A System Dynamics Approach for Assessing the Development of the CEP market in Urban Areas

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Abstract

The overarching objective of the project is to link a System Dynamics (SD) model with a microscopic freight transport simulation – in this case the Multi-Agent Transport Simulation (MATSim). By this approach the freight demand of private households and the economy as well as the resulting freight transport demand of courier-, express- and package (CEP) services are examined. Furthermore, efficient solutions to regulate this freight transport demand are identified. This approach mutually uses the forecast capability of SD and the detailed resolution of MATSim. The SD model developed is able to assess the development of the CEP market in urban areas in the course of time. In this paper, the authors present the current version of the quantitative SD model, which explicitly shows the internal structures of and the interdependencies between population and economy as freight demanders and the CEP services as freight transport providers.

Keywords: Urban freight transport; Courier, express and package service providers; System Dynamics; Freight transport demand modelling; Stakeholder analysis;

Introduction: Problem definition and research objectives

Since 1950, an exponential growth of population in agglomerations has been observed worldwide. In 2050, approximately 70 per cent of the world's population will live in urban agglomerations (OECD 2012). The demand pressure on transport infrastructure and the traffic share of freight transport increase. Due to e-commerce activities of private households as well as the replacement of storage stocks in the industrial and retail sector a trend towards more flexible and small-scaled deliveries in freight transport is stated. The result is a significant increase of trips of small- and medium-sized vehicles with corresponding environmental damage and – due to their frequent stops - with relatively strong disruptions of traffic flows. Especially, the courier, express and parcel (CEP) service market is driven by these trends and profits from them as the fastest growing and most dominant freight transport market in urban areas. Kille (2012) certifies a high growth potential for this market. 2010, CEP services had a share of 38 per cent on urban freight transport (Sonntag, 2012). But the resulting rising freight transport volume of the CEP services in urban areas has also negative effects. Due to its current and future relevance, we focus our research on the CEP market at an urban level.

From methodological point of view, we develop a System Dynamics (SD) based microscopic freight transport simulation. By this approach the development of the behavioural patterns of relevant stakeholders in the CEP market at an urban level can be investigated in the course of time and at a detailed infrastructural level. Furthermore, the impact of the stakeholders' behaviour on urban freight transport can be estimated. The SD model developed carries out long-term forecasts and trend analyses. The results of the SD model are transferred to the microscopic, freight transport simulation – in this case the Multi-Agent Transport Simulation (MATSim), which is developed by Balmer et al. (2009) and extended with an integrated logistics module by Schröder et al. (2012), to carry out a point-in-time forecast of freight transport demand for one day. The SD results serve on the one hand as an input to generate the synthetic world and population and on the other hand to generate the activity plans of CEP drivers in MATSim. The outcome of MATSim is also transferred back to the SD model to adjust the traffic-affected parameters (e.g. transport volume, transport distance, transport lead time, greenhouse gas [GHG] emissions and transport costs). This research approach is tested within a case study. The investigation area is Berlin, Germany.

In this contribution, the quantitative SD approach with main focus on the CEP market and its impact on freight transport demand and environment will be presented.

In the following, the state of the art focusing on CEP market and SD will be shown. Afterwards, the SD model developed for investigating CEP market at an urban level will be discussed in detail.

State of the Art

This chapter provides an overview of the state of the art in CEP market analysis and in SD modelling with regard to transport planning, spatial development and freight transport as well as economic and social sciences.

CEP market analyses

The state of the art in research with focus on the CEP market, the interactions between the stakeholders involved and e-commerce activities is discussed.

There are a number of national and international studies and scientific publications on the CEP market. Straube & Pfohl (2008) periodically analyse the global trends and strategies in the entire logistics market. They focus on trends in trade and service sector (i.e. CEP services). An overview of the market structure, trends and strategies of the CEP service providers is given by Deutsche Post AG (2010), Esser & Kurte (2014), Klaus et al. (2011), Kille & Schwemmer (2012), Salehi et al. (2011), Zanker (2012) and Manner-Romberg et al. (2009, 2012). These works partly characterise the demand side of the CEP service providers. Studies of Esser & Kurte (2012) and Bogdanski (2015) go more in-depth. Both observe the future of inner city deliveries by CEP services. Thereby, Esser & Kurte (2012) select two shopping streets in Cologne as investigation areas, whereas Bogdanski (2015) examines the city centres of Nuremberg and Frankfurt. Since the urban structures of major cities in Germany are classified as similar, the main results of these studies are representative and can be generalised and applied to other cities. Petermann (2001) deals with the innovation conditions of e-commerce from the perspective of production and logistics. He explicitly considers the logistics to supply the end consumer (Business-to-Consumer; B2C) and the logistical handling of intercompany transactions (Business-to-Business; B2B). He also discusses trends and growth potential of this logistics market. He also refers to the traffic and environmental impact of e-commerce and derives scenarios for the freight and logistics industry. Helmke (2005) addresses both supply and demand structures. In particular, he examines the customer satisfaction and customer loyalty in the CEP market. Other scientific papers give a comprehensive overview of the market and business models of CEP service providers (i.e. Glaser, 2000; Vahrenkamp & Mattfeld, 2007). Gruber (2015) carries out an empirical study with main focus on downtown deliveries by electric cargo bicycles in the German cities Berlin, Hamburg, Munich, Dusseldorf, Bremen, Leipzig, Nuremberg, Potsdam and Mainz. Clausen & Schaumann (2012) and Arnold (2008) discuss research basics concerning *last mile distribution*. Kümmerlen (2013) reflects possible future strategies and developments in the field of urban logistics. Rebstock (2001) dedicates to the topic of e-commerce and analyses structures, markets and transactions in electronic business processes. E-commerce structures at national and international levels are also examined in-depth. Riehm et al. (2003) investigate the effects of e-commerce on transport, ecology, economy and society.

