A CONCEPT FOR MODELLING FREIGHT TRANSPORT WITHIN SUPPLY NETWORKS OF THE AUTOMOTIVE INDUSTRY

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ABSTRACT

The automotive industry has been a driver for innovations in logistics and production for the last decades. Most car plants are situated at the end of a multi-tier value adding network. At best, companies have limited knowledge about small parts of these networks, i.e. single supply chains for single car plants, but there is no industry wide analysis of freight transport and material flows. From the perspective of a transport planner or researcher, these modern supply networks, which rely on the global distribution of work force and just-in-time deliveries, generate a transport demand that has specific requirements and cannot be explained by traditional transport models. Hence, for freight transportation analysis as well as for a sectoral vulnerability analysis models that map the specific characteristics of the automotive industry are needed.

This paper includes an overview of the different data sources available and how to merge them in order to benefit from their informative value in a sectoral model. Another part of the concept describes the model structure including objects and stakeholders, like supplying companies, car manufacturers, and transport service providers. Not only the stakeholders will be described but also the way they interact within the model. One central topic in this regard is how supply chains along multiple tiers are established in the model and how this can be based on empirical data and knowledge.

In summary, this work formulates a concept for modelling the (German) automotive industry regarding freight transport and constitutes the starting point for the future model implementation.

Keywords: freight transport demand model, automotive, logistics, supply networks, industrial economics

INTRODUCTION

The automotive industry claims an outstanding position in the German economy. Only the manufacture of motor vehicles and transport equipment already accounted for 7 % of the German GDP in 2010 (DESTATIS 2011a).

For scientists this particular industry offers a challenging area for interdisciplinary research as there is a high level of linkage between companies on a supply chain level and a permanent strain for innovation and excellence in products and production processes.

Analysing the regional distribution of automotive activity, several local clusters can be identified, which strongly depend on the prosperity of this sector. The intensively applied concept of distributed value creation leads to a high demand for transport. A strong dependence on the reliability of the transport system results from modern provisioning concepts like just-in-time (JIT) and just-in-sequence (JIS) deliveries. Therefore, transport infrastructure and services become competitive factors in the global competition.

The automotive industry faces major challenges for the future as it needs to adapt to market shifts, regulatory measures and changes in customer preferences. As a reaction towards these expected changes in future demand, future vehicles will need to integrate new technologies like (hybrid) electric powertrains and lightweight constructions. Together these aspects may lead to new collaborations and influence supply chain structures.

Currently available statistics and freight transport models do not allow for analysis of changes in freight transport due to the expected future developments. Most of the existing work has been done on different levels of aggregation like individual commodity flows, supply chains or total freight transport demand. A sound representation on the sector level as an aggregation of the vast number of single supply chain patterns still is missing.

This paper starts with an insight into future scenarios for the automotive industry and how their assumptions influence freight transport demand. Upon that a system analysis of the German automotive industry is presented, which leads to a brief presentation of available data sources. The paper closes with a description of the planned model concept.

FUTURE SCENARIOS

The construction and application of models always follows a certain research question or modelling purpose. The target of the presented model concept is to estimate freight transport demand and its spatial distribution as it rises from the automotive supply chains towards car plants in Germany. Thus, the model shall be able to estimate future transport demand for a set of scenarios. These scenarios can contain one or more assumptions about the future of motor vehicle production that influence the induced transport demand. A selection of trends based on experts' opinion and our own considerations is described below.

Changes in the product

Strict environmental regulations and customers' demand for increased energy efficiency will force car manufacturers to build vehicles with less output of CO2 and particles. Already today the numbers of newly registered electric and hybrid vehicles are rising strongly, even if still on a very low level (see Figure 1). However, in the next decades conventional combustion engines will be more and more replaced by alternative powertrains. This change will also have a strong impact on production networks and the transports within as the production process of current powertrain technology is substantially different from its electric alternative. With the target of reduced fuel consumption, car producers develop technologies regarding lightweight constructions like carbon bodies. Thus, the flow of goods from other industries into the automotive sector as described in the input-output calculation of the national accounting will shift from metal-bound industries towards industries relying on lightweight materials like carbon fibre.

