for local and long-distance transport and transport volume. Apart from the variable revenue and the company size, which are coded ordinal, all variables are scaled metrical.

For metric-scaled data a bivariate linear and non-linear regression analysis was carried out. The shapes of the regression function, which were considered for the nonlinear case, are for example quadratic, cubic, logarithmic, and exponential. In addition to the bivariate regression analysis, we also carried out a multivariate linear regression analysis to determine the relationship between a dependent variable and independent variables. In order to take the variables company size and revenue as dependent variables into account, we used the multi-nominal logistic regression. By recoding the ordinal variables we included them as independent variables in the multivariate linear regression.

Cook's distance was applied to identify outliers of the independent and dependent variables. Outliers were eliminated in the linear as well as in the non-linear case.

A broad and international oriented literature research was compiled to investigate how transport logistics hubs are currently integrated in freight transport demand models in application. Therefore, more than one hundred models were examined regarding their consideration of logistics and transport logistics hubs.

The analysis of international sources revealed that, although models covering regions around the world were analysed, most models integrating logistics and logistics hubs could be identified in the U.S. and Europe. However, different methods to integrate transport logistics hubs in freight modelling were identified (see chapter 2).

Different statistical methods as well as common modelling methods were used to draw the outline of a simple but robust approach in order to model transport logistics hubs and their hub specific transport. In order to test the usability of such an approach, the generated statistical values and the approach were brought together. The different steps of the designed approach were implemented in a spreadsheet to assure ability to run and to test database connections, which are necessary for further modelling steps (e.g. step 1).

4. RESULTS

In this chapter we will present our results concerning the integration of logistics hubs in freight transport demand models. First of all we present the typological order of logistics hubs including the characteristics of such hubs. Afterwards, the results of the secondary and primary data collection are presented. Finally we will draw a outline for how the derived data could be used in modelling.

4.1. Typological order of logistics hubs

The result of the first step is a theoretical typological order of logistics hubs, which serves as the basis for the questionnaire design in order to collect primary data needed for further steps. The focus of the derived systemization is on logistical characteristics of the hubs, characteristics and attributes of the transport volume and performance as well as the description of the companies located at the logistics hubs and their customers. Within these three overarching characteristic categories, further subordinate characteristic categories are determined for the systemization of the logistics hubs (logistical master data, hub integration in network structures and transport chains, transport and transhipment objects, transport modes and transport infrastructure, organizational structure of the logistics hubs). The following figure shows the characteristics for the typology of logistics hubs (see figure 1).

Characteristics of the logistics hubs		
Logistical master data	Hub integration in network structures and transport chains	Transport and transshipment objects
• Size of the total area • Size of the transshipment area • Size of the storage area • Maximum handling capacity • Total transshipment volume in previous year • Number of ramps for local and long-distance transport	• Geographical position of the location • Interface between local and long-distance transport • Number of further locations • Network density • Network structure	• Type of goods handled • Handling equipment used and volume • Loading units entry/exit and volume

Characteristics of transport volumen and transport performance

Transport modes and transport infrastructure

- Connections to transport modes
- Vehicle type used per transport mode
- Transport volume per transport mode
- Transport performance per transport mode
- Maximum and average transport distance for delivery in local and long-distance traffic
- Intra-day distribution of in- and outbounds
- Load factor of transportation means
- Share of empty trips

Characteristics of the demand side

Organizational structure of the logistics hub

- Type of enterprise (type of logistics hub)
- Industrial sector of the customer(s)
- Organisational structure
- Revenue of the location
- Size of enterprise (Number of employees at the location)
- Number of involved enterprises

Figure 1: Theoretical typology of logistics hubs (Thaller et al. 2013a, b)

In order to design a substantial typological order, it was necessary to concentrate on general characteristics of logistics hubs. It becomes apparent that, on the basis of the literature analysis, only few approaches concerning logistics hubs – especially transport network hubs – do already exist. The present approach has closed this research gap. The developed typological order finally allows describing logistics hubs in a detailed way.

