Project description

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Carrier Agents and Interactions with Traffic Flows

(Sub-project of package project "Shippers and Recipients in a Multi-Agent Framework for Commodity Transport Demand Modelling")

NOTE: Text passages with few changes compared to the original submission are grayed out.

1 State of the art and preliminary work

State of the art

(A) Multi-step commodity transport demand models All comprehensive state-of-the-art freight transport modelling systems are based on the classical 4-step framework which has its origins in passenger travel demand modelling (Ortúzar and Willumsen, 2001; Lohse, 1997). Comparably to passenger transport, freight transport demand models include at least the steps of commodity-flow generation, distribution (= destination choice), modal split, and traffic network assignment. In order to incorporate the particularities of commodity transport systems, these initial four steps are often complemented by additional sub-model steps including (i) lot-size-models (e.g. Combes, 2009), (ii) logistics network models (e.g. Tavasszy et al., 1998), (iii) virtual transport network models (e.g. Jourquin and Limbourg, 2004), and tour models (e.g. Lohse et al., 1997). Most of these developments are described and analysed in a couple of overview papers (see de Jong et al., 2004; Tavasszy, 2006; Chow et al., 2010).

According to the objective of the underlying modelling task and the resulting model's focus, the different steps are elaborated in more or less sophisticated ways or even left out: Urban freight demand models generally put a detailed focus on tour generation; in turn, they omit the mode choice step. In contrast, most interregional models contain a sophisticated mode choice step, but often disregard the phenomenon of tours.

In order to predict future traffic flows, the influential factors in the different model steps are configured according to certain scenario assumptions, and the different model steps are executed sequentially. Feed-backs are mostly established by only one variable (in form of prices or generalised cost) and affect demand segments as a whole. This inhibits the propagation of effects of fine-tuned policies to the upstream logistics decisions (cf. Heinitz and Liedtke, 2010). In addition, most of such freight models employ aggregate model steps (such as aggregate regression analysis, entropy maximisation or iterative proportional fitting) and thus, the models' reactions to policy measures – if existing – are not consistently based on micro logistics behaviour. In all these aspects, most freight models have many similarities to the so-called 1st generation passenger travel demand models and share their typical downsides.

The further development of freight models towards policy sensitivity and behaviour foundation is hindered due to some particularities of real-world freight transport demand systems (cf. de Jong et al., 2002):

- Logistics decisions are distributed among different decision makers and decision levels. In consequence, logistics actors co-ordinate within firms but also on markets, and therefore it is not possible to structure a commodity transport demand model as a hierarchical discrete choice model similarly to the 2nd generation passenger travel demand models (e.g. Ben-Akiva and Lerman, 1985; Train, 2003).
- Decision makers and decision objects are heterogeneous. Thus, aggregate discrete choice models reach their limits or cannot capture important influencing factors.

- Micro logistics decision problems (such as logistics network design or vehicle routing) constitute highly combinatorial optimisation problems. Micro models addressing these spatio-temporal problems cannot avoid using elements of mathematical optimisation.
- Logistics structures (networks and tours) emerge on the markets as a result of entrepreneurial activity (in contrast to public transport planning where a public transport planner decides about network structure and time-table).

One attempt to overcome the limitations of aggregate multi-step commodity demand models is the incorporation of micro-simulation such as the aggregate – disaggregate – aggregate (ADA) approach of de Jong and Ben-Akiva (2007). The approach enables the combination of lot-size and transport-chain choices taking into account heterogeneity.

A resulting further development of the micro approach leads to the new model category of multi-agent (MA) models (see, for instance, Holmgren (2010), Roorda et al. (2010), and Samimi et al. (2011)). A MA model structure is considered as promising because it explicitly addresses the phenomenon of distributed complex decision making in logistics. In a MA model, individual logistics decision problems are encapsulated and treated by that type of agent who is in charge of that problem. Accordingly, each agent fulfils her own optimisation goal. The model's architecture leaves the freedom to model the decisions of agents in different ways including discrete choice models or heuristic optimisation. For the moment, the documented models exploit the potentialities of an MA architecture only sparingly –the artificial intelligence is often limited to discrete choice models.

(B) Tour-based models for urban freight transport Especially in urban transport, freight vehicles perform complex movement patterns in time and space (”tours“) to pick-up or to deliver shipments. Thus, a crucial modelling step in urban freight models is the transformation of shipments (or stops) into tours. For the moment, no suitable way has been found to model tours using a ”behavioural“ or ”micro-economic“ approach. Instead, various other methods for tour generation have been developed (see the overview of Liedtke and Friedrich, 2012): Tours are calculated using entropy maximisation (Wang and Holguin-Veras, 2009). Lohse et al. (1997) determine a vehicle matrix with respect to certain constraints and assuming a certain spatial shape of tours using multi-linear equation systems. Wisetjindawat et al. (2007) compute tours for a whole city based on a firm-to-firm shipment matrix and using optimisation, under the implicit assumption of dealing with an efficient and transparent transport market. The heuristic approach of Sonntag et al. (1996) integrates de-central consolidation strategies of single carriers into an integrated heuristic optimisation. Finally, Hunt and Stefan (2007) simulate a growth process of single tours based on conditional probabilities and using Monte Carlo Simulation. Joubert et al. (2010) apply a tour-based approach to simulate a large-scale scenario of both private and commercial vehicles in Gauteng, South Africa. They define a tour to be a sequence of commercial activities and derive those activities from GPS-logs. Based on that, they use conditional probabilities to construct commercial activity chains. Schneider (2011) constructs trip chains based on observed trip chain protocols. In a sequence of steps, a tour is derived according to the underlying socio-economic and geographical data, likely activity purposes and the geometry of observed tours.

(C) City logistics models The tools and models mentioned so far are well established in transport and infrastructure planning. When it comes to analysing the effects of fine-tuned incentive-oriented transport policies, these models reach their limits since they are not consistently based on logistics behaviour. City logistics models explicitly address behaviour by applying optimisation methods. Taniguchi et al. (2012) consider optimisation as a crucial tool to understand and to improve urban freight distribution. Most city logistics models focus on operational decisions in urban commodity transport. Crainic et al. (2009) also model tactical and strategic decisions such as logistics network design. City logistics models are successfully used to assess the effects of transport policies on individual actors (Tamagawa et al., 2010; Figliozzi, 2007; Wang and Holguin-Veras, 2009; Munuzuri et al., 2005; Kanaroglou and Buliung, 2008; Gentile and Noekel, 2009; Taniguchi et al., 2007; van Duin et al., 2007). Typically, city logistics models analyse behaviour of one single firm or a couple of firms. When it comes to the modelling of individual firms, however, a lot of information and/or simplifying modelling assumptions are required. Therefore, it can always be questioned whether the results of such an analysis can be generalised for a whole sector. It is thus advisable to concentrate on typical features of behaviour that are common to all members of the examined population and to refrain from going too much into the details of single actors. For the moment, city logistics models have not been coupled with dynamic traffic assignment tools. Thus, the feed-backs between the traffic flow system and individual decisions are not considered. In fact, there is a significant gap between commodity transport demand models and city logistics models.

(D) Types of freight transport measures Urban commercial transport is steadily growing. With its growth, its burdens in terms of congestion, noise, vibrations, pollution, and green house gases (GHG) emissions become increasingly visible. Urban transport policy has developed measures to influence, control and regulate urban freight transport (Munuzuri et al., 2005). The European White Paper of Transport (European Commission, 2011) proposes a set of measures to achieve its ambitious goals to make the European Transport Area more competitive and more resource efficient. For urban transport, it proposes user charges according to user's and polluter's pay principles, delivery time windows, and vehicle type dependent access restrictions. A comparable strategic plan for Germany's cities – the Weißbuch Innenstadt (BMVBS, 2009) – proposes environmental zones with access regulation for delivery vehicles. The typical measures are initiated to address local problems, and in particular, congestion and emissions. Overall there is a trend towards more and more differentiated urban transport policies, differentiating between area, time of day, users and vehicle types. By this way, congestion problems and noise reduction goals can be addressed very precisely. In the future, new and cheaper information and control technologies will further support the implementation of such differentiated measures.

Differentiated measures are also more and more established in interregional commodity transport. Directive 2011/76/EC of European Parliament and Council of the European Union (2011) amending Directive 1999/62/EC on the charging of heavy goods vehicles allows for differentiated mileage-dependent tolls; the German charging system "Toll Collect"[1] offers the technical possibilities for such differentiations. There are various measures aiming at fostering the usage of intermodality (investment grants for terminals and intermodal hubs). Other measures are connected with working-hour and behind-the-wheel-time regulations.