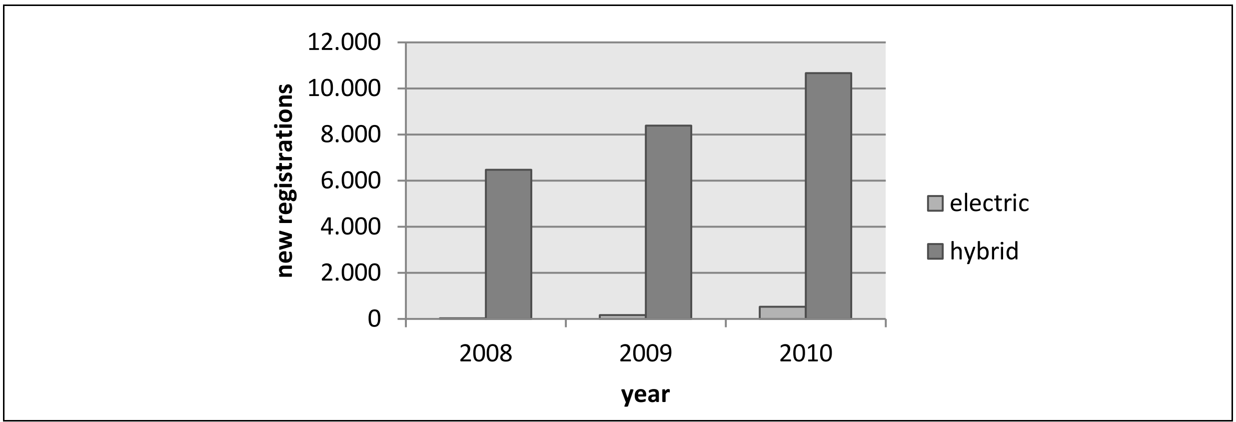

Figure 1: Annual numbers of new registrations of vehicles with hybrid or electric powertrain, data from KBA (2013)

Changes in market and industry

Customers' higher cost sensitivity and changes in mobility behaviour could lead to smaller and more standardised vehicles. Hence, cars would become mid-price commodities losing complexity in the product and the production process potentially allowing for new transport optimisations.

Urbanisation and changing mobility needs could also lead to a strong decrease in demand for automobiles on a European or even global level. Significant drops in demand would force car producers to fundamentally redesign their production networks and totally change the landscape of vehicle producing companies, so called Original Equipment Manufacturers (OEM).

For the general structure of the industry multiple changes are expected. For OEM as well as suppliers a trend towards stronger market concentration can be identified as companies are forced out of the market due to cost pressure and takeovers. New brands from Asia bring some new heterogeneity but at the same time their entry into global competition strengthens the price pressure as Europe already has excess capacity in the production of automobiles (PwC 2012).

Changes in production network

The future location and number of car plants may differ from today's layout due to shifts in costs or other uncertainties like availability and reliability of infrastructure. Under conditions of rising freight transport in the road system and higher road transport costs modal shifts towards rail or waterway for inbound transport could become desirable for the automotive industry. In order to achieve sustainability targets governments could even force companies to shift their transports away from road by regulatory measures.

New developments in production technology might also lead to major changes. A lot of research and development is currently invested into modular production systems that allow for smaller lot sizes and transportability of production facilities. For selected parts this trend would lead to multiple small manufacturing locations in direct neighbourhood to the car plant instead of large single factories supplying several OEM.

SYSTEM ANALYSIS OF THE GERMAN AUTOMOTIVE INDUSTRY

On the national level the automotive industry accounts for 5 to 15 % of the total employment (Tillmann 2009). This wide range results from the difficulty of defining borders for a certain industry and the underlying objective from interest groups when estimating these numbers. Our approach to define automotive industry starts from the car plants and then stepwise follows inbound flows upstream till a level of generic supplies is reached. This definition is wider than those used in current statistics.