4.2. Secondary and primary data collection

For the secondary and primary data collection companies located at logistics hubs and operators of logistics hubs in Germany were investigated. For the whole project 2,395 locations of logistics hubs in Germany could be collected, which were the basic population for the primary data collection. About 1,500 of our contacts are forwarding agencies and logistics service providers. The core of these contacts were build up by members of the 13 freight forwarding networks established in Germany (e.g. DB Schenker, CargoLine GmbH, System Alliance GmbH). The freight forwarding networks in Germany consist of about 900 locations. In the survey all together 627 of the contacted companies took part and answered our questionnaire. After data cleaning of non-usable cases a net sample of 393 usable questionnaires was included in the assessment of the survey. Out of this 211 companies belong to the group of forwarding agencies and companies for road freight transport. The answers of those 211 companies will be the basis for the data analysis which follows now. They will be summarised as freight forwarding companies.

The answers of the freight forwarding companies reveal that 81 of them are individual enterprises, 37 are main establishments and 70 establishments of bigger companies. 149 of the 211 companies see themselves as interface between local and long distance transports. Most of the companies (35 percent) have between 100 and 249 employees. Further 24 percent have between 50 and 99 employees, 22 percent have 10 to 49 employees. The revenues of the companies are in half of the cases between 10 and 50 million euros. Thirty percent generate revenues of less than 10 million euros, ten percent more than 50 million euros. Out of the 211 companies 97 are unimodal and do road transports, 37 are bimodal whereof 18 do road and rail transports. Additional to this company data we gathered logistical data for the 211 freight forwarding companies, which are summarised in table 2.

The presented data allow us to describe typical characteristics of locations of freight forwarding companies in Germany. They will be used to develop the modelling approach later on.

In the following the results of the regression analysis are presented. We only introduce results, which are significant ($\alpha < 0.05$), fulfil the conditions of the respective regression method (e.g. normal distribution) and where the coefficient of determination R^2 is greater than or equal to 0.3. Furthermore, we present only the best results if different methods were used for a variable constellation. If constellations of variables were not taken into account, then one of the above conditions is not fulfilled.

Statistical value	Unit	First quartile	Median	Third quartile	Arithmetic mean	n
Size of total area	m²	8,000	24,000	45,000	34,200	131
Size of transshipment area	m²	1,300	3,300	8,000	7,600	127
Size of storage area	m²	1,200	4,000	15,000	13,000	115
Ramps for local transport	Number	10	22	57	37	78
Ramps for long-distance transport	Number	7	15	35	27	75
Maximum handling capacity	tons	180	30,000	250,000	265,000	56
Degree of capacity utilisation	Percent	71	88	96	77	71
Vehicles used for local transport	Number	18	37	70	50	153
Share of own vehicles used for local transport	Percent	0	35	90	38	56
Vehicles used for long-distance transport	Number	13	38	71	56	141
Share of own vehicles used for long-distance transport	Percent	0	24	100	44	54
Trip generation local transport	Number	15	42	90	66	135
Trip generation long-distance transport	Number	10	30	60	46	137
Share of empty trips	Percent	10	10	20	14	44
Load factor of vehicles	Percent	80	85	90	84	47
Source: own survey						

Table 2: Statistical values of freight forwarding companies

The results of the bivariate and multivariate linear regression analysis are summarized in Table 3 and 4, where N denote the sample size. As mentioned above the two ordinal variable revenue and company size were also considered in the multivariate linear regression beside the metric variables. In our survey the revenue is divided into the classes from 0 € to (below) 2 million €, from 2 million to 10 million, from 10 million to 50 million and above or equal 50 million. The size of the company consists of the following seven classes: from one employee to 9 employees, from 10 to 49, from 50 to 99, from 100 to 249, from 250 to 499, from 500 to 999 and greater or equal 1000. As part of the multivariate linear regression analysis a binary decision variable (dummy variable) is introduced for each revenue class (respective $\mathrm{x_{r1}}, \ldots, \mathrm{x_{r4}}$) and employee size class (respective $\mathrm{x_{e1}}, \ldots, \mathrm{x_{e7}}$), where e.g. $x_{\mathrm{r1}} = 1$ if the revenue is between 0 € and 2 million € and $x_{\mathrm{r1}} = 0$ otherwise.