A recent overview on policy measures concerning freight transport in urban areas is given by Holguin-Veras et al. (2014a,b). The authors list about 150 public interventions in the field of urban freight transport. Depending on the spatial, economic and legislative circumstances, various measures to influence both demand and supply in urban freight transport are classified and assessed. To our knowledge, this is the most comprehensive overview both with respect to width and depth on policy measures in urban logistics.

(E) Assessment of Freight transport measures As a general rule, each measure generates winners and losers. Multi-stakeholder moderation as well as multi-objective optimisation (see Sirikijpanichkul, 2008) aim at making measures more effective and targeted and thus, to increase public acceptance. But finally, especially when it comes to investment-intensive measures, an economic assessment is required. Multi-criteria analysis (MCA) evaluates if the objectives will be achieved; a benefit-cost analysis answers the question if the policy increases the net benefit for the whole society. Criteria for an MCA are compiled in the TERM (Transport and Environment Reporting Mechanism) indicator list of the European Environment Agency (Europäische Umweltagentur, 2000).

There are several ex-ante assessments of urban freight measures: Filippi et al. (2010) deal with the implementation of various measures to alleviate congestion and pollution in the city centre of Rome. They combine econometric data analysis with a simulation model that assigned shipments to vehicles and time slices. The comparison of external cost savings to the implementation costs of the measures suggests the creation of an urban distribution centre for all freight transport companies. Impacts of various kinds of restrictions imposed on transport companies in cities in the United Kingdom are addressed by Anderson et al. (2005). Taniguchi and Tamagawa (2005) introduce five stakeholder types, each with own criteria and behaviour, to a simulation model of a test road network.

[1] See `http://www.toll-collect.de`.

Ex-post evaluations of measures were subject of the European research projects SUGAR and BESTUFS (BESTUFS project, 2007; SUGAR project, 2011). Handbooks containing best practice measures were created. A recent overview on policy measures concerning freight transport in urban areas is given by Holguin-Veras et al. (2014a) and Holguin-Veras et al. (2014b). Depending on the spatial, economic and legislative circumstances various measures to influence both demand and supply in urban freight transport are classified and assessed.

(F) Calculation and assessment of emissions The transport sector in Germany generates about 20% of the country's CO2 emissions.[2] Of these, the freight sector contributes 34%.[3] The situation is similar for other emission components (Kickhöfer and Nagel, 2016). The estimation of transport-related exhaust-emissions can be performed on different levels of aggregation. The use of aggregated origin-destination matrices or aggregated demand functions together with expected future trends and elasticities of demand is the simplest option to come up with a forecast of the development of exhaust emissions (e.g. Creutzig and He, 2009; Michiels et al., 2012). However, those approaches do not allow for estimations of how policies would affect the activity/delivery chain and scheduling decisions of individual travellers or the logistics actors, respectively. Additionally, congestion effects and traffic states are ignored. More sophisticated approaches link activity-based models to macroscopic emission models (e.g. Beckx et al., 2009). The drawback here is that emissions resulting from congestion are not captured. Other approaches link microscopic traffic flow simulators to instantaneous emission models (e.g. Hirschmann et al., 2010). Even though that approach allows for very detailed emission calculations, because of the computational complexity it is not applicable to large-scale scenarios of major European cities. A comparison of static and dynamic traffic assignment models by Wismans et al. (2013) shows that "emission hotspots" are predicted at wrong locations by the static model, since it ignores spill-back effects. Hatzopoulou and Miller (2010) use an activity-based multi-agent simulation for emission calculations. Their approach accounts for activity chains of individuals and spill-back effects, while still being applicable for large-scale scenarios; however, in their work the authors focus on light-duty vehicles. A similar approach has been developed by Hülsmann et al. (2011) and applied by Kickhöfer and Nagel (2016) to a large-scale scenario. Since it is based on HBEFA (INFRAS, 2010), the approach can in principle be used for any scenario of arbitrary European cities. It is also capable to take different traffic states and vehicle categories into account.

(G) Summary and identification of research needs Independently from the types of network and policy measure under consideration, an economic assessment faces the tasks of (i) predicting the effect of that measure on individual behaviour, (ii) translating behaviour adaptations into changes of the infrastructures' usage and (iii) determining the effects on the environment and the quality of the traffic system. Finally, the effects need to be evaluated. If a benefit-cost analysis is being applied, all effects need to expressed in monetary values.

Especially when it comes to freight transport measures the following problems arise:

- Commodity transport demand models struggle with bridging the gap between micro logistics behaviour on the one hand and macro phenomena on the level of traffic flows on the other hand. City logistics models represent exemplary applications of optimisation tools known from business economics and operations research in order to evaluate transport policies in a given sector. In contrast, transport demand models – developed for the purposes of forecasting and policy appraisal of the full traffic system – have not yet reached a consistent behavioural foundation.
- Because of the lacking behaviour foundation, it is not possible to determine soundly the effects of a policy measure on the individual welfare of shippers, recipients, and transport companies. This concerns the willingness-to-pay (or to avoid) and changes in the logistics and transport processes.
- Although a major proportion of measures deals with spatio-temporal equalisation of traffic flows in order to reduce congestion and with incentives for behaving in a more ecologically sustainable

[2] http://www.bmub.bund.de/themen/luft-laerm-verkehr/verkehr/herausforderung-verkehr-und-umwelt/verkehr-und-umwelt-weniger-treibhausgasemissionen-auf-der-strasse-mehr-im-flugverkehr/

[3] http://www.bmub.bund.de/themen/luft-laerm-verkehr/verkehr/gueterverkehr/

way, no model is capable to capture the spatio-temporal effects of a measure and to translate changes in traffic flows into changes of emissions.

- Since feed-backs between model steps are either not established or one-dimensional / one-directional it is difficult to predict the impact of measures on upstream logistics decisions. However, policy measures are expected to be particularly effective if they induce behaviour changes of the final customer of transport and logistics services.

A Multi-Agent (MA) framework is potentially suited to address combinatorial optimisation at the micro level and local interaction between heterogeneous agents. Existing micro-economic behaviour models can be integrated into such a framework. A MA framework constitutes a systematic generalisation of city logistics models, which usually neglect multiple actors, interactions, and institutions.

Own work: VSP

(a) Simple models for large scale microscopic traffic simulations The cellular automata (CA) method investigated by Nagel and Schreckenberg (1992) formed the basis of the TRANSIMS (TRansporation ANalysis and SIMulation System; see `http://code.google.com/p/transims/`) project at Los Alamos National Laboratory. Much of VSP's current work is about the so-called queue model (Gawron, 1998; Simon et al., 1999), which is even simpler and in consequence even faster (Cetin and Nagel, 2001) than the CA model. Recently, we investigated how mixed traffic, and in this case cars and bicycles, can be integrated into the queue model without losing its advantages (Agarwal et al., 2013).

(b) Learning and adaptation; coupling to activity-based demand generation The fast traffic flow simulations described above made it possible for the first time to microscopically simulate large scenarios (Nagel, 1996; Rickert and Nagel, 2001) and thus, to move the microscopic method closer to real-world applicability. Subsequent work concentrated on incorporating learning behaviour into the agents while keeping large-scale scenarios computationally tractable (Raney and Nagel, 2004; Balmer et al., 2004). Large scale applications with several million travellers are now quite standard not just by us[4] but also by other teams.[5] With the new agent-oriented approach it was then possible to include additional choice dimensions beyond route choice into the iterations: activity time scheduling (Balmer et al., 2005), mode choice (Grether et al., 2009; Rieser and Nagel, 2009), and destination choice (Horni et al., 2012).

(c) Automatic calibration of agent-based simulations We have developed a calibration procedure based on a Bayesian approach (Flötteröd, 2008; Flötteröd et al., 2011a). It uses the degrees of freedom in the simulation to systematically calibrate the traffic demand models against real-world observations. Somewhat more specifically, the approach replaces the draws from the prior, purely behavioural probabilities by draws from posterior probabilities given the measurements. Using this approach, Flötteröd et al. (2011b) created a close-to-reality demand for transport for motorised traffic in Zurich, using hourly traffic count data on selected road section. The approach has also been used for the calibration of passenger routing in public transit systems (Moyo Oliveros and Nagel, in press, 2012; Moyo Oliveros, 2013).

(d) Emissions In a recent DFG project, MATSim was enabled to calculate (particulate) emissions individually for each vehicle (Hülsmann et al., 2011; Kickhöfer et al., 2013). The approach is based on HBEFA (HandBook Emission Factors for road transport, INFRAS, 2010). At the end of each road section, the vehicle speed, the link type, the engine temperature, and some other variables are identified for each vehicle. Then, the emissions according to the HBEFA database are determined. Since MATSim traces individual vehicles, freight vehicles can be included as well.