The economic, transport and social geography as well as the general social and trade research analyse the spatio-temporal demand structures for different demand markets (B2B, B2C, C2C). During the last 15 years, these research fields increasingly focus on the dynamic development of e-commerce and its impact on trade, transport and society. In this context, studies are already known that specifically deal with the demand structures, especially with space, time and content differentiated demand structures. Henschel (2001) and Popp & Rauh (2003) investigate the location factors of e-commerce and study the interactions and dependencies between consumers, producers, retailers and logistics providers. Schellenberg (2005) reflects the impact of consumer-related e-commerce on the supply and location structure of retail and retail-related services. Farag (2006) explores the factors that influence the purchasing behaviour in e-commerce and in the shops. In addition, he examines the geographical distribution of Internet users and e-shoppers. Ducar & Rauh (2003) discuss the prospects for the current trade research and practice with regard to the development of e-commerce. Richter et al. (2007) develop a new approach to structure the changing conditions and consequences caused by the e-commerce. Kulke (2006) considers the new supply strategies of trade and the demand patterns of consumers. Kulke (2005) and Kulke & Paetzold (2009) investigate the adjustment mechanisms of the retail industry in the course of internationalisation. Nerlich et al. (2010) focus on the end-user perspective and highlight the implications of online shopping on the mobility and consumer behaviour as well as on transport and regional development. Various contributions in the anthology of Lenz (2010) deal with the traffic and spatial impacts of e-commerce on the adaptation requirements of logistics systems and supply chains (i.e. CEP service providers). Pütz & Schröder (2011) dedicate to the current retail development and refer to the "post-modern" consumer behaviour. They focus on the historical development of trade and consumption patterns and consider the geographies of consumption and the impact on space, culture and economy. Esser & Kurte (2012b) highlight the concrete relationships between the segments of the CEP industry in inner cities. The study provides empirical data and profiles of CEP affine economic sectors and private households. Göddecke-Stellmann (2013) discusses developing trends of the German population and describes their possible consequences in detail. The Sinus-Institute Heidelberg (2015) provides a classification of the population according to their income, their attitude and their lifestyles. These results with regard to sinus milieus play an important role for market research. This includes the work of Humpf et al. (2009), which deals with future customer requirements. In the work, some megatrends are identified and concrete demands of the customers on the CEP services are placed. Rauh et al. (2008) provide a basic view of the different types of consumption depending on groups of product requirements. Even the HDE (2009) focus on suppliers and consumers as well as their customer requirements. An investigation with focus on the population as part of the supply chain is conducted by Traumann & Wellbrock (2012), who study and evaluate the different strategies of supply chain management, thereby analyse private customers as CEP customers. Glose & Tönskötter (2012) examine the impact of logistics on prosperity and quality of life and see the population also as private CEP customers. At the interface between transport geography and behavioural science Visser & Lanzendorf (2004) show the influence of e-commerce on individual activity patterns and mobility behaviour. They derive interactions between the freight transport as well as logistical and budgetary decisions. Schliephake & Schenk (2004) analyse mobility behaviour, infrastructure development and logistical decisions that are in the field of tension between supply and demand. From market research and marketing perspective TNS Infratest (2012, 2013) researches the user behaviour and the customer requirements in terms of e-commerce. In particular, they characterise the market development, sector-specific developments as well as the attitudes and the online behaviour of consumers. DHL (2012a) also considers the changing customer behaviour of private households due to e-commerce and explicitly deals with customer attitudes differentiated by profile types and socio-demographic and socio-economic features. Rauh et al. (2012) develop an agent-based model for illustrating the consumer behaviour. The approach aims to estimate sales forecasts for retail locations or location agglomerations. As a side effect, it allows to represent the shopping trips and transport flows caused by supply trips.

Concerning the development of the retail sector there are several studies, which can be accessed. The studies used focus on the development of the downtown relevant retail. The HDE (2014) reports on the development of retail and assesses trends and possibilities to increase the attractiveness of inner cities. Genth (2014) also gives an assessment of the current state and future possibilities of retailing. Wotruba (2014) discusses meaningful coupling effects, which can be achieved in combining certain sectors in inner cities. Rieper (2014) examines the opportunities of retailers in the field of Multi-Channelling. Granzow & Schulze (2012) investigate strategies to enhance the efficiency in the supply chain of urban retailers. Illiges & Lehmann (2009) specifically deal with the retail sector in Berlin. They focus on the overall development as well as on the development of single city districts. Furthermore, already presented works of Esser & Kurte (2012), Bogdanski (2015) and Traumann & Wellenbrock (2012) can be well used for studying the retail sector, since they provide information on its supply side.

In summary, these studies provide a comprehensive picture of the CEP market and its stakeholders. By these approaches the internal structures of and the interdependencies between the stakeholders involved can be explained in detail. These existing secondary databases with regard to supply and demand as well as e-commerce patterns are used to parameterise the following SD model.

System Dynamics modelling

In this chapter, the state of the art in SD modelling in the research fields of transport planning, spatial development, economics and social sciences is shown. This approaches presented are investigated in detail and proved if they are suitable for our own research focus.

The methodology SD is developed by Forrester (1961), who examines the interdependencies between economics, business and organisation systems by his Industrial Dynamics. His first model is based on the General System Theory and Control Theory. The World Dynamics model, which is developed on behalf of Club of Rome, focuses on the interrelations between population, consumption, raw materials and environment (Meadows et al., 1972).

SD is used to explain complex, dynamic systems and its development in the course of time, which are formalised by non-linear and differential equations. Besides this, SD allows to illustrate the internal structures, system behaviour and the external interdependencies or feedbacks between different stakeholder systems in a qualitative and quantitative way. (Rosenberg et al., 2012; Bossel, 2004a, b; Sterman, 2001; Weidmann et al., 2012; Thaller et al., 2016) Furthermore, impacts of decision-making processes in complex systems can be shown. By an iterative modelling procedure the interrelations between different stakeholder systems have to be adjusted and formalised. (Thaller et al., 2016; Weidmann et al., 2012)

In the last decades, this methodological approach has also been applied in the research fields of transportation, spatial development, urbanism and economics as well as social sciences (see Bossel, 2004a, b, c; Sterman, 2001). Overviews of the selected approaches applied in these fields are presented in the following table, which shows the research focus, objectives and spatial resolutions for each approach (see Table 1).

Table 1: A review of selected SD approaches (Source: own diagram based on Thaller et al., 2016)

SD approaches	Research focus	Research objectives	Spatial resolution
• **Lee (1995)**	• Transport & land use	• Improving transport quality	• Urban
• **Heimgartner (2001)**	• Transport & land use	• Identifying sustainable transport policies	• Urban
• **Raux et al. (2007)**	• Effects of urban transport policy instruments on passenger transport	• Sustainable passenger transport	• Urban
• **Pfaffenbichler (2003)**	• Land use & transport	• Identifying sustainable measures for MIT and public transport	• Urban
• **Wang et al. (2008)**	• Interdependencies between population, economy, transport demand & traffic supply	• Measuring traffic congestion and environmental effects of greenhouse gas emissions	• Urban
• **Zhan et al. (2012)**	• Interrelations between population, economy, passenger transport, traffic infrastructure & environment	• Exploring environmental effects of passenger transport	• Urban
• **Ruutu et al. (2013)**	• Mode choice of private and public transport	• Investigating transport policies to reduce negative environmental effects	• Urban
• **Schade et al. (2000), IWW (2000), Schade (2004), Kuchenbecker (1999)**	• Interdependencies between macroeconomics, regional economics, transport & environment	• Investigating effects of transport policy measures for a sustainable development	• National, regional
• **Hong et al. (2011)**	• Investigating highway infrastructure projects during the construction and operating stage	• Assessing sustainable performance of highway infrastructure projects	• National
• **Han & Hayashi (2008)**	• Examining the inter-city passenger transport	• Policy assessment and CO2 mitigation potential analysis	• National
• **Salini & Karsky (2002)**	• Investigating freight transport market	• Investigating the interactions between transport modes, productivity & enterprise capacity	• National
• **Weidmann et al. (2012)**	• Analysing freight transport systems regarding its stakeholders	• Sustainable last-mile distribution	• Regional
• **Gacogne (2003)**	• Investigating the interdependencies between logistics organizations & freight flows	• Assessing impacts of increased freight rates on logistical systems and on freight flows	• National
• **Aschauer (2013, 2015)**	• Investigating interdependencies between logistics strategies & freight transport	• Identifying logistics strategies for minimizing transport costs	• National
• **Kühn & Krail (2013)**	• Investigating the interdependencies between freight transport demand & vehicle size of light duty vehicles (LDV)	• Understanding of the fleet operator behaviour for a more realistic vehicle fleet forecasting	• Company level
• **Meyer Sanches et al. (2013)**	• Investigating the long term effects of freight vehicle circulation restriction policies	• Assessing impacts of these policies in the congestion level as well as the transportation costs	• Urban
• **Villa et al. (2013)**	• Analysing retailer order decisions in dependency of supplier capacity acquisition delays	• Characterising retailers‘ performance in the system and replicating retailers‘ ordering behaviour	• Company level
• **Bockermann et al. (2005)**	• Examining the interdependencies between economic development, energy and material consumption and their environmental effects	• Investigating sustainable strategies for the EU 15 economy	• EU
• **Engel (2010)**	• Investigating demographic determinants of the energy demand of private households	• Assessing the impact of demography on the energy demand of private households	• National
• **Jin et al. (2009)**	• Examining the interdependencies between population, consumption, economics and energy consumption	• Supporting policy making processes for urban sustainability improvement	• Urban

To sum up, most of the presented approaches investigate the impact of transport policy instruments on passenger transport. Other approaches focus on the interdependencies between transport and land use at different spatial resolutions. Freight transport is only considered in few approaches, which illustrate freight transport processes at a national level or along the whole supply chain.

