Package Project

Shippers and Recipients in a Multi-Agent Framework for Commodity Transport Demand Modelling

with the sub-projects

Carrier Agents and Interactions with Traffic Flows

Shipper Agents and Interactions with Transport Markets

proposed by

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1 Motivation

All over the world, migratory movements towards urban areas entail the formation of mega-cities and large agglomeration zones. In these areas, commercial transport accounts for more than 20 percent of vehicle kilometres. Its impact on the environment, quality of life of the residents, severe accidents, traffic flows, and greenhouse emissions is even larger.

In this situation, existing models of commercial traffic are not sufficiently sensitive against many policy measures. For example, the models of the German National assessment exercise ("Bundesverkehrswegeplan"; see Planco et al., 2015) do not even consider freight hubs, although these are an important determinant for freight traffic flows. If a model considers hubs (e.g. De Jong et al., 2010), they can normally not be added or removed, thus making such models incapable of displaying fundamentally new transport solutions.

In fact, there was a similar situation for passenger transport modelling until about a decade ago, where the so-called four step process was not sensitive for many modern measures of transport demand management such as peak hour pricing, public transport incentives, or improved bicycle infrastructure. Here, modern activity-based demand modelling (e.g. Arentze and Timmermans, 2005), in conjunction with modern dynamic traffic assignment (e.g. Peeta and Ziliaskopoulos, 2001) has made important steps towards addressing these issues. We see the consequences in our own studies (Kickhöfer and Nagel, 2016): While we can now model CO_2 reduction for passenger transport, as a reaction to policy measures, this is not the case for freight transport, since freight actors are not endowed with sufficiently reactive behaviour in these simulation studies.

Our own 2000W-City project (Liedtke and Nagel, 2010–2015) has somewhat improved the situation: It is now possible to include behavioural freight carriers into the modelling system. They still assume that hubs and goods flows are given, but can react by modifying their fleets and/or their tours. However, the link to congestion is still too weak, and hubs can still not be moved endogenously by the model. It is, however, to be expected that in most cases upstream logistics decisions (supplier choice, logistics network design, and warehouse policy design) are much more flexible than their passenger-transport counterparts (choices of residence and activity patterns). Thus, freight traffic is one of the most promising parts of traffic in urban areas in terms of mitigating negative impacts without having to accept unnecessary limitations to the accustomed levels of service.

The behaviour of freight transport agents is connected with complex optimisation tasks. Multi agent (MA) modelling addresses the challenge to map the behaviour and the interactions of economic agents pursuing their goals and possessing solution strategies for complex planning problems. These are exactly those characteristics which are needed to analyse the effects of policy measures on various types of logistics agents. In fact, there is an increasing research about using MA modelling techniques in the area of commodity demand modelling (for instance Russo and Comi, 2010; Cavalcante, 2013; Samimi et al., 2012). Such models are capable of generating spatio-temporal structures such as tours or logistics networks from the behaviour rules of multiple actors. This is an important requirement once it comes to a coherent long-term policy impact assessment and a consistent scenario formulation.

The proposed project extends an existing MA framework for freight transport by modelling the demand side of the transport market, i.e. shippers and recipients as well as logistics service providers, in a detailed way. To the best of our knowledge, it will be the only existing freight demand model that (i) includes several decision dimensions, (ii) makes use of complex optimisation, (iii) interacts with time-dependent traffic flows, and (iv) is available as an open source program that has been tested by various other researchers.

The composition of the consortium ensures the application of the model to real-world cases as well as the problem-independent applicability and later expandability. The consortium members unify long-standing in-depth experience with large scale traffic flow microsimulation, modelling of travel and logistics behaviour, microeconomic market modelling, and applied optimisation.

2 Overview of the package project

The package project consists of two sub-projects "Carrier Agents and Interactions with Traffic Flows" ("sub-project 1") and "Shipper Agents and Interactions with Transport Markets" ("sub-project 2"). The overall objective of the two interrelated sub-projects is to model all relevant decision makers in urban freight transport and their adaptations to each other as well as to the traffic flows. Special emphasis is put on the propagation of effects from shippers via transport companies to the traffic network (and on environmental damage) and in the opposite direction. It is accepted knowledge that freight transport is derived from the exchange of goods in trade and production relationships. Hence, we concentrate on modelling the relevant upstream actors in the freight and logistics sectors, and their interactions with the congested transport system. These upstream actors are shippers/recipients and logistics service providers.