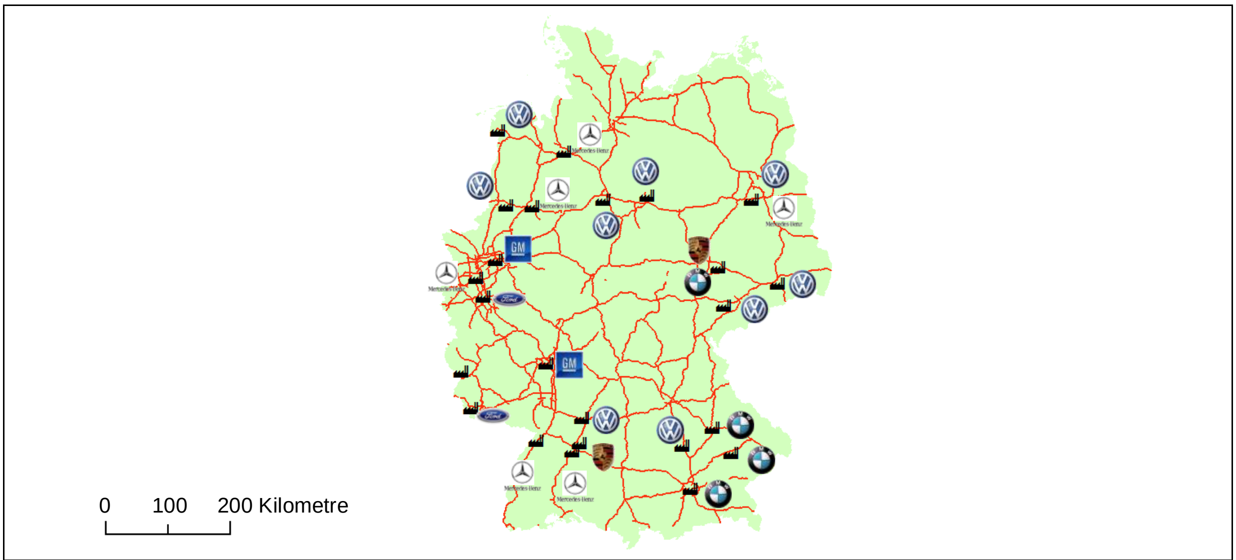

Figure 2: Map of Germany with locations of car plants by OEM together with motorway network, data from OpenStreetMap (2012) and AUTOMOBIL PRODUKTION (2008)

On the transport side, the category *vehicles and parts thereof* accounts for a share of 4 % as part of the total annual freight transport performance on road as well as rail measured in tonne-kilometres (DESTATIS 2013a; DESTATIS 2013c). The map in Figure 2 shows an overlay of the German motorways and the location of car plants. Here, a strong adjacency between production facilities and motorways can be observed. This fact supports the assumption of correlation between transport and automotive production even if the emergence of the overall structure underlies many more influences.

Regarding the locations of all brands' car plants in Germany, we cannot identify a single cluster of car production. Instead regional agglomerations of factories are spread over the country. Naturally, the regions around car plants strongly depend on the employment effects generated by the production of cars. Going into detail for a single region, Southern Hesse in this case, the mutual affinity of transport infrastructure and business establishments of the automotive industry can also be observed on the more detailed level. This correlation is visualized in Figure 3.

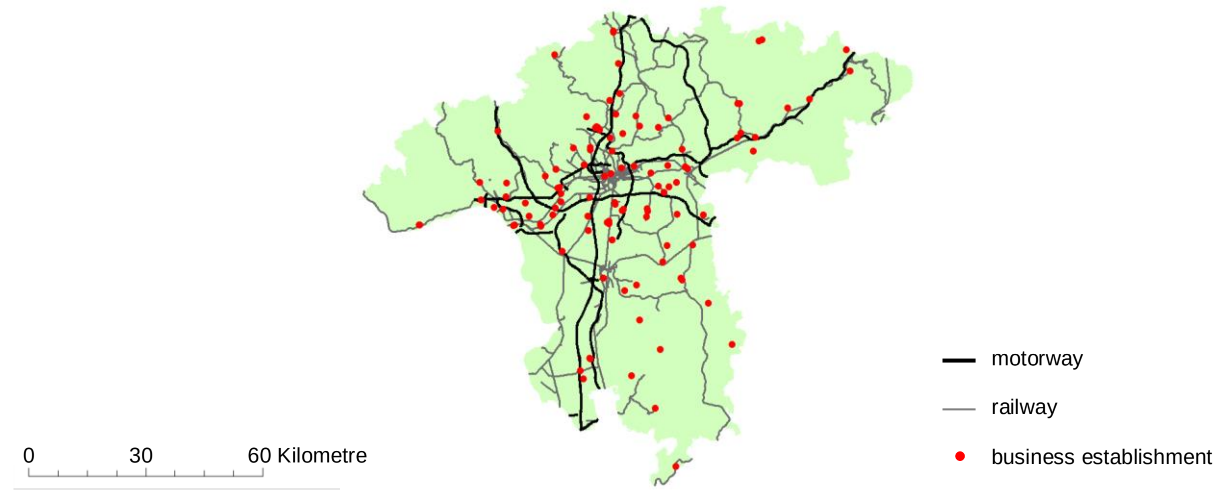

Figure 3: Business establishments of automotive suppliers in Southern Hesse (Germany) and transport infrastructure (infrastructure data from OpenStreetMap 2012 and business establishments from proprietary data from D&B)

In the following paragraphs we analyse the German automotive industry in regard to characteristics relevant for the model purpose of estimating freight transport in future scenarios.