For this reason, this identified research gap is closed by the following approach, which focuses on the interdependencies between freight demand and freight transport demand as well as the impacts on logistics and environment at an urban level.

System Dynamics model

In the following, the quantified SD approach is discussed in detail. The internal structure of and the interdependencies between the different submodules are shown. We differentiate between *population*, *household structure*, *freight demand*, *freight transport demand* (including freight transport volume and performance as well as fuel consumption), *fleet development*, *tour characteristics and transport lead time*, *transport costs* and *environmental effects*. The changes in behaviour and development of the relevant stakeholders in this system can be illustrated by this approach. We decide to use 1 day as a time step, since MATSim calculates the interactions of freight and private transport at an infrastructural level within a day. When we stop the forecast, the saved results of the final time can be transferred to MATSim to initialize and update the MATSim world. After the MATSim simulation we grab the end results of the daily simulation and transfer these to the SD model. In this case, the initial values of the stocks and the auxiliaries are adapted and adjusted for the next forecast. Due to this procedure we have identified the parameters in the system, which should be transferred from the SD model to MATSim, from MATSim to the SD model or both. For this reason, we mark the parameters, which are transferred from the SD model to MATSim in orange, from MATSim to the SD model in blue, as well as both in green.

The following submodules have been quantitatively formalised based on literature analyses and assumptions of qualitative causal loops. The approaches in the field of SD (see Table 1) have been investigated and adapted to the requirements of this model approach. We have focused on the accuracy and the level of detail within the modelling procedure to illustrate the changes in behaviour and the development of this stakeholder system in-depth. Furthermore, this model has also been adjusted on the requirements of the existing secondary databases. The different stakeholder systems have been differentiated and illustrated in small submodules to guarantee the traceability for the reader.

Population development

Several SD approaches model the socio-demographic structure of the population (e.g. Lee, 1995; Heimgartner, 2001; Raux et al., 2007; Pfaffenbichler, 2003; Bossel, 2004c; Schade et al., 2000; IWW, 2000; Schade, 2004; Kuchenbecker, 1999; Engel, 2010; Jin & Xu, 2009; Wang et al., 2008; Zhan et al., 2012; Ruutu, 2013 and Han & Hayashi, 2008).

Starting point of this SD approach is the population development based on Bossel (2004c). The results of the population development are more accurate, the more age cohorts are considered. The following approach of Bossel (2004c) is extended and differentiated in eight age cohorts. This modelling approach allows a more detailed investigation of the population structure and fulfils the necessary claims for adapting the total model. Furthermore, the approach also enables to consider both the consequences of the demographic change and migration tendencies on the whole population. This submodule effects on further subsystems, e.g. *freight demand of private customers* and *environmental effects of the total transport volume*.

The first cohort *population less than 14 years* does not directly effect on the *freight demand* of private customers. Cohorts 2–5 (*population from 14 to less than 54 years*) include in each case 10 years and reflect the working population together with the cohort 6 (*population from 54 to less than 67 years*). The breakdown *to less than 67* has been chosen due to the retirement age. Each person, who was born in 1964 or later, can receive full pensions from the age of 67. The retirement age from the 65th year of life is only possible for people, who were born before 1947. Due to this aspect and the model purpose for a medium- and long-term forecast, the age cohorts to less than 65 years have been dispensed with. The 7th cohort includes again 10 years (*population from 67 to less than 77 years*). Finally, the 8th cohort shows the population with *77 years and older*. From the sum of all age cohorts the total number of residents (*population*) is derived.

The following constants exert an influence on the development of the 8 age cohorts.

+ Immigration rate
– Transition from the previous to the next age cohort
– Mortality rate
– Emigration rate

An age cohort increases or decreases by the age cohort specific immigration, emigration and mortality rates depending on the number of residents within this cohort. For this reason, the quantity of the migration is adapted by the population development from year to year. Within the modelling procedure fixed values for the immigration and emigration are dispensed with to guarantee a dynamic model as well as to avoid a negative or false number of residents for each age cohort. Furthermore, the migration is typically dependent on the number of residents in the real world. Due to the increasing urbanisation, the people in Germany and in other countries choose their place of residence according to the population structure, quality of life and job offer. The distribution of refugees is regulated by the GDP (economic performance) and the number of population of a city.

Each year, an age cohort increases and decreases by the persons, who pass to the next age cohort due to their advancing age. This transition is calculated by dividing the number of residents – including the immigration as well as excluding the emigration and mortality – of each age cohort by the number of years included in each age cohort, which varies from 10, 14 and 17. In addition, the development of the 1st age cohort is influenced by the total number of births (*birth total*). This variable results from the multiplication of *fertility rate* and number of *population* from the age cohorts 1–6, so that every person younger than 67 years is included in the calculation of the birth rate. Persons (67 years and older) have no births due to their age. For this reason, they are not considered in the calculation of the births.

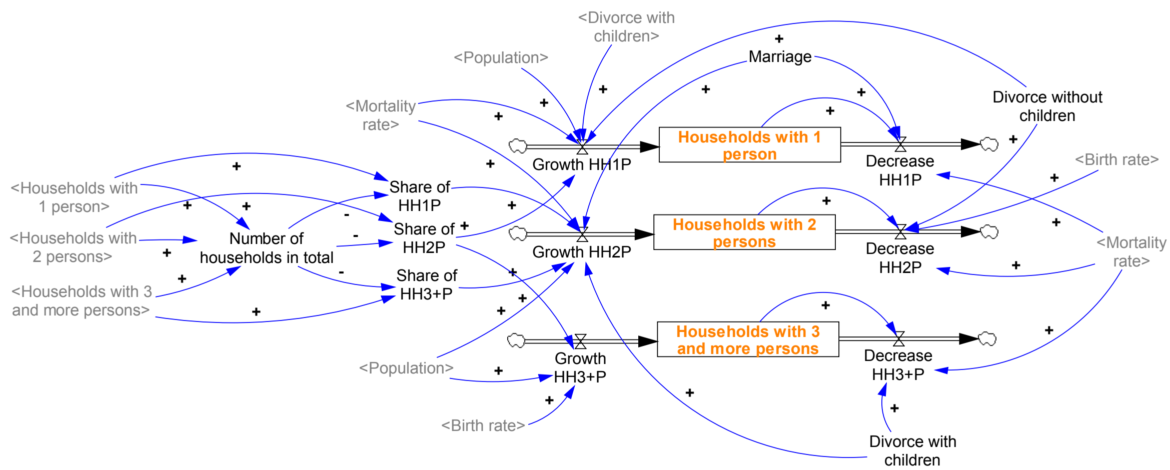

Figure 1: Quantitative SD approach of household structure (Source: own diagram based on Engel, 2010)

In regard to the linked approach with MATSim, final values of the stocks of each age cohort are transferred to the MATSim world after a SD simulation to generate and adjust the current number and composition of the *population* by age cohorts.