[4] Raney et al. (2003); Balmer et al. (2009) for Switzerland, Lämmel et al. (2009) for Padang (Indonesia), Neumann et al. (2014) for Berlin.

[5] E.g. Gao (2009) for Toronto, Fourie (2010) for Johannesburg/Pretoria, McArdle et al. (2012) for Dublin, Erath et al. (2012) for Singapore, or Zhang et al. (2013) for Shanghai.

(e) Software design; collaboration Over the years, it became increasingly clear that no single group could develop all the pieces necessary in the longer run. We have thus made important efforts to modularise MATSim (Grether and Nagel, 2013), making it possible to add contributions without always interacting with the software design of the MATSim core. The MATSim freight extensions (see Sec. (m) below) is a direct outcome of this approach. Note that the extension's core, the jsprit engine, is a separate library also being available to other projects (see `https://github.com/jsprit/jsprit`); CaDyTS (see `http://people.kth.se/~gunnarfl/cadyts.html`) is a similar example.

(f) Applications MATSim is making it into practice, including an application by the Berlin public transit company BVG, helped by our commercial spin-off "senozon".[6] Also, the knowledge acquired with the MATSim project and related work gives us the necessary background to work on ministerial contracts related to the German cost-benefit analysis for federal transport projects ("Bundesverkehrswegeplan", see Nagel et al., 2010, 2012, also see (o) below).

Own work: WIV-DLR

(g) Multi-Agent traffic demand modelling – INTERLOG The INTERLOG model (Liedtke, 2009) is the first reported large scale multi-agent commodity transport demand model. It consists of several modules. The first one deals with the generation of synthetic firms. The second one deals with establishing microscopic commodity flows between firms. The third module is about market interactions: In a continuous process, shippers try to minimise their total logistics cost by choosing optimum shipment size and the best suited carrier. Carriers are cost minimisers and pursue cost based pricing. In some complementary studies, methods have been developed to merge transportation data and production data and to cluster tours using fuzzy logic (see, for instance Liedtke et al., 2011; Babani et al., 2006).

(h) Tour construction decision engine "jsprit" In the course of the DFG-project "2000W-City" (Liedtke and Nagel, 2010–2015) we developed a Java toolkit to model typical decision problems of urban freight carriers (Schröder and Liedtke, 2014). These developments resulted, among other things, in an Open-Source project called jsprit. jsprit solves rich vehicle routing problems (VRPs) such as the VRP with time windows, multiple depots and heterogeneous fleet, and it can accommodate an arbitrary number of additional real world problem constraints to reflect the peculiarities of specific industries. It is based on a single all-purpose heuristic which is a large neighbourhood search that combines elements of simulated annealing and threshold-accepting algorithms (Schrimpf et al., 2000, p. 142). jsprit undergoes continuing development, and is documented and hosted at `http://github.com/jsprit/jsprit`.

(i) Large-scale dynamic traffic assignment In the RMLOG project (KIT et al., 2012) a large scale dynamic assignment model based on MATSim has been set up. The model generates the daily plans of synthetic agents based on publicly available data, such as the official origin-destination matrices of the German federal infrastructure development masterplan or the survey "mobility in Germany". For the sake of simplicity, three types of agents are distinguished – commuter, non-commuter and freight agent. Each agent has a different daily behaviour pattern and departure time (Zhang et al., 2012). The time-profiles of commuter agents have been determined using a regression analysis where the disparity between residential population and jobs is the influential explanatory variable. For long-distance travellers, a new activity-schedule scoring function has been developed. The parsimonious model in terms of network and behaviour data achieves a good matching between modelled and observed daily traffic volume and daily distribution (Liedtke et al., 2014).

(j) External cost of transport Gernot Liedtke participated in several projects dealing with full and marginal cost of transport. The project "Study on the Cost of Transport in the European Union in order to estimate and assess the Marginal Costs of the Use of Transport" of Doll and Liedtke (2001) compiles different studies dealing with external cost of infrastructure use. The project MOSCA (Gringmuth et al., 2001) analyses the potential reductions of the external cost of a delivery system through an innovative planning instrument. Gringmuth et al. (2005) analyse noise emissions using a noise propa-

[6] See `http://senozon.com`, `http://senozon.com/clients`.

gation model and calculate the costs and benefits from urban transport measures. The study of PWC and IWW (2007) deals with a preliminary assessment of a European freight logistics action plan from an economic and from an ecological perspective. IWW and NESTEAR (2009) determine the amount of future infrastructure charges once external cost components are included according to the Handbook on External Cost (INFRAS et al., 2008) and in line with the European Directive 2011/76/EC on the charging of heavy goods vehicles for the use of certain infrastructures (European Parliament and Council of the European Union, 2011). Furthermore, the impact of an external cost charge on the usage of intermodal transport services is modelled. In the project LOGOTAKT (Selinger et al., 2010) about the development of an innovative synchronised multimodal transport service, the WIV-DLR institute was responsible for the assessment including the economic viability from a managerial and national perspective. The latter analysis also includes external costs.

Own work: UP

(k) Multiple MATSim models in South Africa CoTD (= the Centre of Transport Development at the University of Pretoria, see `http://cotd.ie.up.ac.za`) started using MATSim in 2007. This decision was based on the need to be able to incorporate a variety of modes, including the dynamic paratransit mode, referred to as minibus taxis in South Africa. The heterogeneity of the population was also better addressed using the approach of autonomous agents in the synthetic population of MATSim. Initially the dynamics were demonstrated using the agent-based functionality within an early version of the AnyLogic software (Diedericks, 2006), but the use case was not scalable to a city level.

Since 2011 the South African National Treasury has sponsored the development of multiple MATSim models, the largest of which is the province of Gauteng with nearly 10 million inhabitants. The richest and most comprehensive scenario is that of the Nelson Mandela Bay Metropole that includes private and multiple public transport modes, as well as commercial vehicles. The data is publicly available under `http://cotd.ie.up.ac.za`.

(l) Freight data and analysis An initial step to embed detailed travel demand into an agent-based model is to understand the activity chains of those entities, i.e. agents, who travel within the model. The body of knowledge that exists about the structure and characteristics of freight vehicles' activity chains by far trails that of private vehicles. To address the shortcoming, Joubert and Axhausen (2011) studied and analysed the activity chains of more than 40 000 commercial vehicles in South Africa. The activity chains were extracted from Geospatial Positioning System (GPS) data that was recorded over a 6-months period. The information was subsequently used to generate a synthetic population of commercial vehicle agents (with limited behavioural capability), each with a realistic activity chain, and modeled for the large, multi-metropolitan area of Gauteng, South Africa (Joubert et al., 2010). The knowledge of the activity chain structure was used to study the network of connectivity between firms, and this was achieved through complex networks (Joubert and Axhausen, 2013).

Own work: joint

(m) MATSim Freight Contrib In the course of the DFG-project "2000W-City" a conceptual framework called "Freight Transport Lab" has been developed to couple various logistics decision levels with the traffic simulation of MATSim (Schröder et al., 2011b,a, 2012). Logistics decisions have been allocated to two different roles: Logistics service providers, which create transport chains, and carriers, which plan tours and schedule vehicles. Both agent types can consolidate shipments at their respective level and take advantage of economy of scale effects. The lowest tier of the model – which contains individual freight vehicles – is integrated into the MATSim traffic simulation to create an integrated model for freight and passenger traffic. Changes in passenger demand, disturbances in the traffic system or new policy measures can be picked up by truck drivers and propagated upwards to influence decisions on the levels of vehicle scheduling and transport chain building. A software prototype has been implemented in Java. This work received the "Outstanding Paper Award" at the 7th International Conference on City Logistics in Spain, 2011. Based on this conceptual work the implementation of carriers and their behaviour has been pursued which resulted in an Open-Source freight extension for MATSim (see `http://www.matsim.org/extensions`) and a toolkit for solving rich vehicle routing problems called jsprit (see `http://github.com/jsprit/jsprit`).

(n) Policy analysis using optimisation The MATSim extension jsprit was used to assess transport policy measures differentiating between vehicle types, area and time of day (Schröder and Liedtke, 2014). More specifically, the effects of following urban policies have been estimated for a real world scenario in relation to the food retailing distribution in the city of Berlin (Gabler et al., 2013): a cordon and distance toll for heavy vehicles operating the environmental zone (e-zone), a prohibition of heavy vehicles in the e-zone, and a noise protection scheme that prohibits heavy vehicles to access the e-zone from 10pm to 7am. It is shown that the modelled carriers adapt to changes in the transport system by changing departure time, depot locations, customer sequences in routes, fleet composition as well as actual paths through the physical network considering varying general transport cost in the traffic system. Due to the high data requirements and the strong underlying assumption of complete information, the application of this model is still limited, especially when it comes to classical transport planning. These limitations call for further research activities with regards to general calibration techniques and to calibrating behavioural freight models with sparse data/information.