After claiming the patent for the construction of the first automobile with a combustion engine in 1886, the name Benz is still well-known in the car-market today. In the meantime manifold new companies and brands appeared in the industry, whereof some had to leave again and some stayed. For Germany, there are a number of multicorporate enterprises producing cars in Germany, some of them having multiple brands in their portfolio. The largest of these is the Volkswagen Group, combining brands like VW, Audi, Porsche and many more under one roof. In total there are approximately 30 car plants in Germany run by the different OEM. Even if collaboration exists in some areas, the car producing enterprises rely on distinctly organized supply and transport networks. For this reason stakeholders representing certain functional units in the model need to be either independent or assigned to one or more brand networks, in order to define their planning scope.
The final assembly of the car in the car plant is the last step of a long chain of distributed value creation. Typically, several key processes are located on the car plant's compound as they require enormous process knowledge and transport of the intermediate output to the assembly is difficult or expensive on larger distances. In most cases, this is the press shop, body shop and paint shop (Ihme 2006). Still, the model must allow for flexible setups as some plants vary from this classic layout.

Parts and components needed for the final assembly are produced in a pyramid-shaped supply network with the car plant being located at the top. On the first level so called tier-1-suppliers assemble components to modules, which are delivered directly to the assembly line where they are put into the vehicle in a job flow system. The number of modules per vehicle is limited and almost identical between most vehicles if seen from our level of abstraction. Therefore, the material flow from tier-1-suppliers to the OEM can be based on discrete objects and numbers derived from generalized material bills per vehicle. The producers of these assembly-ready modules as well as the functional units for press shop, body shop and paint shop are considered as homogenous group of stakeholders as they have the same position in the supply chain, delivering their output directly to the assembly line. Thus, they share common challenges. As most cars are customer specific and therefore build to order, it is a demanding but also crucial task to supply the needed parts to the right station of the assembly line in the correct order and at the needed time. As a result the automotive industry developed advanced logistics systems for internal and external material flows. In the case of tier-1-suppliers this leads to a large number of modules being delivered by truck as direct JIT or JIS transports to the assembly line. The transport strategy as well as the tight collaboration with the OEM influences the location choice of suppliers. Thus, many tier-1-suppliers run business establishments near the car plant to minimize the risk of delays due to traffic disturbances. One measure against transport vulnerabilities is the joining of so called supplier parks. These are located in direct neighbourhood to the car plant and offer space to supplying firms for their plant specific production (Becker 2006). For the model this spatial distribution of suppliers is important for the realistic simulation of sourcing behaviour.

Table 1: Inputs to the production of *motor vehicles trailers and semi-trailers* from selected sectors by national production and imports, data from DESTATIS (2012)

CPA-Code	**Description**	**National Production** [million EUR]	**Imports** [million EUR]
29	Motor vehicles, trailers and semi-trailers	97 421	28 512
25	Fabricated metal products, except machinery and equipment	11 847	1 758
22	Rubber and plastic products	7 868	2 560
24.5	Casting services of metals	6 469	6
24.1-24.3	Basic iron, steel and ferro-alloys and other products of the first processing of steel	3 476	5 924
52	Warehousing and support services for transportation	3 383	18
27	Electrical equipment	2 998	1 982
28	Machinery and equipment n.e.c.	2 382	5 450
20	Chemicals and chemical products	2 123	2 479
24.4	Basic precious and other non-ferrous metals	814	1 092

The described tier-1-suppliers get their inputs from so-called tier-2-suppliers who produce automotive-specific products from more generic inputs. On this level, the distinct assignment of business establishments and their outputs to single car plants or even brands is no longer possible. However, the output from tier-2-suppliers can be identified as automotive goods although they are not specific for single vehicle types or brands. Thus, the behaviour of this group of suppliers cannot be modelled by disaggregation of bills of materials into discrete objects. Instead we propose to cluster tier-2-suppliers by homogeneity of their output and its transport characteristics as well as used inputs.