Household structure development

In the following section, the submodule household structure is shown, which is differentiated between three household cohorts according to their size. This chosen approach is based on Engel (2010) and extended to the requirements of the model accuracy to ensure the detailed development of the household cohorts within the simulations.

The endogenous parameters in this context are the stocks and flows to calculate the household development differentiated between three household sizes. The share of each household type is also internally calculated. Only the rates (e.g. marriage, divorce without children and divorce with children) are exogenous parameters. In this stock-flow chart, the parameters in grey and in a content bracket are so called shadow variables, which are already existing parameters of other submodules. (see Figure 1)

Possible changes of each household cohort are only illustrated by simplified socio-demographic processes. Basically, it is differentiated between *households with one person*, *two persons* and *three and more persons*. *Marriages*, *divorces with* and *without children* as well as *births* and *deaths* are considered as influences, since these lead to changes in household size in almost 100 % of cases. For the model it is assumed that a *marriage* results in a decrease of *households with 1 person* and in an increase of *households with 2 persons*. With regard to *divorces without children* this scheme works exactly reversed. If children are involved in divorces, we assume that a *household with 3 and more persons* is subdivided in a *household with 1 person* and a *household with 2 persons* or *3 and more persons*. In 54 % of cases an additional *household with 2 persons* results, since only one child is a member of this household. Otherwise a *household with 3 and more persons* remains unaffected. A death always leads to the decrease in household size. The probability depends on the mortality per person in the household, which is considered in the formalisation. Furthermore, the *share of each household cohort* is integrated in the formalisation of the flows *growth HH1P, HH2P* and *HH3+P*. These shares are adapted for each time step by dividing each household cohort by *number of households in total* within a feedback loop. *Number of households in total* is the sum of the three household cohorts.

This submodule is only dependent on the population development. But it does not effect on other submodules of the total system. The current values of the stocks of each household cohort are only necessary to generate and adjust the synthetic population of MATSim, which illustrates different household cohorts with their different compositions.

Interdependencies between freight demand and freight transport demand

In the following, the interdependencies between the freight demand of private and commercial customers of CEP service providers and the resulting freight transport demand of CEP services are shown in detail. By this approach the impacts on freight transport volume and performance are explained. The freight demand of private customers caused by their e-commerce activities and of commercial customers (e.g. retailers, which are supplied by CEP service providers) generates the freight transport demand of the CEP service provider. The shippers (e.g. producers, wholesalers), who initially receive the orders from the customers, are not considered as an intermediate between customer and CEP service provider. The information and communication process between customer, shipper and CEP service provider takes only one or two days and is processed via electronic means. Freight transport demand of CEP service providers is dependent on the existing transport capacity of the CEP services. In the following, the internal structures and interdependencies between *freight demand*, *freight transport demand* and *freight transport capacity*, *freight transport volume* generated and *road mileage performed for last mile and fuel consumption* are shown and described in detail. The stock-flow chart is derived from Villa et al. (2013), Bossel (2004 c), Schade et al. (2000), IWW (2000), Schade (2004), Aschauer (2013), Aschauer et al. (2015), Weidmann et al. (2012), Kühn & Krail (2013), Meyer Sanches et al. (2013), VDI (2002), Moder (2010), Kuchenbecker (1999) and Kaczmarek et al. (2003) (see Figure 2).

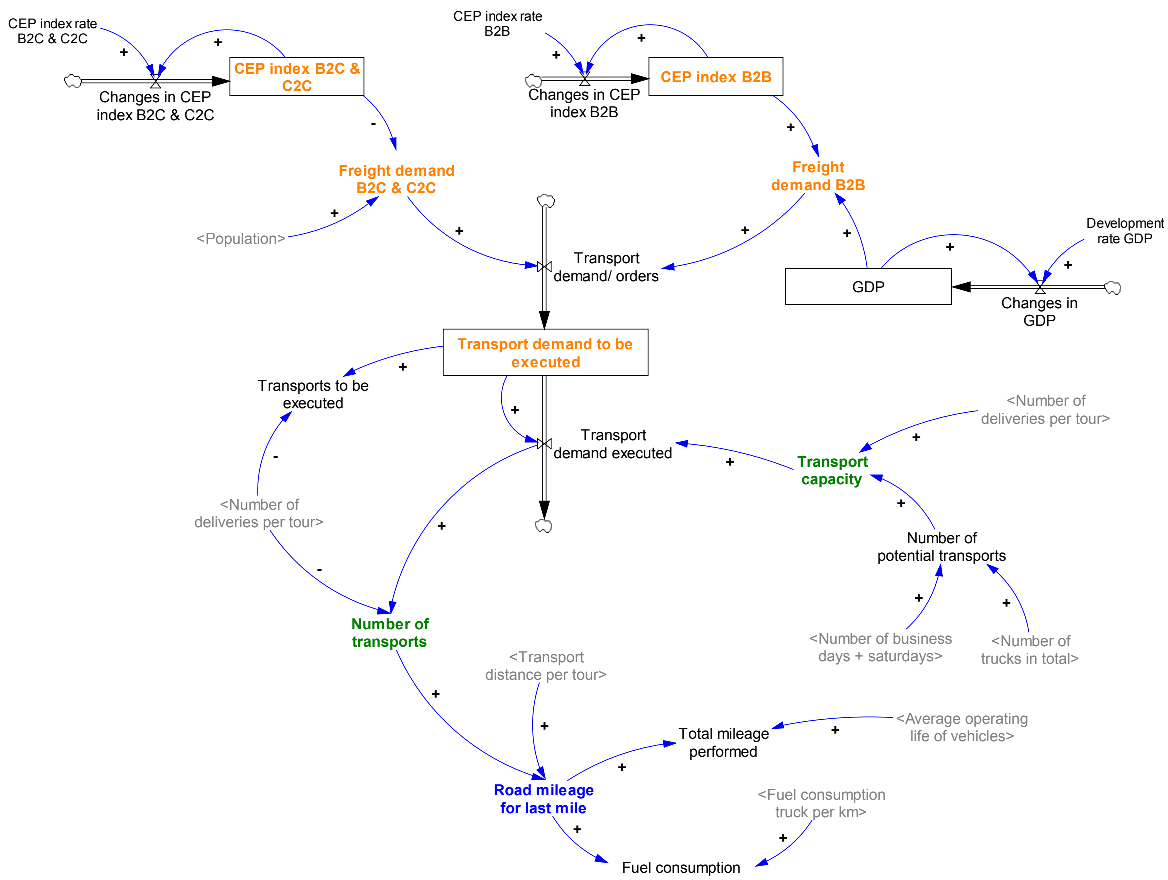

Figure 2: Quantitative SD approach of the interdependencies between freight demand and freight transport demand (Source: own diagram based on Villa et al., 2013; Bossel, 2004 c; Schade et al., 2000; IWW, 2000; Schade, 2004; Aschauer, 2013; Aschauer et al., 2015; Weidmann et al., 2012; Kühn & Krail, 2013; Meyer Sanches et al., 2013; VDI, 2002; Moder, 2010; Kaczmarek et al., 2003; Kuchenbecker, 1999)

Freight demand development

This stock-flow chart is derived from Villa et al. (2013), Bossel (2004 c), Schade et al. (2000), IWW (2000), Schade (2004), Kuchenbecker (1999) and Kaczmarek et al. (2003).