(o) BVWP VSP and WIV-DLR were both involved in a methodological study concerning the cost-benefit analysis for the new German federal transport infrastructure development masterplan (Planco et al., in preparation). On the one hand, they collaborated in a particular development of the economic appraisal method – a new approach to calculate the benefits for mode-switchers and induced traffic, both for passenger and for commercial traffic. On the other hand they had coordination tasks for various other projects in order to ensure that welfare aspects were modelled consistently by all of them. The coordination requested insights in various aspects of transport modelling as well as in economic topics in order to remain informed about the single projects and to respond quickly to questions and irregularities. A special aspect was the incorporation of reliability as a component of economic assessment of infrastructure projects.

(p) Heterogeneous tolls and heterogeneous values of time VSP and UP have worked together on setting up a toll simulation for the Gauteng province (10 mio inhabitants) based on the work described under (k) and (l). It is the first MATSim simulation which includes both heterogeneous values of time (cf. Kickhöfer et al., 2011) and heterogeneous toll (cf. Kickhöfer and Nagel, 2016) in a combined set-up, and takes steps to make this much easier to configure (Nagel et al., 2014).

1.1 Project-related publications (up to 10)

1.1.1 Articles published by outlets with scientific quality assurance, book publications, and works accepted for publication but not yet published

Agarwal, A., M. Zilske, K. Rao, and K. Nagel. An elegant and computationally efficient approach for heterogeneous traffic modelling using agent based simulation. *Procedia Computer Science*, 52(C), 962–967, 2015. doi:10.1016/j.procs.2015.05.173.

Joubert, J. W. Analyzing commercial through-traffic. *Procedia Social and Behavioral Sciences*, 39, 184–194, 2012. doi:10.1016/j.sbspro.2012.03.100.

Joubert, J. W. and K. W. Axhausen. Inferring commercial vehicle activities in Gauteng, South Africa. *Journal of Transport Geography*, 1, 115–124, 2011. doi:10.1016/j.jtrangeo.2009.11.005.

Joubert, J. W. and K. W. Axhausen. A complex network approach to understand commercial vehicle movement. *Transportation*, 3, 729–750, 2013. doi:10.1007/s11116-012-9439-0.

Liedtke, G. Principles of micro-behavior commodity transport modeling. *Transportation Research Part E: Logistics and Transportation Review*, 45(5), 795–809, 2009.

Liedtke, G. and D. G. Carrillo Murillo. Assessment of policy strategies to develop intermodal services: The case of inland terminals in Germany. *Transport Policy*, 24, 168–178, 2012.

Nagel, K., B. Kickhöfer, and J. W. Joubert. Heterogeneous tolls and values of time in multi-agent transport simulation. *Procedia Computer Science*, 32, 762–768, 2014. doi:10.1016/j.procs.2014.05.488.

Schröder, S., M. Zilske, G. Liedtke, and K. Nagel. A computational framework for a multi-agent simulation of freight transport activities. Annual Meeting Preprint 12-4152, Transportation Research Board, Washington D.C., 2011. Also VSP WP 11-19, see `http://www.vsp.tu-berlin.de/publications`.

Schröder, S., M. Zilske, G. Liedtke, and K. Nagel. Towards a multi-agent logistics and commercial transport model: The transport service provider's view. *Procedia Social and Behavioral Sciences*, 39, 649–663, 2012. doi:10.1016/j.sbspro.2012.03.137.

1.1.2 Other publications

Zilske, M., S. Schröder, K. Nagel, and G. Liedtke. Adding freight traffic to MATSim. VSP working paper 12-02, see `www.vsp.tu-berlin.de/publications`.

2 Objectives and work programme

2.1 Anticipated total duration of the project

36 months.

The present project can be brought to conclusion within that time frame. It is also, however, part of a wider effort of making activity-oriented traffic assignment model widely applicable, and in that sense builds on pre-existing efforts, in particular the existing software infrastructures at `http://matsim.org` and `http://github.com/jsprit/jsprit`.

2.2 Objectives

2.2.1 Approach

The main goals of sub-project 1 are (i) the enhancement of the carrier's capabilities, (ii) its improved integration into the traffic-flow simulation-model and (iii) the creation of interfaces to connect the Carrier Agent to the upstream logistics system.

This sub-project assumes given and fixed shippers and shipper behaviour. The LSP (Logistics Service Provider) agent – who is implemented together with the second sub-project – transforms transport demand into shipments and allocates them to carriers. Consequently, this sub-project focuses on the planning behaviour of carriers and the effects of the resulting freight vehicle movements on the quality of traffic flows and the environment. Inversely, the vehicle routing engine of the carrier agent picks up the effects of road congestion and policy instruments. If appropriately, behaviour changes are triggered. The propagation of these effects on the upstream logistics decisions is performed by the LSP agent. This is the task of sub-project 2 which will incorporate a cost allocation engine into the LSP agent.

The research programme of this sub-project is structured in 5 work packages (WP). They can be grouped into three development streams which finally support policy analyses:

The first development stream (WP1 and WP2) deals with the specification of the agents and the creation of interfaces. This includes interfaces to the traffic simulation and emission estimation. Basic procedures are agreed upon together with sub-project 2 including potential requirements of other users.

The second stream (WP3) deals with the sensitivities of tour construction and fleet composition.

The third stream (WP4) deals with methods which generate the totality of commercial transport through the means of geometric tour construction. Calibration procedures from passenger transport are extended to commercial and commodity transport, too.

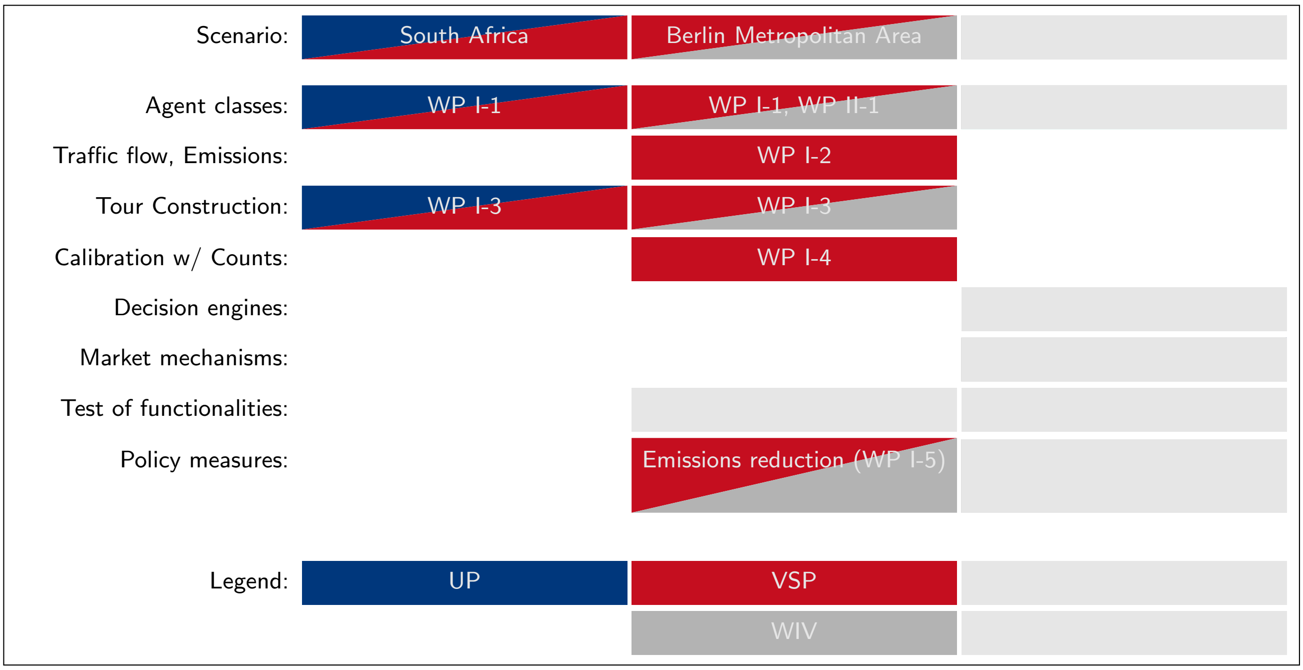

Figure 1: Structure of the package project "Shippers and Recipients in a Multi-Agent Framework for Commodity Transport Demand Modelling" – Tasks within subproject 1. In those cases where three or more partners are involved in a WP, only the two most important contributors are shown.