In our concept, we consider the supplies from tier-3 to the tier-2-production as generic inputs split up into NACE sectors A-L. Thus, the shape of flows between these elements in the supply chain can only be estimated via the use of aggregated data from the input-output-table.

Obviously, the decision where to locate the production of supplying parts is mainly driven by minimisation of total costs. Therefore, labour intensive production gets shifted to low cost countries increasing transport costs and transport vulnerability, especially in JIS/JIT environments. For example, several suppliers moved their manufacturing of cable harnesses to Tunisia still offering JIS/JIT deliveries (Najjar 2010). Not only northern Africa experiences a growth in the number of vehicle component suppliers but also Eastern Europe benefits from the OEM's rising cost sensitivity (VDA 2004). The German input-output-table shows that still most intermediate products that are consumed as inputs by the automotive industry come from national production if measured by value. Table 1 compares imports and national production for inputs from selected sectors. It is not possible to directly estimate the amount of transported goods from these numbers. In expert interviews we found out that most imported goods are characterised as high technology or labour intensive products, which usually strongly differ in their physical attributes. Nevertheless, we can derive that imports play an important role in OEM procurement. Therefore, foreign trade and cross border material flows cannot be ignored in the model. Instead, we propose to tackle this challenge by defining spatial markets for categories of goods respectively components. Depending on the good considered these markets can be local, national, regional (regional standing for regions on a global level like Europe or Northern America) or global. By choosing this approach we can include aspects of competition and global sourcing in our model and reduce the level of detail whenever possible. As an example, it is not important for the Hinterland transport whether its origin is Asia or South America but it is important to know that the sourcing for the good transported takes place on a global market in order to assign realistic amounts to inbound sea transport.
The further distribution of value creation also leads to innovative transport solutions. For example a major share of Audi's engines is produced in Győr (Hungary) and build into the vehicles at different plants in the wide-spread Volkswagen production network (Audi 2013). Most of the transports leaving the engine factory in Győr rely on block trains delivering the built engines directly to the Audi plant in Ingolstadt (Germany) in a low cost and environmentally friendly way (Audi 2008). Following this trend, it is a declared target of the Volkswagen Group to shift more transports from road to rail in the future. Thus, the model must capture the different modes of transport and intermodal transports. In our understanding this is not the outcome of a single modal choice but of a choice between different transport chains consisting of one or multiple, possibly intermodal, legs. This idea is also presented by Schröder et al. (2011).

DATA SOURCES

During model design it is necessary to decide which parameters need to be endogenous and which can be considered as exogenous. The decision also depends on the availability of data as the values of exogenous parameters can either be the outcome of assumptions or be defined by using data. Data from statistics or surveys can also be used for model calibration and verification. Therefore, already at an early stage, it is important to get an overview on existing data sources that can be used in the model.

The location of car plants can easily be taken from publications like AUTOMOBIL PRODUKTION (2008). This source contains a summary, which also gives the number of employees at the car plants and the annual number of cars produced. Getting the locations of the production facilities supplying the car plants is more challenging. Commercial data providers like Dun & Bradstreet (D&B) do have databases on business establishments together with a categorisation by economic sectors. The big disadvantage of this data is its proprietary character meaning that it is not available publicly and that it does only partly follow standards defined by governmental statistical offices. Also, there are directories about automotive suppliers published by interest groups like member lists of the German Association of the Automotive Industry (VDA) or product related reference books (AUTOMOBIL-PRODUKTION 2011) but these do only cover a random range of the existing companies. Full sector coverage is offered by the employment statistics available from the Federal Employment Agency. This data allows for the regional distribution of economic activity in Germany based on detailed employment statistics that disaggretate to the level of NUTS-3 regions and 3-digit sector codes. In addition the distribution of business establishment sizes are available up to a 3-digit classification of economic activity (DESTATIS 2013b). Information on the production of goods can be found in the national production statistics (EUROSTAT 2013). The national input-output table (DESTATIS 2012) gives data on the existing economic connections between different sectors. Similar data has been collected in the input survey (DESTATIS 2009). Combined with the foreign trade statistics, the mentioned data will be used as input for estimations on the flow of goods into the production of cars.