The result of the statistical analysis (see Table 1,3, and 4) are used in our transport model, which is descripted below. For the multi-nominal logistic regression we could not find any constellation of dependent and independent variables, for which the respective model is significant.

dependent variable y	independent variable x	N	R^2	regression function	domain
Transport volume	Size of total area	102	0.310	$y = 95.294 + 0.004x - 0.000000076x^2$	$x \in [0; 250000]$
Transport volume	Size of transshipment area	103	0.6	$y = 0.2851x^{0.77}$	$x \in [0; 100000]$
Transport volume	Number of ramps for local distance	62	0.303	$y = 35.446x^{0.471}$	$x \in [0; 200]$
Transport volume	Number of ramps for longer distance	61	0.38	$y = 31.563x^{0.531}$	$x \in [0; 205]$
Transport volume	Number of ramps	79	0.35	$y = 91 + 2x$	$x \in [0; 405]$
Size of the total area	Size of the transshipment area	122	0.507	$y = 54x^{0.719}$	$x \in [0; 100000]$
Size of the transshipment area	Number of ramps for long-distance	69	0.425	$y = 579.98x^{0.582}$	$x \in [0; 205]$
Size of the storage area	Number of ramps for local	81	0.407	$y = 8779.7 - 281.561x + 3.302x^2$	$x \in [0; 200]$
Number of ramps local-distance	Number of ramps for long-distance	68	0.558	$y = 1.2586x^{0.08}$	$x \in [0; 205]$

Table 3: Bivariate regression results for metric variables

dependent variable y	independent metric variable x	N	R^2	regression function	domain
Transport volume	Size of total area (x_1), Number of ramps for local (x_2)	71	0.424	$y = 68.034 + 0.002x_1 + 3.273\,x_2$	$x_1 \in [0; 250000]$, $x_2 \in [0; 200]$
Transport volume	Size of total area (x_1), Number of ramps for long-distance (x_2)	69	0.512	$y = 50.395 + 0.002x_1 + 4.357\,x_2$	$x_1 \in [0; 250000]$, $x_2 \in [0; 205]$
Transport volume	Size of transshipment area (x_1), Number of ramps for local (x_2)	70	0.508	$y = 61.321 + 0.014x_1 + 2.991\,x_2$	$x_1 \in [0; 100000]$, $x_2 \in [0; 200]$
Transport volume	Size of transshipment area (x_1), Number of ramps for long-distance (x_2)	68	0.525	$y = 63.741 + 0.009x_1 + 4.059\,x_2$	$x_1 \in [0; 100000]$, $x_2 \in [0; 205]$
Transport volume	Size of transshipment area (x_1), Number of ramps (x_2)	70	0.508	$y = 45.884 + 0.011x_1 + 2.314\,x_2$	$x_1 \in [0; 100000]$, $x_2 \in [0; 405]$
Transport volume	Size of total area	38	0.549	$y = 158.3 + 0.003x - 141.737\,x_{r1} - 92.802\,x_{r2} + 15.589\,x_{r3}$	$x \in [0; 250000]$, $x_{r1}, x_{r2}, x_{r3} \in \{0,1\}$
Transport volume	Size transshipment area	37	0.445	$y = 359.997 + 0.005x - 326.257\,x_{e1} - 284.576\,x_{e2} - 193.261\,x_{e3} - 57.181\,x_{e4} + 249.317\,x_{e5}$	$x \in [0; 250000]$, $x_{e1}, x_{e2}, x_{e3}, x_{e4}, x_{e5} \in \{0,1\}$

Table 4: Multivariate linear results for metric and ordinal variables

4.3. Possibilities to integrate logistic hubs in demand modelling

In order to reproduce the hub specific transport processes and integrate the knowledge gained from the survey and the corresponding analysis into freight transport modelling, different approaches could be used. Approaches focusing on hub specific transport only as well as the comprehensive integration of hub specific transports via a logistics module are only two possible alternatives. The first one could be designed as multi-step approach. Figure 2 illustrates the model flow adapted to hub specific transports of freight forwarding companies. It consists of the steps: 1. Implementation of hubs in a “synthetic world”, 2. freight generation, 3. freight distribution, 4. mode choice and 5. route assignment. We will exemplify the approach for transport logistics hubs of freight forwarding companies, which often operate in big networks.