The *freight demand of B2C (Business-to-Consumer) and C2C (Consumer-to-Consumer) in e-commerce (EC)* is directly related to the population and its development as well as the affinity for consumption via the Internet (e-commerce). Latter reflects the number of ordered packages per person and time interval (*CEP index B2C & C2C*). *CEP index B2C & C2C* is changed in each time interval by a developing rate (*CEP index rate B2C & C2C*). The impacts of potential qualitative and quantitative improvements of e-commerce or delivery forms and strategies (e.g. more/ bigger packing stations) on an eventually rising *freight demand* are only indirectly taken into account in this model by the *CEP index B2C & C2C*.

The *freight demand of the economy (Business-to-Business: B2B)* is dependent on the development of the *CEP index of the economy (CEP index B2B)* and the *gross domestic product (GDP)*. (see Figure 2)

After the simulation run the final values of the stocks *CEP index B2C & C2C* and *CEP index B2B* as well as the *freight demand B2C & C2C* and the *freight demand B2B* are transferred to MATSim to distribute the *CEP index* to the synthetic population, to determine the customers of the CEP service provider and to inform the CEP service provider about the current total freight demand of his customers.

Freight transport demand & freight transport capacity development

Based on Villa et al. (2013), Weidmann et al. (2012), Kaczmarek et al. (2003) and Kuchenbecker (1999) the following submodule is developed and adapted to the requirements of the illustrated system.

The *transport demand or orders* of the CEP customers is the sum of *freight demand B2C & C2C* and *freight demand B2B*. *Transport demand to be executed* is derived from the *transport demand or orders* per time interval and transport demand, which could not be executed in the last time interval due to a lack of the total *transport capacity*.

In this case, the delivered packages per time interval (*transport demand executed*) are dependent on *transport demand to be executed* of each period and the *transport capacity*. For this reason, we have to discuss the following scenarios.

1. If more packages have to be transported as the *transport capacity* allows, only the maximum number of packages corresponding to *transport capacity* is delivered and the remaining packages are added on the *transport demand to be executed* in the next time interval.
2. Due to the existing *transport capacity* more than packages required could be transported, the entire transport demand of each period is executed.

The *transport capacity* results by multiplying the *number of potential transports* by the *number of deliveries per tour*. Thereby, the *number of potential transports* is derived by multiplying the existing *number of trucks* by the *number of business days incl. saturdays* within a year. Berlin has in average 304.78 business days incl. saturdays. It is assumed within the model, that a truck or a CEP driver executes one tour per day. (see Figure 2)

After SD forecasting the final value of the stock *transport demand to be executed* is transferred to MATSim to inform the CEP service provider, how many packages have to be delivered within the time period. The final value of *transport capacity* is also passed to MATSim to the CEP service provider. After the simulation runs by MATSim the final results are transferred back to SD to adjust the initial value of *transport capacity*.

Freight transport volume development

The submodule *freight transport volume* is developed on the basis of the mathematical formalisations of Moder (2010), Aschauer (2013), Aschauer et al. (2015), Weidmann et al. (2012), Meyer Sanches et al. (2013) and VDI (2002). This submodule is directly dependent on *transport demand executed*. Focusing on freight transport volume development in the course of time the *number of transports* per time interval are calculated by the ratio of *transport demand executed* and the *number of deliveries per tour*. In addition, *transports to be executed* results by dividing the *transport demand to be executed* by *number of deliveries per tour* for each time interval. In contrast to the *number of potential transports*, which corresponds to the maximum transports depending on transport stock, *transports to be exe-*

cuted are the tours, which are necessary to meet the transport demand. This parameter determines the transport deficit or supply gap of the CEP service provider (see submodule *fleet development*). This submodule effects on the submodules *fleet development*, *transport lead time development* and *environmental effects of total transport volume*.

After each simulation run of the SD model and MATSim the final values of the parameter *number of transports* are transferred to the respective other simulation model. In this case, the most important data transfer is the one from MATSim to SD to adjust its initial value. This parameter is influenced by the *infrastructure capacity,* the *infrastructure utilisation* and the *level of congestion*. Since SD can only model infrastructure on an aggregated level, the spatio-temporal dependency of this parameter cannot be modelled by SD in a realistic way.

Road mileage performed for last mile and fuel consumption development

In the following, the submodule *road mileage performed for last mile and fuel consumption development* is discussed, which is influenced by the *freight transport volume development*. Based on Aschauer (2013), Aschauer et al. (2015), Weidmann et al. (2012), Kühn & Krail (2013) and Meyer Sanches et al. (2013) this submodule is mathematically formalised. The *road mileage for last mile* per time interval is derived by multiplying the *number of transports* by the *transport distance per tour*. This parameter shows the kilometres performed on road for last mile distribution. Furthermore, the *total mileage performed* is dependent on the *road mileage for last mile* and the *average operating life of vehicles*. In this case, we assume that a CEP vehicle has an operating life of 6 years. Based on the multiplication of *road mileage for last mile* and *fuel consumption per truck and km* we calculate *fuel consumption*. (see Figure 2) This submodule has a direct impact on *transport costs development* and *environmental effects of total transport volume.*

After the MATSim simulation runs the final result regarding *road mileage for last mile* is transferred to SD and integrated as the new initial value of this auxiliary.