IMPLICATIONS FOR MODEL

The use of models is recommended whenever access to the system of interest is somehow difficult (Simon 1996). Instead of using the real life system an abstraction is created that helps to explain or predict system behaviour in a controlled environment. Thus, there are two major model purposes for freight transport models. The first might be described by the objective to capture the current state of the freight transport system for certain analyses. The second kind of model purpose aims at the prediction of system behaviour as a reaction towards internal or external influences.

Traditionally, freight transport models were built according to passenger transport models following a 4-step design. Usually they do not include causal relations explaining system elements' behaviour. Therefore, their suitability for the analysis of system behaviour as a reaction towards internal or external influences is limited. Instead we propose to use sectoral models for the analysis. This is supported by data availability on the sectoral level and the higher homogeneity of behaviour within product groups and economic stakeholders within a branch. For the case of the automotive industry we recommend a multi-layer model that includes a representation of the sector reaching from the geographical distribution of business establishments up to traffic and transport flows between them. The different layers are show in Figure 4 and described in the following.

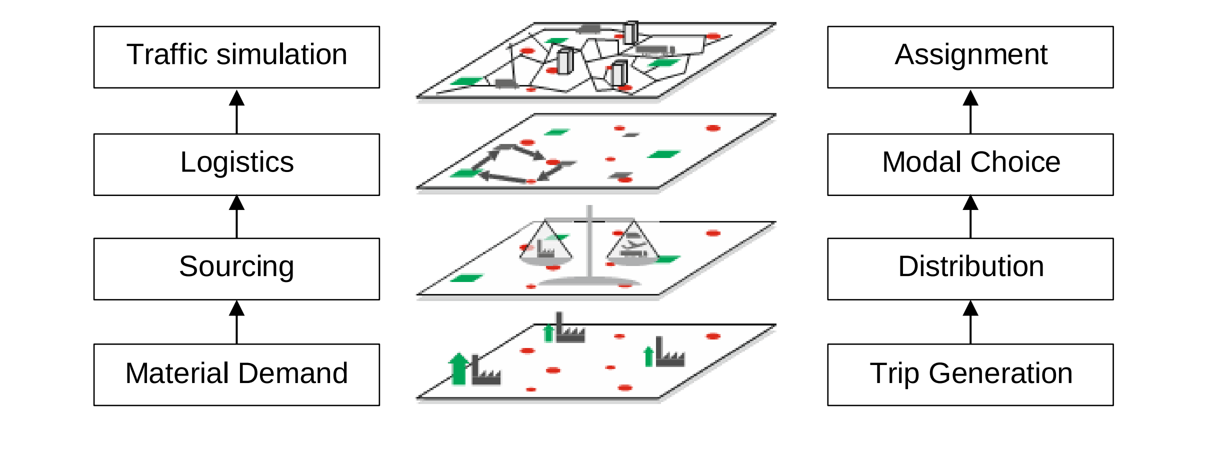

Figure 4: Comparison of presented approach and common 4-step model

Material Demand and Sourcing

As mentioned before the automotive industry strongly relies on distributed value creation and specialised supply chains. Therefore, the location of the involved business establishments is of great importance for a freight transport model. For the location of car plants and their output exact data is available. As this is not the case for business establishments they are put into an artificial industry landscape by Monte-Carlo simulation that is based on company size distributions and disaggregated employment data from the national statistics. The employment data contains information on the number of employees per NUTS-3-region and 3-digit NACE classification of economic activities. A similar approach was used for example by Friedrich (2010). The output of this step in the model is a list of all business establishments including their location, number of employees and economic activity (*manufacturing of vehicles or parts thereof* or related industries).

In the next step transport demand is assigned to these business establishments. Transport demand in this context means the demand for transport of a certain amount of goods of a certain type from source to destination. As we consider the chain of firms supplying the car plants the overall demand is determined by the final output of vehicles from the car plants. Precise data on the number of vehicles produced per car plant and vehicle type are available. Hence, it is possible to dissolve these vehicles into modules and components following simplified parts lists. For each identified type of module certain sourcing rules can be defined following available case studies (e.g. Wilhelm 2009). Defining the car plant itself as an agglomeration of assembly (at least), body shop etc., the same concept can be applied for the inbound flow of raw materials. Usually, the tier-1 suppliers assemble their products near the car plant from external components. Thus, their inbound flows of goods can be estimated on simplified parts lists per module as well. As it is not possible to track every single item needed for the production there is a remaining amount of goods that must be rather roughly estimated from statistics. Therefore, we consider each business establishment as a node that has equilibrium between input and output together with expenditure ($\sum input = \sum output + \sum material\ loss$). Through the employment data and productivity rates from statistics we are able to assign this remaining demand by using a modified gravitation model. The assumed supply chain structure and input data to the artificial sourcing are shown in Figure 5. The output of this model-step is an artificial sourcing for every business establishment that is based on statistics and available industry-specific knowledge.