All streams are combined in the case study (WP5). That case study will initially start with the models and sensitivities developed in this sub-project, but then increasingly integrate models and methods from sub-project 2.

2.2.2 Scenarios

Our work will be based on the following scenarios:

Scenario Berlin The team has considerable experience with modelling the passenger transport side of Berlin (Rieser et al., 2007; Neumann et al., 2014; Kaddoura and Kickhöfer, 2014) and also some experience with the commercial sector (Schröder and Liedtke, 2014; Turner, 2015). Among others, we are in the possession of the following data sources:

- KiD2002 (Wermuth et al., 2003; Wermuth, 2003) – Geo-coded trip diaries with focus on commercial vehicles. The survey is nationwide, but because of the geo-coding we are able to pull out the regional results if necessary. The newer KiD2010 will also be available, but according to our information it was spatially transformed for privacy reasons to a level that renders it less useful for our questions. Nevertheless, it can be used to derive industry specific tour statistics such as number of stops per tour, stop duration, leg lengths and total tour duration and distance etc.
- Ordering behavior of pharmacies and a selection of GPS tracks from one of the biggest pharma logisticians in Germany
- Shipment data from 8 different German courier companies operating cars and bicycles from 2011 to 2014 (Gruber, 2015; Gruber et al., 2014)
- Selected tours and their GPS tracks of 3.5 tonnes vehicles from DHL (German parcel service)
- B2C and C2C eCommerce ordering behaviour, i.e. order behaviour of households (GIM, 2014)

The Berlin scenario will be the central scenario which binds everything together: It will be used for all work packages of this sub-project, and it will be used to integrate the outcomes of sub-project 2 (see WP 5).

Scenario South Africa Gauteng The team has considerable experience with modelling passenger and commercial vehicles in Gauteng (Joubert et al., 2010; Joubert and Axhausen, 2011, 2013). Among others, we are in the possession of the following data sources:

- A significant portion of South African commercial traffic is equipped with permanent GPS tracking. The consortium is in the possession of tracks by one of these companies, covering about 45 000 vehicles from Jan/2009 to Jun/2009 as well as 16 000 vehicles from Jan/2010 to May/2014 (cf. Joubert and Axhausen, 2011, 2013).
- We are in the possession of daily deliveries of a food logistics company for a ten month period during 2012–2013, thus allowing to analyse ordering strategies and repetition frequencies (cf. van Heerden, 2014).
- The toll gantries in the Gauteng province register vehicle IDs and from there know the vehicle types. We have all those transactions for all gantries for two months: February 2014 and October 2014.

The South Africa Gauteng scenario will be used to (1) make our methodology more general by applying it to a very different situation, and (2) help in certain cases – in particular with the calibration of tour construction – where we may be unable to procure equivalent data in the German context.

2.2.3 Relevance to fields other than science

The policy studies, which are part of the proposal, will support decision makers in cities to make better decisions with respect to urban planning, air quality, and noise. In addition, the developed model system can be applied to other regions or urban areas, and to other policy measures than the ones investigated in this proposal.

The research is also connected to the methodology of the assessment of transport investments: Transport investments are a major share of most government's infrastructure investments.[7]

In order to avoid mis-allocation of these funds, most countries run detailed transport investment analysis programs, for example in Germany the Bundesverkehrswegeplan (BVWP, see BMVBW, 2003). The methodology for these studies needs to be continuously improved (BVU et al., 2003; Planco et al., 2015). Still, the current methodology is not well suited to investigate measures for the *reduction* of emissions: Since the current methodology essentially balances time gains against environmental losses, it could at best search for infrastructures where destruction results in the smallest amount of time losses against the largest amount of environmental gains. What is missing is that the underlying system may be able to *structurally* re-organize – in the case of freight by re-organizing the logistics networks. Investigating models of such structural re-organization is the topic of the present proposal – and the final case study in consequence looks at the –possibly hypothetical– goal of zero emissions freight traffic.

Clearly, our results will also enter our teaching agenda. Finally, components of the Multi-Agent simulation system can be used in logistics planning and consulting.

2.3 Work programme including proposed research methods

WP 1: Agent implementation The travel demand model used by MATSim consists of agents representing individual users of the traffic system. Since MATSim was originally developed with passenger traffic in mind, the highest (and only) layer of decision making is the individual traveller optimising his or her schedule. In previous joint work of VSP and WIV-DLR, we developed an extension to MATSim which models freight vehicle drivers as non-autonomous agents employed by freight operators (carriers), which in turn are modelled as agents who employ their drivers to deliver shipments while optimising their resources. This software layer has interfaces in three directions:

- With the MATSim mobility simulation, into which the vehicle fleets of the simulated carriers are injected as driving agents, and from which the experienced traffic conditions are picked up.

[7]For example, at the German federal level, transport investments account for approximately 12 000 mio € out of 26 100 mio € overall.
`https://de.wikipedia.org/wiki/Bundesverkehrswegeplan_2015`
`http://www.bundesfinanzministerium.de/Content/DE/Bilderstrecken/Mediathek/Infografiken/bundeshaushalt-2015.html?docId=325918&notFirst=true&countIx=9`

- With the optimisation software (jsprit), which solves the carrier's planning problem initially and with respect to current traffic conditions between iterations.
- With the layer which represents the consumer of transport services delivered by carriers, i.e. LSP agent.

WP 1.1: Improvement and finalisation of the MATSim-jsprit interface [WIV-DLR, VSP] MATSim and jsprit exist,[8] and the interfaces to the freight package have been tested with both illustrative and realistic scenarios (see Sec. (n)). What is not finalised is how congestion is fed back to jsprit. Options include that jsprit receives so-called MATSim "events", most importantly of every vehicle entering or leaving a link, and builds its own congestion model from that. An alternative is that jsprit makes use of the existing MATSim infrastructure by re-using aggregated time-dependent link travel time which MATSim collects anyway. Issues to be resolved include how jsprit reacts to changes in time resolution on the MATSim side (jsprit may become too slow when the time resolution becomes too high) or how to include the effect that trucks may have lower speeds than cars (see WP 2).

WP 1.2: Design and implementation of the LSP interface [WIV-DLR, VSP] We model the LSP (Logistics Service Provider) as organiser of transport chains (in contrast to Carriers, which route and schedule vehicles). A transport chain is a sequence of logistics activities induced by the transportation of goods. The simplest transport chain is the direct transport from a sender to a recipient. More sophisticated transport chains emerge, for instance, when the LSP operates a hub-and-spoke network.

Each leg of a transport chain is an elementary movement and shipment. For each of these shipments, the transport services of a different Carrier can be contracted. The contract interface between Carrier and LSP agent is currently realised as a "stub", where a fixed set of contracts is inserted which does not change over the iterations.

Since a working LSP agent will be developed in sub-project 2 of this package project, this interface, too, will have to be made operational. Therefore, the information needs of the LSP in relation to the Carrier and the traffic flow system will be identified. Since the LSP plans transport chains, the information to be transmitted includes transport times, transport costs, as well as departure and arrival times at destinations (e.g. at the hubs).

Conversely, the information that the Carrier requires from the superordinate LSP layer will be determined. An example is the information that a contract has changed.

Finally, when it comes to information flows from the the traffic simulation and the Carrier to the LSP layer, we expect that existing infrastructure can be leveraged. We expect that it will be favourable to operate with non-aggregated information from the traffic simulation or Carrier, respectively, and aggregate where it is required, i.e. at LSP level. When it comes to information flows from the LSP agent to the Carrier, we need to investigate whether simple contract change information is sufficient. Also, it will be examined what happens with the already existing Carrier schedules when a Carrier contract has changed, especially with regard to the fact that these schedules implicitly contain knowledge about the transport system. There is a need to develop ways to adapt to changes in contracts while preserving the Carrier's experience.

WP 2: Traffic dynamics of light and heavy goods vehicles, particulate emissions, noise [VSP] MATSim is based on a queue model (Gawron, 1998), also called store-and-forward algorithm (Gazis, 1974) with blocking (spill-back), which is fast since it processes vehicles only when they enter or leave links, but not in between. In this approach, vehicles obtain an earliest link exit time when they enter a link, based on the free speed travel time on the link. Vehicles are then stored in a FIFO (first-in first-out) queue, which is served with the link's flow capacity. In addition, the number of vehicles on a link is limited by the link's storage capacity; once a link is full, upstream links can no longer discharge into the full link.