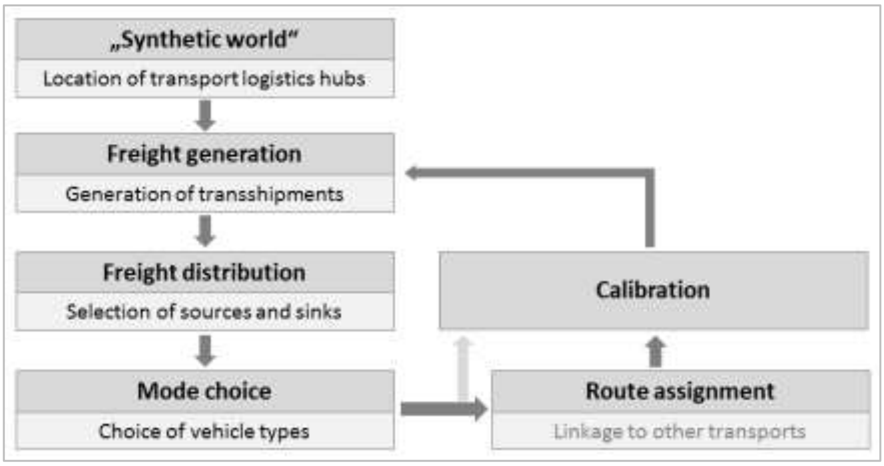

Figure 2: Possible designs of the multi-step approach

In the first step all transport logistics hubs are listed and located in a “synthetic world” using their exact addresses or geographic coordinates, which were obtained as part of the secondary data collection. Furthermore, all attributes (like hub type, floor space data, transshipment capacities or number of employees) that could be collected are added for every specific hub. Besides the identified hubs the synthetic world also consists of a set of firms; each firm location with its characteristics like number of employee, spatial attributes or firms economic sector.

In a second step the freight generation or transshipment respectively, is calculated. Therefore, the model differentiates in the generation step between inbound and outbound trips for short-distance as well as for long-distance transports. The necessary data are processed by regression analysis using hubs characteristics deduced from secondary data and surveyed data . As a result, hub type specific functions were derived (see Table 3 and 4). Using these functions, specific freight generation rates are calculated and allocated to each hub dependent on the specific characteristics of each hub.

In order to catch every single transport leg, the transport chains are split in step 3 (freight distribution) into main legs (long-distance transport between hubs) and first and last mile legs (pickup and distribution short-distance transport between hubs and customers). Two further steps, which are described below, were implemented to achieve this.

Freight distribution for short-distance transport is calculated first in order to link the hubs (for local distribution/consolidation) and customers and to identify them. Since different hub types handle transshipments of different customers, which can be assigned to numerous economic branches, the relevant economic branches for each hub are determined first. To capture this in our model, conditional probabilities are determined for the industrial sector of the primary served customers based on the surveyed data for each type of hub. Using the data of the “synthetic world”, where hub types and characteristics as well as customer locations and branches are recorded, the model assigns the identified potential customers and hubs to each other. The result is a matrix of all potential relations. In order to calculate specific relations between customers and hubs, different data are obtained from the “synthetic world” (e.g. locations, costs, employees). A gravity approach which is fixed for the source as well for the sink is then used to evaluate the utility for every hub-customer-relation for inbound/outbound trips for each hub. The so called EVA-utility function (Generation (E), Distribution (V) and Mode Coice (A)) is used to calculate the utility dependent on costs. Furthermore results are weighted using the number of employees at the customer location in order to benefit customers with plenty production input/output.