In order to illustrate the decisions that finally lead to the movements of heavy goods vehicles in an urban area, Fig. 1 shows six sequential activities that precede these vehicle flows. If the state of the whole system of interacting agents has to be modelled, the elements on this decision sequence have to be brought into a consistent state.

Purchasing and sale contracts entail the need for moving commodities between contracting parties that are located in different places. The way how these movements are carried out depends on the requirements that are defined by shippers, recipients, and those who are in charge of the transport process. All these activities leading to the transport requirements as well as the coordination between the mentioned actors can be subsumed under the concept of "logistics". Shipments are usually carried in predefined transport logistics networks of the contracted transport company. Within such logistics networks, tours are constructed, which in turn results in vehicle movements on the traffic network.

In each of the six activities in Fig. 1, there are various possibilities for the involved agents to act according to their particular goals. As there are interdependencies between these decision problems, coordination mechanisms have to be established. These mechanisms can be grouped into internal and market-based coordination: Internal coordination links different decision levels within the complex organisation of a firm; market-based coordination has additionally to do with the selection of business partners in a market environment.

As there are various sequential decision layers that have to be coordinated, changes in the traffic network are likely to affect upstream decisions. The farther the considered decision layer is away from the road network, the more degrees of freedom exist for the decision makers and to evade traffic congestion and policy measures.

The proposed package project aims at modelling the behaviour of different agents, and the coordination between various agents and decision levels. The participating institutes already worked successfully on various of these decision levels: Wisetjindawat et al. (2007) and Liedtke (2006) dealt with the layer

Source: Adapted from Liedtke et al. (2009)

Figure 1: Sequence of upstream decisions preceding physical freight traffic

of "Purchase and Sales" by addressing the choice of suppliers by the recipients. As far as "Logistics Planning" is concerned, Friedrich (2010) developed a micro-logistics model for the food retailing sector. Scholz (2012) dealt with the optimisation of a transport network for air cargo. Logistics Planning was also covered by the lot size models developed in BVU et al. (2014) and Liedtke (2012). The chair of Transport Systems Planning and Transport Telematics takes a leading part in the development of the traffic flow simulation software MATSim (Multi Agent Transport Simulation) which is an internationally recognised standard model. MATSim models the physical execution of mobility plans (activity patterns or vehicle tours) and the level of "Route choice".

The coupling of these decision layers will be achieved by adding two new types of agents to the existing MA model "Freight Transport Lab", which is a plugin into the MATSim (Multi Agent Transport Simulation) project. In addition to the already existing implementations of the Driver and Carrier agent, Logistics Service Provider Agents and Shipper/Recipient agents will be developed to reflect the behaviour on the corresponding decision layers in Fig. 1.

These new agents embody the behaviour of the demand respective supply side in the transport market. Their functionalities are capable to close the aforementioned gap in Fig. 1.

Furthermore, existing models on the levels "Vehicle Tour Construction" and "Route Choice" will be enhanced. Vehicle tours depend on the situation on the traffic network. Especially in urban areas, there is considerably slower traffic during peak hours. In some cases this is taken into account by transport companies when constructing the tours of their vehicles. In reality, tour construction is often not based solely on cost minimisation, but also on other more intangible aspects as habits, side agreements, or rules-of-thumb. Therefore, the step "Vehicle Tour Construction" will be altered in order to obtain tour patterns that fit to observed company data.

In the project, it is intended to modify MATSim in such a way that it can deal with vehicle types with different speed profiles. This, together with the enhancement of the tour construction and route choice levels, opens the door to improve the deduction of noise, CO_2, and particle matter emissions.

Acceleration and deceleration as well as idle running cause particularly high emissions, and this holds true especially for trucks. In this way, an integrated assessment of the impact of policy measures on logistics cost and on external cost is enabled.