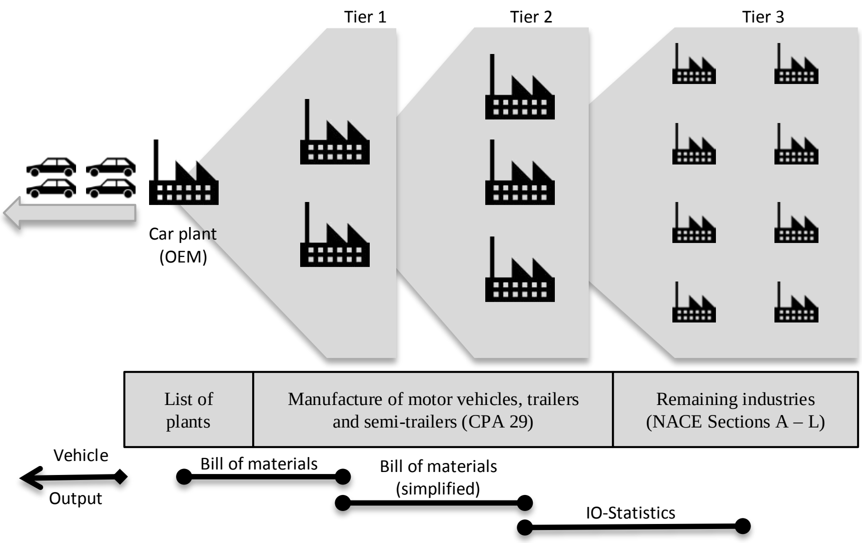

Figure 5: Schema of sourcing relations and data sources

Logistics

In the precedent steps we created the input for what we call the step of logistics simulation. Here, we generate transport chains according to the transport concepts applied in the automotive industry, including direct as well as combined transports. As economic stakeholders are mainly driven by cost optimization the assignment to certain transport chains can be done by the evaluation of cost functions for each alternative. The profitability of logistics service providers strongly depends on their realised economies of scale. Thus, the bundling of compatible commodity flows needs to be integrated into the model. Regarding the model architecture for creating logistics networks and simulating market interaction for the assignment of flow to certain providers a concept is used similar to the transport service provider agent as introduced by Schröder et al. (2011).

Traffic simulation

Once commodity flows between business establishments have been assigned to transport chains it becomes possible to create vehicle tours in order to fulfil the planned transports. Instead of simulating all traffic the non-automotive part will be represented in an abstract way as time dependent resistance. Therefore needed resistance functions are calculated from time dependent data for the German major road network. Once the road network is annotated with time dependent impedances the vehicle movements necessary for the automotive supply chains can be simulated. After the assignment of transports to the traffic system has been completed its outcome can be fed back into the logistics simulation. In this way the effect of different scenarios in the underlying model layers can be evaluated. One application for such scenario analysis would be the comparison of different transport concepts towards their robustness against delays due to breakdowns in the transport system. This becomes relevant especially under future circumstances when total traffic continues to grow.

CONCLUSION AND OUTLOOK

In this paper, we presented a system analysis of the German automotive industry as a basis for future sectoral freight transport demand models. We also laid out, which data sources are available for such a model. To give an impression of related research questions we summarized possible future scenarios of automobile production focussing on trends leading to changes in freight transport demand. In the final part of the paper we recommended a model concept that allows to capture the multiple influences on the resulting freight transport demand. The next steps of our work will focus on the development of a realistic sourcing behaviour that combines sectoral knowledge and available data.

LOEWE
Exzellente Forschung für Hessens Zukunft

The presented article is based on research results of the research project “Dynamo PLV – Dynamic and Seamless Integration of Production, Logistics and Transportation” funded within the framework of Hessen ModellProjekte, financed with funds of LOEWE – Landes-Offensive zur Entwicklung Wissenschaftlich-ökonomischer Exzellenz, Förderlinie 3: KMU-Verbundvorhaben (State Offensive for the Development of Scientific and Economic Excellence).

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