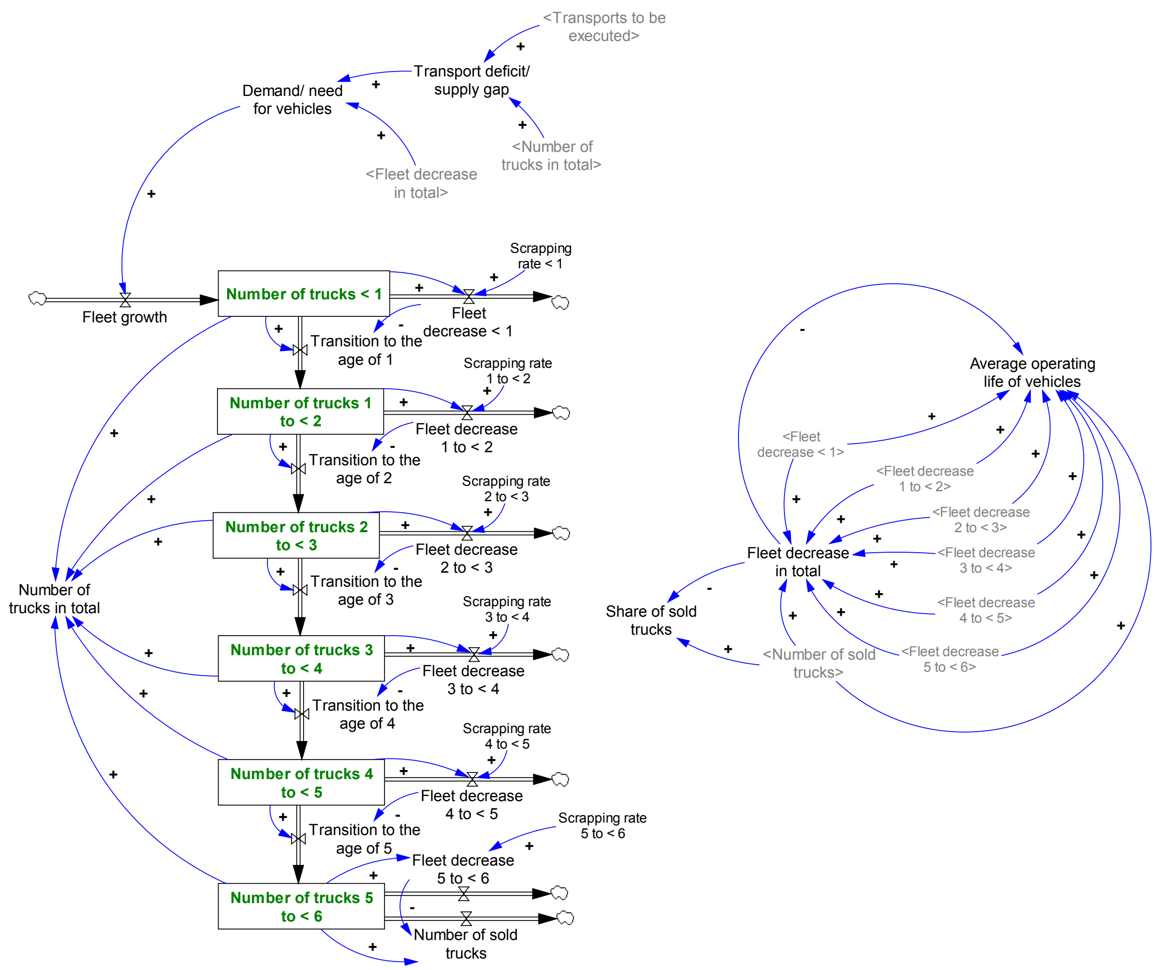

Figure 3: Quantitative SD approach of fleet development (Source: own diagram based on VDI, 2002; Kuchenbecker, 1999; Kühn & Krail, 2013; Meyer Sanches et al., 2013; Weidmann et al., 2012)

Fleet development

Based on the mathematical formalisations and assumptions of VDI (2002), Kuchenbecker (1999), Kühn & Krail (2013), Meyer Sanches et al. (2013) and Weidmann et al. (2012) the following submodule is developed. This model is only influenced by the *freight transport volume development*.

The *number of trucks* of the CEP service providers is subdivided in six age cohorts due to the average operating life of the vehicles and the legal depreciation term of such vehicles. (see Figure 3) The age cohort *number of trucks less than 1 year* is adjusted in the course of time by *fleet growth* and *fleet decrease less than 1 year*, which is influenced by the *scrapping rate less than 1 year*. A positive *fleet growth* is affected by the *demand or need for vehicles*. As soon as this demand is greater than 0, a growth in the positive integer is generated. The *demand for vehicles* is the result from the sum of *fleet decrease in total* and the *transport deficit or supply gap*. This *transport deficit* is derived from the difference between the *transports to be executed* per time interval and the existing transport stock (*number of trucks in total*). The age cohorts *number of truck 1-6 years* change in the course of time due to the *transition* to each next age cohort and the *fleet decrease* of each age cohort. In this study, we concentrate on light duty vehicles (3.5 tones maximum permissible weight), which are usually used by CEP service providers for the last mile distribution in urban areas. For this reason, we need to consider only one truck type in the business as usual scenario. For future and trend scenarios, we could introduce electric vehicles with the same internal structure of this submodule.

This submodule effects on *freight transport demand* and *transport capacity development* as well as *transport costs development*.

After the SD simulation run the final value of *number of trucks in total* is transferred to MATSim to the CEP service provider. With this initial fleet stock the CEP service provider can generate the activity plans for the CEP drivers. After the MATSim simulation runs the final results for number of necessary trucks are passed back to SD to adjust the initial value of this auxiliary.

Tour characteristics and transport lead time development

In this chapter, the submodule *tour characteristics and transport lead time development*, which is only dependent on *freight transport volume development*, is discussed. This submodule is derived from the mathematical formalisations of Moder (2010).

Transport distance per tour is in average 55.4 km per tour and day (Bogdanski, 2015). *Number of stops per tour* is derived from the ratio of *number of deliveries per tour* and the *drop factor.* On a tour approximately 165.5 packages can be delivered (corresponds to the constant *number of deliveries per tour)* (Bogdanski, 2015). The parameter *drop factor* determines how many packages are delivered during one stop. The average *drop factor* for a CEP service provider in urban areas is 1.675 deliveries per stop. (Bogdanski, 2015) The *average distance between stops* (density of stops) results by dividing the *transport distance per tour* by *number of stops per tour*. The *transport lead time per tour* is derived depending on *transport distance per tour, average speed on road, number of stops per tour* and the *average stop time*. We assume that a CEP driver needs for a stop about 2.5 minutes, corresponding to 0.04 hours of in total approximately 5.5 hours per tour. (Bogdanski, 2015) The *total transport lead time* per observed time interval results from the product of *number of transports* and the *transport lead time per tour*. This submodule effects on *freight transport capacity, freight transport volume, road mileage performed* and *transport costs*. (see Figure 4)

The constants *drop factor*, *transport distance per tour*, *number of deliveries per tour*, *average stop time* and *average speed on road*, which are influenced by traffic, are iteratively adjusted by the simulation results of MATSim.

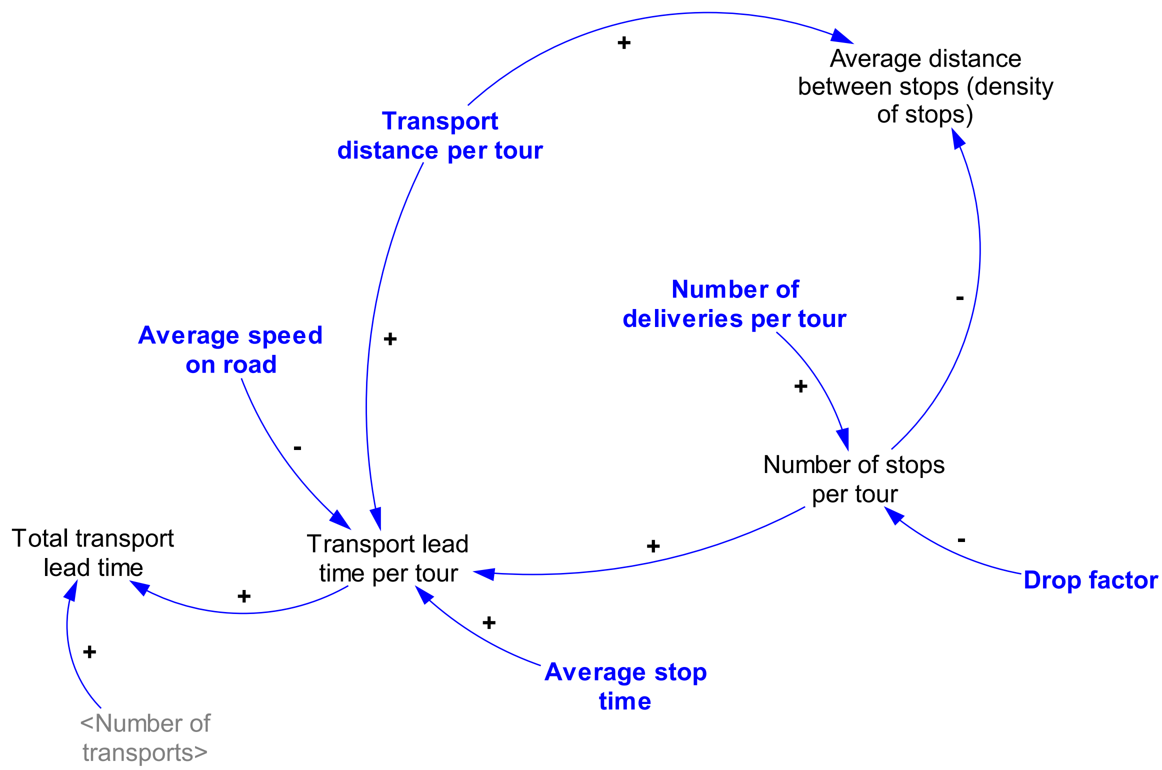

Figure 4: Quantitative SD approach of tour characteristics and transport lead time development (Source: own diagram based on Moder, 2010)

Transport costs development

In the following, the full-cost accounting for the vehicles used of CEP service providers for last mile distribution is shown. This calculation for freight transport costs could be used for different truck types. As mentioned above, we focus only on light duty vehicles in this study.