Besides the continuous coverage of the whole chain of decisions, the unification of already existing partial behavioural models of the partners in one coherent model is an important aim of the project. The operational model will allow applications for different geographical regions. The resulting model will be a further step towards the analysis of the influences that various policy measures or developments like increasing fuel prices have on the various stakeholders. Thus, the model will significantly contribute to the ongoing discussion about distributional aspects of policy measures and the related acceptance by multiple stakeholders.

3 Package project structure

In order to reach the project objectives, a multidisciplinary project team with profound competences in software design, economics, logistics, and traffic engineering has been formed.

Prof. Dr. Kai Nagel has over 20 years of experience with the combined simulation of travel behaviour and traffic flow, and is one of the main authors of the MATSim software, which will be used to feed traffic flow characteristics back to "Freight Transport Lab".

Prof. Dr. Gernot Liedtke has 14 years of experience in micro-level modelling of freight transport demand, and in particular in agent-based simulation models. The software "Freight Transport Lab" is built on his work.

Prof. Dr. Johan Joubert comes from industrial organisation, where he was interested in the logistics behaviour of commercial enterprises. Recognising the important influence of the underlying general transport network, he has embarked on building multi-agent freight simulation models, with a focus on applications in South Africa.

Dr. Wisinee Wisetjindawat carried out extensive research on freight transport demand modelling. She has special competence in the generation of microscopic freight flows by the means of spatial econometrics. She is one of a few experts who covered all steps in freight transport demand modelling, especially concerning the upstream logistics decisions.

Prof. Dr. Kay Mitusch brings a classical industrial economics perspective into the project. His experience in game theory, market forms and industrial organisation will contribute to the modelling of the freight transport market.

The researchers have successfully collaborated in the past, for example within 2000W-City project (Liedtke and Nagel, 2010–2015), in several scientific projects in connection with the update of the strategic German infrastructure development masterplan (Bundesverkehrswegeplan), during a research semester of Kai Nagel in Pretoria, or a research visit of Wisinee Wisetjindawat at the DLR Institute of Transport Research arranged by Gernot Liedtke. These collaborations have resulted in several scientific publications.

The starting point for the proposed project is the existing traffic flow simulation MATSim, which was complemented by a new package in the 2000W-City project – the "Carrier agent" on the layer "Vehicle Tour Construction" in Fig. 1. Together, these packages constitute the already mentioned "Freight Transport Lab". Using the class library jsprit, the Carrier agent generates tours in time and space, which are injected into the MATSim traffic microsimulation. In the course of iterations, Carrier agents improve their tours and fleet compositions, and finally a dynamic equilibrium crystallises. The Carrier agent serves as a link between the simulation of the physical transport of goods and the logistics and intangible decisions on the freight transport market. Two feasibility studies of how to extend the basic model to include the upstream logistics decisions of shippers and forwarders have been conducted in the framework of the 2000W-City project, too (Schröder and Liedtke, 2014; Schröder et al., 2012).

The first goal of the present project is to enhance the capabilities and characteristics of the Carrier agent in order to match observed behaviour and to improve environmental policy analyses. The second goal is the extension of the multi-agent framework to upstream logistics decisions, i.e. the implementation of the Shipper/Recipient and the Logistics Service Provider (LSP) agent classes.

From Fig. 2, the planned cooperation between the involved institutes in the package project can be seen. Five groups are involved in the project. The top row shows the three different scenarios; the colors denote which groups will be responsible for them. In the scenarios which take place in South Africa and Tokyo, the corresponding foreign institutes are involved. The leftmost column of Fig. 2 shows the various tasks. The inner cells of the table show which task will be investigated by which team with which real world scenario in which work package; the roman number part of each work package denotes the corresponding sub-project. The proposals for the two sub-projects will show the same figure, with the non-relevant cells greyed out.