In freight transport, there are various vehicle types with different impacts on traffic flows, emissions and noise, i.e. light goods vehicles with two axles and a maximum gross weight of 3.5t and heavy goods

[8] `http://matsim.org`, `http://github.com/jsprit/jsprit`

vehicles with 2-6 axles and a maximum gross weight bigger than 3.5t (up to 44t). These types can, for example, be included in the queue model by varying the space consumption of each vehicle, or by varying their free speed travel time. A heavy duty vehicle could, for example, have a higher free speed travel time and a larger space consumption. Agarwal et al. (2013) investigates some consequences of such an approach, with a focus on a mix between bicycles and cars. The present WP will continue these investigations, with a focus on a mix of heavy duty vehicles and cars.

WP 3: Iteration dynamics, sensitivities and carrier behaviour The MATSim design, based on a general design of evolutionary systems (e.g. Ferber, 1999, Chap. 8.5), uses innovative modules that generate a range of approximate solutions (plans). Those are then executed in a synthetic reality (traffic flow simulation); their scoring (utility, fitness) is based on their performance during that execution.

This approach makes it possible that the innovative modules do not have to be exact "best reply" algorithms, but can operate on simplified approximations of the system. For example, a router can use congestion information averaged over 15 min time bins rather than full (second by second) information. Since the innovative modules generate a diverse range of different solutions, adaptations to details of the (synthetic) reality can be achieved by trial-and-error rather than by an exact (and computationally expensive) best reply algorithm (Nagel et al., 2014).

This feature will be used for a series of investigations in the context of carrier plans. First, the tour construction engine will be modified so that it can generates a diversity of solutions, more precisely different types of solutions such as orbital tours, irregular tours, shuttle tours, etc. (WP 3.1). This will be followed by two sets of experiments which test the sensitivity of the overall approach when confronted with congestion.

WP 3.1: Calibration of tour planning [WIV-DLR] Currently, when applying jsprit for planning carriers' vehicle routes, we make the strong assumption that we – as modelers – have complete information about the costs of the carriers. Additionally, we assume that carriers have complete information about the transport system and about good solutions for their vehicle routing problem.

These assumption often yield unrealistic tours, i.e. tour lenghts and distances may deviate significantly from what empirical data suggest.

In this WP, therefore, jsprit will be adapted in such a way that it reproduces various tour patterns as observed in reality. We find that the relaxation of the assumption of complete information is a good point to start from. Our idea is to relax it by accepting not just only optimal solutions for the optimization problem of the carriers, but also near-optimal solutions (optimal solution + a certain epsilon). In literature this is known as epsilon-optimization and it can be interpreted in terms of bounded rationality. Consequently, each agent has a set of solutions. Each agent can choose a tour from this set of solution, for example with a certain probability or such that for a certain type of agents the tours are similar. A relaxation or tightening of the constraints is also an option to include incomplete information into the decision making process of the agents.

To compare the geometry of generated and observed tours, the method developed by Babani et al. (2006) will be applied: The different ideal tour types are defined through a set of linguistic variables. Then, using the degree-of-equality operator of Fuzzy-logic, each tour is allocated to a certain tour category. The method and different applications are also documented by Liedtke and Schepperle (2004) and Liedtke et al. (2011).

To pursue the calibration of the vehicle routing engine, the research consortium has access to ordering behaviour of pharmacies as well as GPS tracks of a pharmaceutical carrier in Berlin. Additionally, we can draw on ordering behaviour of a food company in South Africa as well as GPS tracks of a significant part of commercial vehicles in South Africa. The advantage of this type of data is that it shows real world vehicle routing problems as well as the resulting vehicle tours by means of GPS tracks. Therefore, we can derive real world constraints of these problems and parameters that are decisive for solving them, i.e. that are decisive for actual tour planning.

Once we have figured out the decisive input parameters that distinguish a real tour from one that is generated by the heuristic, we will incorporate these into the tour building algorithm of jsprit. With the modified heuristic we can also perform case studies in sub-project 2.

The sensitivities of the resulting tour construction engine will be investigated in the following two work packages.

WP 3.2: Sensitivity of tours [VSP] The first sensitivity study concerns the sensitivity to congestion. Congestion levels will be changed drastically, and the sensitivity of the method will be investigated. There are, in fact, several levels of adaptation, from route adaptation to whole new tour configurations.

The South African scenario will be used for this study, since we have both shipments data and GPS traces for a medium sized carrier, and contacts to that company. For the purposes of this WP, the fleet will be assumed as constant, either as homogeneous, or as given by the carrier. Vehicle changes will be investigated in WP 3.3.

WP 3.3: Sensitivity of the fleet structure [VSP, UP] WP 3.2 will have used a constant vehicle fleet. This WP will investigate reactions in the fleet structure. The use case will be a toll or fee on large trucks inside urban areas. Clearly, it is expected that the system will react by using smaller vehicles. It is also expected that overall costs, and also overall emissions, will go *up* as a result. In contrast, noise effects are unclear; the increased vehicle mileage may be offset by the smaller noise footprint of the smaller vehicles.

This WP follows up on Schröder et al. (2012); Schröder and Liedtke (2014). It will, however, look at only one carrier, taken from the real world, investigate it in detail, including noise and particulate emissions. It will also check back with the company for plausibility. Again, the South African scenario will be used for this study, for the same reasons as above.

WP 4: Automatic calibration of Carrier behaviour based on traffic counts A standard problem with behavioural models is their macroscopic calibration: Even when the behavioural models are well calibrated, the emergent properties, for example hourly vehicle counts, sometimes do not match measurements from reality. In addition, sufficient data to calibrate all aspects of the behavioural models is often not available. It is thus desirable that the models are adjusted from other data ("calibration"). Typical data sources for calibration procedures include traffic counts, GPS tracks, or company records. In this WP, we will calibrate the behavioural freight model from traffic counts.

However, at this point the behavioural model is typically only built for one commercial sector, and in addition it is questionable if one would be able to calibrate several sectoral behavioural models simultaneously from counts data which does not differentiate between the sectors. We will thus first build a simpler model for freight tours, called "geometric" model since it uses geometric properties obtained from surveys or GPS traces. This geometric model will then be calibrated against traffic counts. In the final step, one commercial sector in the geometric model will be replaced by a behavioural model, which will then be calibrated within this joint model. This will lead to a calibrated system, within which the sector with the behavioural model will display much higher and richer sensitivity to policy measures. We will use Berlin as case study.

WP 4.1: "Geometric" generation of commercial vehicle activity chains [VSP, UP] As stated above, in order to calibrate against anonymous traffic counts, a model of all freight traffic is needed, since traffic counts do not differentiate between commercial sectors. Yet, building a separate behavioural model for each commercial sector at this point is neither feasible nor is it a practical starting point for calibration. Thus, we need a simpler model which generates demand in all commercial *all* sectors, into which the behavioural model for one or a couple of sectors can then be embedded.

For this, we will consider methods of freight vehicle tour generation described in Sec. B (in state of art). These methods extract regularities from freight trip diaries to generate synthetic vehicles tours from that. As a scenario, we will use Berlin. The approach will be based on data from KiD (Kraftfahrzeugverkehr in Deutschland; Steinmeyer and Wagner, 2005); Schneider (2011) has already demonstrated that such an approach based on KiD data is possible.

WP 4.2: Calibration of the "geometric" model with vehicle counts [VSP, UP] In this WP, we will calibrate the "geometric" model based on anonymous vehicle counts. Calibrating models via their emergent properties is a challenging task. We have experience with the approach described by Flötteröd et al. (2011a) and implemented by CaDyTS (Calibration of Dynamic Traffic Simulations; Flötteröd, 2010). Very roughly, in that approach each agent generates more than one alternative, and CaDyTS picks the one that is most consistent with the measurements.

We will again use the Berlin scenario. When it comes to the counting data, only some of the counting stations count different vehicle types separately, and even this will not help much since much of the urban commercial traffic is done with light duty vehicles (LDVs) or even cars. We will thus attempt to build a full model of passenger and commercial vehicular traffic, and to calibrate all demand segments simultaneously. For the passenger traffic, we are already in the possession of a working model, also the counts are there. For the commercial traffic, we will initially use the "geometric" approach of WP 4.1.