Based on Wittenbrink (2011) the *transport costs* of CEP services are differentiated between *variable* and *fixed costs*. *Variable costs*, which are influenced by the *road mileage performance and fuel consumption, freight transport volume* and *fleet development* as well as *transport lead time*, include the following cost items.

- *Fuel costs*, which depend on the *fuel price development* and the *fuel consumption of the vehicles*
- *Lubrication costs*, which are influenced by the *road mileage performed for last mile*
- *Tyres costs*, which may vary by maximum *tyre kilometres*, *number of tyre sets needed* and the *road mileage performed for last mile* as well as the *tyre prices*
- *Unit-of-production depreciation*, which are influenced by *tyre prices*, *average residual value*, *average operating life of vehicles*, *number of trucks in total*, *road mileage performed for last mile* and *purchase prices* for new vehicles
- *Maintenance and repair costs*, which depend on *road mileage for last mile*

- *Toll costs*, which are results from the *road mileage performed for last mile*, *share of road toll* and *the road toll development*

Fixed costs consider the following cost items.

- *Time depreciation*, which is dependent on *tyre prices*, *purchase prices* of new vehicles, *average operating life* and *average residual value* of the existing vehicles
- *Interest costs*, which are also affected by average *residual values* of existing vehicles, the *purchase price* of new vehicles and *the number of trucks* of CEP service providers
- *Taxes and insurances* are depended on the existing *number of trucks* of CEP service providers
- *Personnel costs (PC)* result from the *total transport lead time performed*, the *time to load vehicles* and the *development of the PC per hour*
- *Other costs* (e.g. fleet management costs, insinuation/ garage) depend on the size of the fleet

The single cost items of this submodule are parameterised by average costs of a selected truck type, which is typically used by CEP service providers. The detailed formalisation of this submodule is based on Wittenbrink (2011), Aschauer (2013), Aschauer et al. (2015) and VDI (2002).

The final values of a SD simulation run of the parameters *fuel price*, *road toll* and *PC per hour* are transferred to MATSim to update the transport cost model. The *total transport costs* calculated by MATSim are passed to SD to adjust the initial value of this auxiliary.

The other cost parameters, marked in green, are recursively transferred and adjusted the initial values of SD and the MATSim transport cost model (see Figure 5).

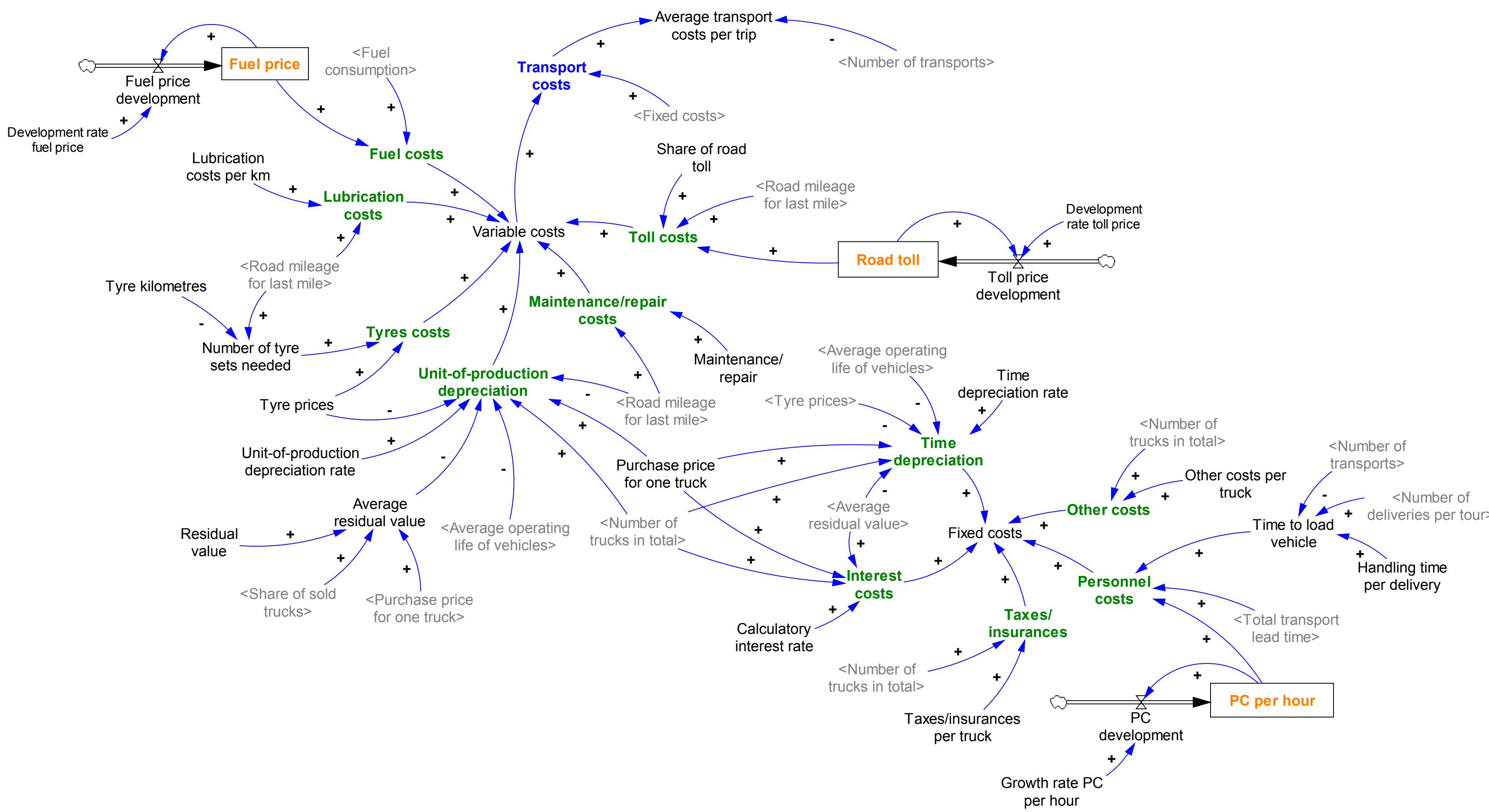

Figure 5: Quantitative SD approach of freight transport costs development (Source: own diagram based on Wittenbrink, 2011; Aschauer, 2013; Aschauer et al., 2015; VDI, 2002)

Environmental effects of total transport volume

In this section, we describe the submodule *environmental effects of the total transport volume*, which is developed based on Lee (1995), Heimgartner (2001), Raux et al. (2007), Pfaffenbichler (2003), Bossel (2004b and c), Schade et al. (2000), IWW (2000), Schade (2004), Kuchenbecker (1999), Engel (2010), Aschauer (2013), Aschauer et al. (2015), Jin & Xu (2009), Wang et al. (2008), Hong et al. (2011), Zhan et al. (2012), Ruutu (2013) and Han & Hayashi (2008). This submodule is influenced by *population development, freight transport volume* as well as *road mileage for last mile and fuel consumption development*.