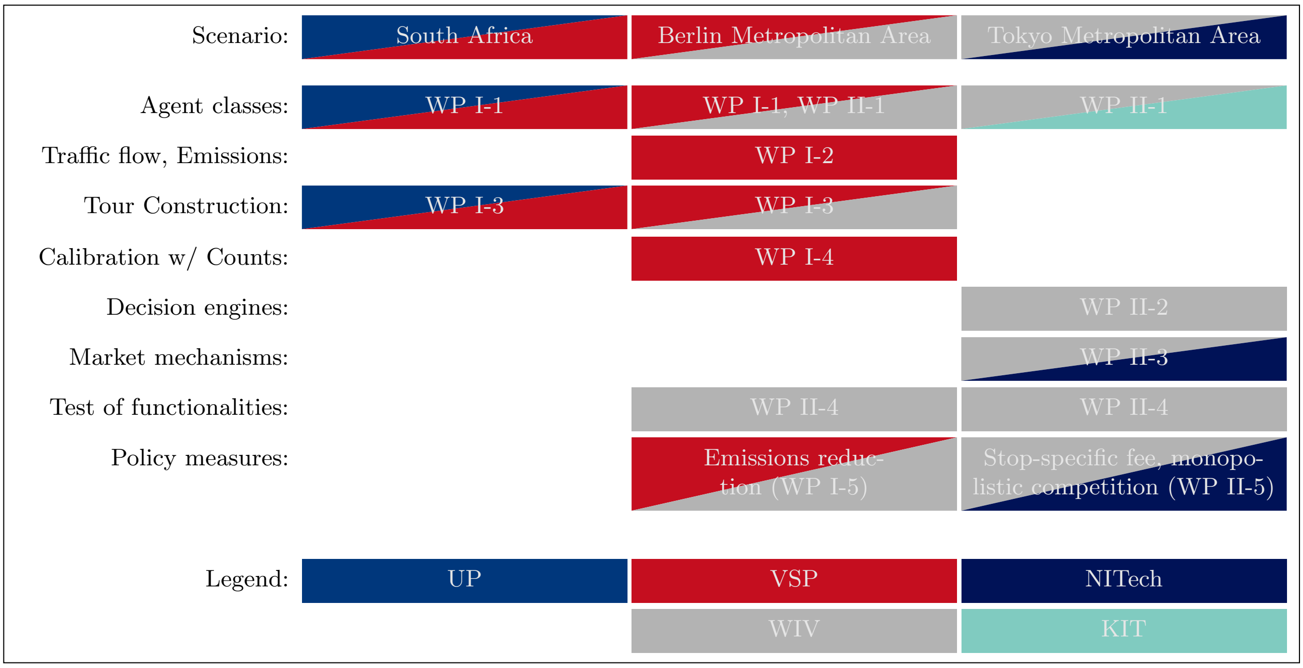

Figure 2: Structure of the package project "Shippers and Recipients in a Multi-Agent Framework for Commodity Transport Demand Modelling". In color.

The agent classes will be integrated into the existing traffic flow and travel behavior simulation MATSim. In several functionality tests, the conceptual modelling of the new agent types will be verified. The effects of policy measures on upstream logistics decisions will be analysed through several case studies. These analyses will embedded in three scenarios (South Africa, Berlin, Tokyo). These scenarios all include a traffic network. Demand for commodity transport is available for a transport company (South Africa), in form of a synthetic firm population (Tokyo), and for selected retail sectors (Berlin). Logistics behaviour is reflected in survey data for Tokyo, GPS data for South Africa, and results from the ongoing KEP-CITY project and a shipment size model (Piendl et al., 2015).

3.1 Objectives of sub-project 1

Sub-project 1 provides a traffic-engineering and software-engineering perspective on the project. It comprises three fields of activity that deal with the enrichment of the existing MATSim core model with capabilities to model the behaviour of freight transport agents, including investigations and case studies using these new capabilities. These fields are:

Software design and agent implementation Two new types of agents, namely the Logistics Service Provider (LSP) agent and the Shipper-/Recipient agent on the corresponding decision layers in Fig. 1, are created. The creation of these agent types is carried out in two stages. First, interfaces will be developed and then programmed in Java that set the frame for the behaviour of the agent types with special emphasis on their interaction with each other and with the already existing Carrier agent. Against these interfaces, Java classes will be implemented by both sub-projects that mimic a simplified behaviour of the agents in order to test and demonstrate the functionality of the new classes. This sub-project focuses on the the compatibility of the interfaces for the new agent types with the existing types of agents in MATSim. The reason for this is the intention to integrate the agent types into the MATSim extensions structure (`http://matsim.org/extensions`). Further, the main parts of the behaviour of the LSP agent will be specified and implemented.