[1] $$U_{i,j}(C,n_E) = \frac{1}{(1+c_{ij})^{\varphi(c_{ij})}} * n_E$$

[2] $$p_{i,j}(U_{i,j}) = \frac{U_{i,j}}{\sum U_{i,j}}$$

Following formula [1] every customer-hub-relation is evaluated, where u denotes the utility for a hub-customer-relation (i-j), c the costs, φ parameter to be determined, n_E the number of employees, p the probability for chosen relation i-j. The probability for every customer-hub-relation is calculated using formula [2].

The demand for long-distance transport between freight forwarding hubs of a network is modelled in a second step using the generated trips for national long-distance transports and the transport costs (here: distances) between the hubs of the same forwarding network. Depending on the economic sector, the evaluation of customer specific relations of every hub (in short-distance transport) could also be used to weight the importance of transport hubs for relations in long-distance transportation. Thus, long-distance trips are assigned to relations between hubs of the same network (following the principle of formula one and two).

Based on the transport relations in short-distance and long-distance transport, a logit model is used to calculate the mode choice for six different vehicle classes (trucks with a total weight ≤3,5t, 3,5t-7,5t, 7,5t-12t, trailer trucks, EuroCombi/overlong truck, other). The choice model follows the following equations

$$[3] \qquad U_v = \alpha * e^{\beta * c}$$

$$[4] \qquad p_v(U_v) = \frac{U_v}{\sum U_v},$$

where u denotes the utility of choosing vehicle v , α and β parameters to be determined, c the costs and p the probability that vehicle v is chosen. The utility functions and the corresponding parameter were determined from the surveyed data and the results of the statistical analysis. They were also validated by using official statistics from the Federal Motor Transport Authority Germany and the study “Motor Vehicle Traffic in Germany” (KiD 2010).

The formulated approach and its overall results (hub-customer-relations and corresponding trips) as well as the findings of singles steps (e.g. trip generation functions) could be used to integrate transport logistics hubs in national freight transport demand models for Germany.

5. DISCUSSION

Following our research questions we presented a typological order of logistics hubs, collected secondary and primary data to derive key values for the traffic generation of logistics hubs and showed how these values could be used in freight transport demand modelling. We demonstrated this for freight forwarding companies in Germany.

The derived typological order of logistics hubs could be used for transport logistics hubs as well as for distribution logistics hubs. The secondary and primary data collection was achieved for different types of transport logistics hubs. In detail, we presented the data collected for one type of transport logistics hubs. Similar data for other types of hubs are also available although the number of data sets on other types is lower and sometimes not high enough to run similar data analyses. The applied univariate and bivariate statistical method describes our data set for freight forwarding companies and enabled us to show interdependencies between different characteristics of this type of logistics hub. These interdependencies were used to determine utility functions which were incorporated into the designed modelling approach. This approach could be used for other types of hubs as well. However, further data analysis would be necessary, which could be accomplished using the collected secondary and primary data.

The integration of logistics hubs in freight transport demand models is an important step to enhance such models. We demonstrated this outlining a simple approach for one specific type of logistics hub. The results of this approach are not validated and calibrated up to now, because a more complex and sophisticated transport logistics model is currently under development, which will integrate all types of distribution and transport logistics hubs in near future. The findings from data analysis represent a valuable basis for that.

Furthermore, the analysis of relevant literature regarding demand models in application showed that the integration of transport logistics hubs is scarcely achieved. If considered – mostly as distribution logistics hubs – logistics hubs are integrated via separate logistics modules. This is a very promising approach that should be followed for the German area. Such an approach will be designed and developed for a macroscopic freight transport demand model developed by the DLR Institute of Transport Research.

6. CONCLUSION

The paper showed that there were, and still are, different matters and several important research gaps to be filled regarding transport logistics hubs and their integration in freight transport demand modelling. For transport logistics hubs we presented different types of hubs and classified them in a meaningfully typology of logistics hubs. The secondary and primary data collection revealed different characteristics and structures for different types of hubs. We present one type of hub as an example. The analysis of transport demand models currently used showed that there are different approaches to integrate logistics hubs. However, transport logistics hubs are marginally considered, especially in Germany. This lack of consideration could be overcome by a comprehensive linkage of data collection and model development. The collected data enabled us to derive key values, which can be used to integrate transport logistics hubs in freight transport demand models more adequately.

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