WP 5: Emissions free urban logistics The EU has set the goal of a nearly 100% reduction in CO2 emissions in urban logistics and 60% reduction of CO2 emissions in the entire transport sector by 2030 (European Commission, 2011).[9] Given current technologies, it is difficult to see how the freight sector could achieve its share of this reduction without large structural changes. In this WP, we will thus investigate how large reductions could be made possible by correspondingly large structural changes in the freight market. We will use our Berlin scenario (Sec. 2.2.2). For freight transport, we start with the entire set of fixed activity chains constructed in WP 4. These will only be sensitive along the choice dimensions of route and departure time choice, that is, they serve as background load without further upstream logistical choice processes. However, as subset of freight transport, we will extract activities related to retail to replace them by a more sophisticated model, i.e. these activities and activity chains will be the result of logistics decisions that are modelled endogenously according to the models developed in both sub-projects. We will first build it up using our capabilities developed in this sub-project 1, and then successively integrate capabilities from sub-project 2.

One way to achieve significant emissions reduction is to move large parts of the inter-regional freight traffic to rail. To achieve zero emissions in urban logistics, urban distribution needs to be further consolidated by means of cooperation; at the same time, large parts of the urban freight traffic need to be shifted to electric vehicles. A possible distribution system could then consist of the following layers: medium-sized electric trucks with ranges of around 100 km[10] that transport between the rail terminals and urban hubs, and electric light vehicles and cargo bikes that transport between the urban hubs and the final destinations. When it comes to electric cargo bikes, additional micro consolidation centers within the urban area might be necessary. We are not claiming that this will be the best or even a possible solution; we are, however, interested in the structural, emissions, and financial consequences of such a change. For this, we will do the following work packages:

WP 5.1: Artificial emissions toll and carrier reactions [VSP] It is well known that first-best solutions can be obtained by internalising the external costs, i.e. by making them relevant for the decision makers causing these negative effects (Pigou, 1920; European Commission, 2011). The simulation will achieve this by computing the marginal external cost of each vehicle on a link, and to charge that cost to the corresponding agent. Kickhöfer and Nagel (2016) did this for passenger traffic, noting that freight traffic would have to be sensitive to such a policy measure as well in order to obtain a full picture. The present WP will do exactly this: Building on WP 2, the emissions from freight vehicles will be computed, monetised, and charged to the vehicles. That cost will increase the total costs of carriers, and it is expected that carriers react to that change. For example, they might combine deliveries into fewer tours with larger vehicles, or they deploy vehicles with smaller marginal external costs such as electric vehicles and cargo bikes. In this WP, only carrier reactions will be considered; for LSP reactions see WP 5.2 (cf. Fig. 2).

'Backcasting' (Geurs and van Wee, 2004; IWW et al., 1998) means that one starts with an emissions reduction goal and then works backwards towards what would be necessary to achieve that goal. In

[9]Until 2050, compared to 1990 emissions, which are similar to the 2008 level.
[10]E.g. `http://www.emoss.biz/electric-truck/`.

the present setting, this can be achieved by increasing the artificial charges until a certain emissions goal is reached. Presumably, this will lead to a quite drastic change in fleet composition.

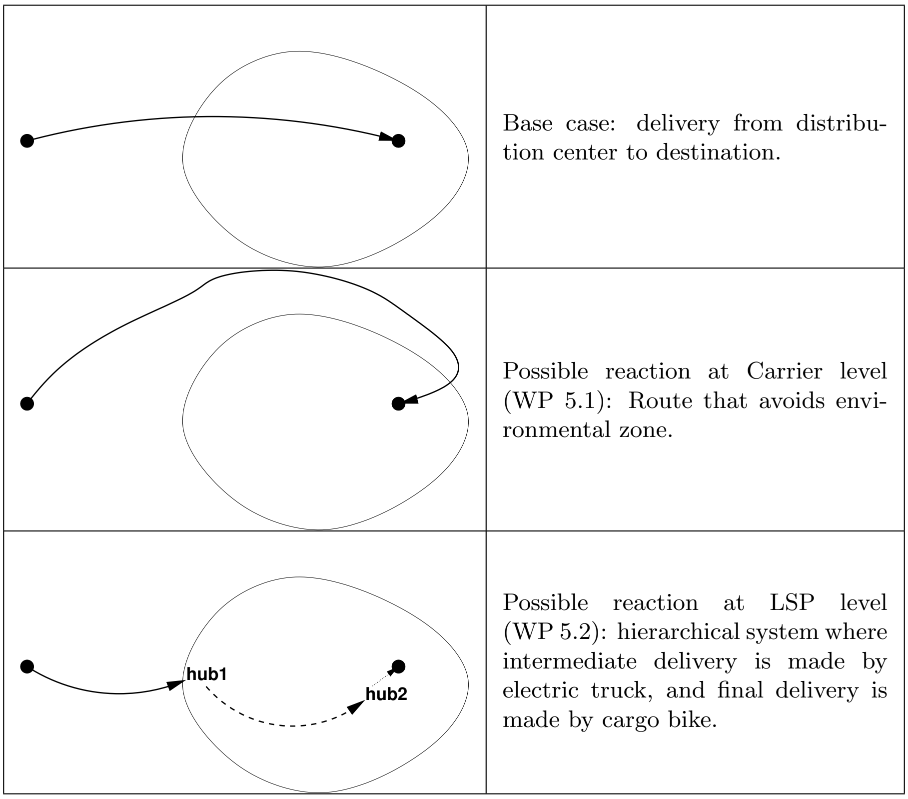

Figure 2: Illustration of possible reactions of the logistics system to an environmental zone.

WP 5.2: Artificial emissions toll and upstream logistics reactions [VSP, WIV-DLR] In WP 5.1, we assumed that an emissions toll impacts carrier behaviour only, i.e. the carrier need to adapt its operation without having the possibility to propagate increased costs to upstreaming decision makers. Here, we will now include the LSP and Shipper/Receiver reactions developed in sub-project 2. In consequence, carriers can pass along the increased carrier costs, caused by the artificial emissions toll, to LSPs and Shippers and Receivers. LSPs, for example, will then have to find emissions-reduced or emissions-free distribution systems and transport chains, e.g. they can employ second-tier consolidation centers to operate the last mile with electric vehicles and cargo bikes (cf. Fig. 2). Electric vehicles would be emission-free in our world. However, propagating increased carrier costs will also affect Shipper and Receiver decisions. For example, Receivers, which will be retailers here, might respond by changing their order behaviour from frequent to less frequent ordering.

Thus, the new capabilities developed in this proposal will lead to completely new model reactions and model sensitivities. Note again that at this point we are not aiming for a prediction the future transport system. Rather, we want to generate benchmarks on how to re-organise the system to achieve certain emission reduction goals. The big advantage of running this investigation within a real-world scenario is that we will be able to attach financial costs (e.g. procurement costs, running costs, maintenance costs) to the various elements of each outcome and thus provide input to discussions concerning the feasibility of the investigated approaches.

2.4 Data handling

All MATSim code is available under `http://github.com/matsim-org/matsim`; the MATSim code generated in the present project will be included there. All jsprit code is available under `http://github.com/jsprit/jsprit/`; the jsprit code generated in the present project will be included there.

The South African data is already to a large extent publicly available (`http://cotd.ie.up.ac.za`). Not publicly available are the GPS traces of the freight vehicles. They will be available within the research team, but unfortunately cannot be made fully public.

2.5 Other information

Prof. Johan Joubert, of the Industrial Engineering at the University of Pretoria (UP) in South Africa (SA), is a partner to the proposal. He has extensively visited Germany and spent time both with the VSP and the WIV-DLR groups. In return, Kai Nagel of VSP has visited UP for a research semester, and Daniel Röder and Dominik Ziemke of VSP have visited UP for a month each. This collaboration is very important to the proposal since (1) it ensures that the approach is also useful outside Germany, in quite different contexts, and (2) Prof. Joubert has access to data which we cannot procure at this point in Germany.

Prof. Joubert is unable to procure sufficient funding to collaborate for this project out of his own resources. For that reason, he will be funded out of this proposal according to DFG form 54.013 "Projects Involving Cooperation with Developing Countries".