Hence, we do not only consider the effects of road freight transport, but also the effects of the motorized individual transport (MIT). Starting with the environmental effects of MIT, we have to derive the *number of cars* on road, which is calculated by the number of residents in the city (*population*) and the *number of cars per person*. Based on the product of *number of trips per car and day*, the *number of cars* and the *days per year* (in this case 365 days), *number of car trips* per time interval can be derived. To calculate *passenger kilometres of MIT,* it is necessary to multiply *number of car trips* with *passenger kilometres per trip*. The *changes in GHG emissions per car and km* results by multiplying the *development rate GHG emissions car per km* by *GHG emissions car per km*. *GHG emissions of MIT* could be derived from the product of *GHG emissions per car and km* and the *passenger kilometres of MIT*. *GHG emissions of road freight transport* are calculated by multiplying *fuel consumption* by *conversion factors* for each type of GHG emission. Finally, the *GHG emissions of the total road transport* are derived from the sum of *GHG emissions of road freight transport* and *MIT*. (see Figure 6)

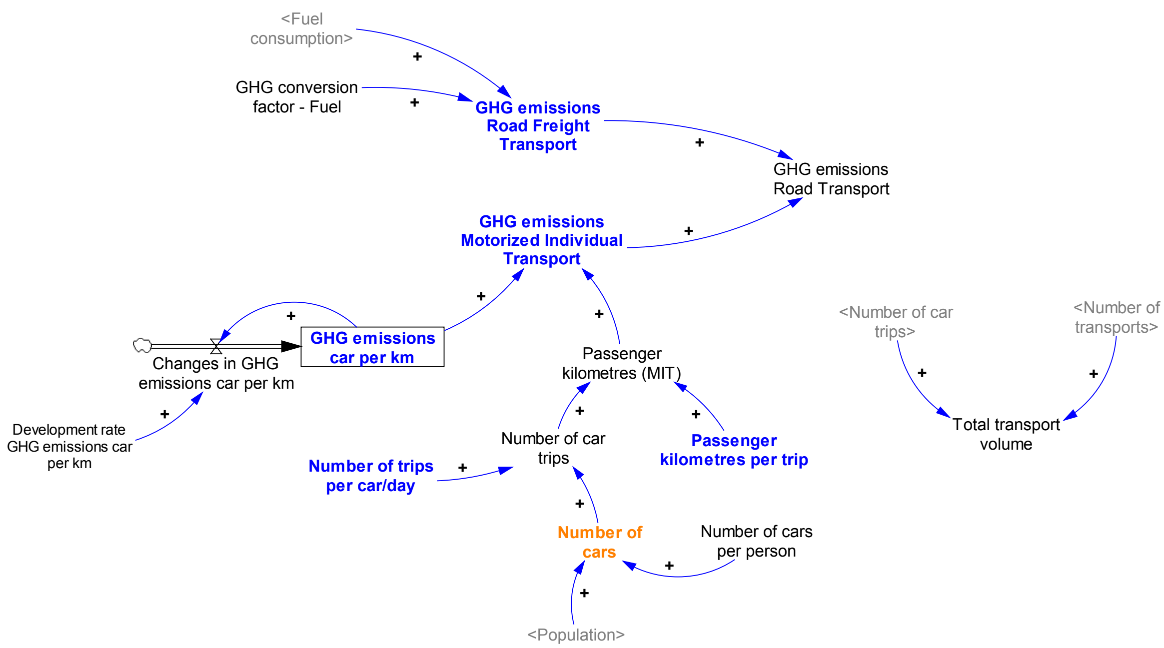

Figure 6: Quantitative SD approach of the environmental effects of total transport volume (Source: own diagram based on Lee, 1995; Heimgartner, 2001; Raux et al., 2007; Pfaffenbichler, 2003; Bossel, 2004 b,c; Schade et al., 2000; IWW, 2000; Schade, 2004; Kuchenbecker, 1999; Engel, 2010; Aschauer, 2013; Aschauer et al., 2015; Jin & Xu, 2009; Wang et al., 2008; Hong et al., 2011; Zhan et al., 2012; Ruutu, 2013; Han & Hayashi, 2008)

The *total transport volume*, trips per time interval, is the result from the sum of *number of car trips* and *number of transports*.

We differentiate between GHG emissions, which are also modelled (e.g. CO_2, particular matter [PM10], carbon monoxide, nitrogen oxide, sulphur dioxide).

After a SD simulation run the current value of the auxiliary *number of cars* is transferred to MATSim to generate and adjust the mobility plans of car drivers. The values of the constants *number of trips per car and day* and *passenger kilometres per trip* are adapted by the results of the MATSim simulation. The values of different *GHG emissions per truck and km* and *GHG emissions per car and km* as well as *total amount GHG emissions of road freight transport and MIT* are also transferred from MATSim to SD.

Conclusion

In summary, we have developed a System Dynamics approach for assessing the development of the CEP market in urban areas. First, we have presented the state of the art in CEP market analyses with main focus on the behaviour and structure of the different stakeholder systems involved (e.g. CEP service provider, private and commercial customer). Afterwards, we have shown an overview of existing SD approaches with main focus on transport planning, spatial development, freight transport and logistics as well as economics and social sciences. On this basis, the quantitative SD model has been mathematically formalised. We have explained that the socio-demographic structure of the population has an impact on freight demand of private customers and on transport demand of MIT. In addition, the effects of freight demand on freight transport demand can also be described by this approach. Furthermore, the freight transport demand is dependent on the transport capacity or existing fleet size, but also effects on changes in fleet size development. Freight transport demand influences the development of freight transport volume, road mileage performed for last mile and fuel consumption. Tour characteristics and transport lead time development can change the development of transport capacity, freight transport volume, road mileage performed for last mile and transport costs. Thus, the transport costs are changed by the road mileage development, fleet size development and transport lead time development. Finally, transport volume of MIT and freight transport effects on GHG emissions.

Within a case study with focus on Berlin city, the discussed SD model will be parameterised in the next steps to start simulations. Within a testing phase the model will be validated by structure and behaviour tests as well as historical and sensitivity analyses. Future forecasts will be carried out for a forecast horizon of 15-20 years. Within this horizon we could assess potential changes in the system. Furthermore, medium-term strategic planning of CEP service providers could also be considered (e.g. same day delivery). New transport policy instruments or measures in the framework of strategic mobility plans could enhance the transport quality for time periods of 5-20 years. By using scenarios we could test the implementation of those logistics and transport planning measures to assess its environmental and economic effects on CEP transports (e.g. city toll, supporting e-mobility and cargo bikes, enhancing the consolidation rate, implementing urban consolidation centres).

This SD model has been linked to MATSim. This approach enables on the one hand medium- and long-term forecasts and on the other hand detailed simulations at an infrastructural level.

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