2.6 Descriptions of proposed investigations involving experiments on humans, human materials or animals – not applicable

2.7 Information on scientific and financial involvement of international cooperation partners – see Sec. 2.5

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4 Requested modules/funds

4.1 Staff effort

	VSP [PM]	WIV-DLR [PM]	UP [PM]
1.1 Improvement and finalisation of the MATSim-jsprit interface	2	4	0
1.2 Design and implementation of the LSP interface	2	4	0
2 Traffic dynamics of light and heavy goods vehicles, particulate emissions, noise	6	0	0
3.1 Calibration of tour planning	0	4	2
3.2 Sensitivity of tours	4	0	2
3.3 Sensitivity of the fleet structure	4	0	2
4.1 "Geometric" generation of commercial vehicle activity chains	6	0	2
4.2 Calibration of the "geometric" model with vehicle counts	6	0	2
5.1 Artificial emissions toll and carrier reactions	6	0	0
5.2 Artificial emissions toll and upstream logistics reactions	6	6	0
	42	18	10

VSP

- ~~**6 PM postdoctoral researcher (100%).**~~[11]
- **6 PM postdoctoral researcher (100%).** This position will be filled by Dipl.-Inf. Michael Zilske (CV included), who is expected to have defended his Ph.D. by project start. He will in particular work on WP 1, benefitting from his knowledge accumulated during the 2000W-City project which developed the Carrier interface and integration.
- **36 PM doctoral researcher (100%).** For the remaining tasks, a new person will be recruited. This person will need conceptual skills to develop the necessary models, programming skills to implement them in software, and analytical skills in order to analyse the simulation results. "Programming" will mean the typical cycle of developing amodel, implementing it in code, testing its sensitivity, and then, if necessary, return to model development.
- **42 PM student student research assistant (80h/month).** Student research assistants will support the doctoral researchers. They will primarily run the simulations and prepare the analysis of the results. If possible, they will participate in the programming.

WIV-DLR

[11] This position is removed from the revised proposal.

- **18 PM doctoral researcher (100%).** This position will be filled by Daniela Luft (MSc.; CV included). DL has been working at DLR since 2012.
- **18 PM student research assistant (80h/month).** Student researchers will mainly do supportive work, such as running simulations, collecting data and evaluate results. It will be tried ho hire a student assistant who has programming skills.

UP as essential project partner in a developing country UP will work on the Gauteng/South Africa elements of the corresponding work packages. They will procure data from local institutions and commercial entities (as listed in Sec. 2.2.2), clean it, run simulations, and perform comparative analyses between that data and simulation results. For this, we request:

- **10 PM doctoral researcher**. The monthly rate for a researcher with a Masters degree but without a Ph.D. at UP is approximately ZAR 10 000. 10 PM of this results in ZAR 100 000 (mar/16: **€ 5 903**).
- **2 × 10 PM student research assistant (60h/month)**. The standard hourly rate of a student research assistant at UP is ZAR 93.75 (see attachment). 60h/month results in 60h × ZAR 93.75/h = ZAR 5625. For the present project, we budget two such a student assistants for 10 months each, resulting in 2 × 10 × ZAR 5625 = ZAR 112 500 (mar/16: **€ 6 641**).

The Gauteng/South Africa case study is essential to the project to stress-test the proposed models in a much different area; it contributes data that we otherwise have no access to; and finally the project builds capacity in South Africa.

The UP staff costs are summarized as follows (in €):

staff costs	UP [€]
10 PM of a doctoral researcher	5903
2 × 10 PM student assistants at 60h/month	6641
total	**12544**

4.2 Scientific instrumentation

Compute server 2 servers × € 4934/server (€ 4146 + MwSt., see quote) = **€ 9 868** . Many problems discussed in this proposal are bi-level, e.g. optimisation of the fleet structure and tours (WP 3.3), or calibration of the "geometric" freight model (WP 4.2), given that drivers optimise their routes. Our experiences show that at least 10 re-routing steps (inner loop) are necessary before another step in the outer loop can be made. Small scenarios can be run on desktops, but larger scenarios need to be moved to servers where they can run for multiple days or even weeks. We therefore request funding for two compute servers, with 2 CPUs, each CPU with 12 cores, and 32 GB of RAM, where we will start with smaller scenarios, and provide more memory towards the end of the project from other funds.[12] The server will be integrated into the structure administered by the school for mathematics at TU Berlin (see Sec. 5). We have no base funding for compute servers (also see Sec. 5); we already pay for all the remaining infrastructure (e.g. switches, RAID disk arrays, cables) out of gains made elsewhere.

Overall The overall instrumentation costs are summarised here:

	VSP [€]
compute server	9868
total	**9868**

[12]For instance, 5 million agents x 5 plans per agent x three routes per plan x 30 edges per route x 8 byte per edge (64-bit architecture) result in 18 GByte RAM; some compression is possible.

4.3 Consumables: not requested

4.4 Travel

Conferences and workshops The doctoral researcher will visit at least one international conference, e.g. Annual Meeting of the Transportation Research Board, Conference of the International Association of Travel Behaviour Research, or conference of the European Association for Research in Transport (hEART), per year, and two (more local) workshops per year. We also request funding for one major conference and one workshop for the PI (K. Nagel), and for one major conference and two workshops for the postdocs (combined). The doctoral researcher from WIV-DLR (DL) will visit two international conferences and four workshops during the course of the project. We also request funding for one major conference and one workshop for G. Liedtke (GL). We estimate the cost of a conference on average as € 1700 (averaging over European and international conferences, 5 days, travel € 800, accommodation € 400, conference fees € 500). Concerning a (more local) workshop we estimate on average € 1000 (travel € 300, accommodation € 400, fees € 300).

Research visits Furthermore, we request funding for research visits:

- VSPs doctoral researcher will visit Prof. Johan W. Joubert, University of Pretoria, South Africa twice. The expected cost for each research visit are € 3100 (30 days, travel € 1500, accommodation € 1600).
- KN will visit Prof. Johan W. Joubert, University of Pretoria, South Africa once. The expected cost for the research visit are € 3100 (30 days, travel € 1500, accommodation € 1600).
- Prof. Johan W. Joubert will visit Germany three times. This will be done in conjunction with the annual MATSim conceptual and developer meetings, which are important to integrate him and his work into the community. The expected cost for each research visit are € 3100 (30 days, travel € 1500, accommodation € 1600).

Overall The overall travel costs are split as follows:

	VSP [€]	WIV-DLR [€]	UP[€]
3 + 2 conferences for doctoral researchers	5100	3400	0
2 + 1 conferences for German PIs	3400	1700	0
6 + 4 workshops for doctoral researchers	6000	4000	0
2 + 1 workshops for German PIs	2000	1000	0
6 research visits SA ↔ DE	9300	0	9300
total	**25800**	**10100**	**9300**

4.5 Publication costs

€ 750/yr × 3 yrs = **€ 2 250**, split as follows:

VSP	DLR
1500	750

4.6 Running costs for materials

Fak. V of TUB, where VSP is located, currently passes on half of the DFG indirect cost contribution, i.e. 10% of the grant, to the research group. In addition, Fak.V grants about 500 Eu per person-year of funding.

4.7 Other costs: not requested

5 Project requirements

5.1 Employment status information

Nagel, Kai, C4 Professor, TU Berlin, permanent

Liedtke, Gernot, Head of Department, German Aerospace Center, permanent

Joubert, Johan W., Professor, University of Pretoria, permanent

5.2 First-time proposal data: not applicable

5.3 Composition of the project group The team of Kai Nagel currently consists of 5 doctoral students, 2 postdocs, 1 technician (50%), and 1 administrative assistant (50%). Relevant for this application are B. Kickhöfer, M. Zilske, and D. Ziemke. They will be hired onto the project as explained earlier.

The team of Gernot Liedtke is described in the companion proposal.

5.4 Cooperation with other researchers

5.4.1 Researchers with whom you have agreed to cooperate on this project Beyond the researchers formally involved in this proposal and its companion, the investigators take an active part in the international research in the area of transport engineering and have scientific contacts to a number of renowned research groups.

5.4.2 Researchers with whom you have collaborated scientifically within the past three years (This lists only scientists who have at least a Ph.D. Many of them are not related to freight modelling but are listed for completeness according to the instructions.)

Axhausen, K.W.; Beckers, T.; Birkmann, J.; Bärwolff, G.; Dressler, D.; Flötteröd, G.; Gerike, R.; Klüpfel, H.; Köhler, E.; Maciejewski, M.; Rao, K.R.; Schlurmann, T.; Schwandt, H.; Skutella, M.; Taubenböck, H.; Tirachini, A.; Waddell, P.; Wang, L.; Winter, M. Also see the list in the other sub-proposal.

5.5 Scientific equipment We are very grateful that the school for mathematics at TU Berlin administrates VSP's servers,[13] but the hardware needs to be procured by VSP and is not available as standard equipment or from base funding.

5.6 Project-relevant interests in commercial enterprises K. Nagel has a 5% stake in Senozon AG. Senozon AG develops and sells software based on the software MATSim. MATSim is used in the present project.

[13]See http://www.math.tu-berlin.de/Rechnerbetrieb/Numerikserverbereich/

List of attachments

- CVs of principal investigators (for CV of Gernot Liedtke see sub-project 2)
- CV of Dipl.-Ing. M. Zilske and M.Sc. D. Luft, who are expected to work on the project
- Letter from Prof. Johan W. Joubert – Limited Resarch Funding
- Email from UP – Salary rates
- Price quote for compute server