Implementation of methods that describe the behaviour of the transport supply agents In an urban environment, most shipments have a size that is not large enough to fill a vehicle. Instead they are carried in mixed cargo and parcel transport systems, in which shipments are collected and delivered in vehicle tours and transshipped at hub facilities. Both the routing of shipments through such a network and the choice of the appropriate vehicles have to be modelled when considering the LSP agent, who organises these transport chains and therefore makes use of the transport capabilities of one or various Carrier agents.

Traffic flow integration and deduction of emissions Freight vehicles, and here in particular heavy duty vehicles, are significantly different from passenger cars both with respect to their traffic flow behaviour and with respect to their emissions characteristics. In order to take this into account, the MATSim traffic flow model will be extended to accommodate heavy duty freight vehicles. This needs to be done with care in order to maintain the current high computing speed of the MATSim traffic flow model which is necessary to treat large regional scenarios. Once the freight vehicles have been integrated in this way, the existing particulate emissions module will be extended towards trucks. Finally, a noise emissions module will be developed.

3.2 Objectives of sub-project 2

Sub-project 2 takes the view of an economist and focuses on upstream logistics decisions that strongly affect the structure of freight flows. These decisions have, amongst others, to do with the planning of transport and logistics networks and the choice of transport options. As the result of these decisions, different freight services connected with different spatio-temporal usage patterns of the infrastructures emerge. Sub-project 2 concentrates on the following aspects:

Modelling the demand for transport services The starting point for modelling freight transport demand at the micro level is the network of supply relationships between all shippers and recipients. These relationships and the responsible actors behind them are represented by the Shipper/Recipient agent who can both serve as a source or drain of commodity flows. We will adapt and generalise already existing methods for creating a synthetic population of such actors. Taking each flow as given and fixed, the Shipper/Recipient agent determines the further details of the transport. Transport cost is only one decision drivers among others. Hence, the modeller is able to see which influence transport has on the logistics decisions of the shippers and recipients.

Modelling of transport market interactions Most shipments are not physically carried by the shipper or the recipient, but rather by a contracted transport company. Freight transport constitutes an own industry in which several suppliers compete for consumers. The supply side in the freight transport market is represented by the LSP agents. In the real world, actors that are embodied by the LSP agents have a wide variety of options to shape their transport services according to the requirements of their customers. Shippers base their LSP choices, among other things, on the offered transport tariffs. Tariffs, in turn, depend on the cost structure and the market form. We intend to concentrate on cost based competition. In the market, suppliers and customers of transport logistics services adjust to each other. Shippers (or recipients) request offers from LSP agents, who set their prices depending on the characteristics of all consignments they have to transport. In the course of the market activities, only those LSP agents that offer competitive prices can break even and subsist in the market.

Modelling the propagation of effects Policy measures to influence traffic are applied to the road network and the vehicles in order to change behaviour. Interventions such as tolls or vehicle bans can only be sustainably successful, if they have an influence on the actual decision makers. In reality, these are mostly shippers and recipients. With the help of the additional agent types, we want to track effects of various policy measures on the demand side of freight transport. The microscopic approach allows to observe the results of policy measures at the level of single companies. This allows to address multi-stakeholder problems and to identify winners and losers. In recent years it was sometimes claimed that changed logistics strategies such as global sourcing or just in time delivery had negative impacts on the traffic situation. The multi-layer model allows to track the effects of such changes to the traffic network.

3.3 Overall objectives

The overall objectives of the package project are as follows:

Modern modelling and simulation base for freight traffic As stated above, a stronger, behaviorally-oriented modelling basis for freight traffic is urgently needed in order to address many of today's questions. Since responses to policy measures in the freight transport sector can occur at several levels of a hierarchy – e.g. path and fleet selection by the carrier, hub selection by the logistics service provider, frequency selection by the shipper/recipient – it is necessary to include all of these levels into the modelling. The present project will come up with operational models for all these levels.

Integrated with components developed outside this project Freight traffic modelling is best done integrated with other modelling components – for example, in order to assess joint congestion, but also in order to benefit from existing noise or emissions calculations modules. The present project will integrate its results into the existing MATSim framework. There, all types of vehicles will compete for road space, and emissions or noise calculations for passenger cars will be re-used by replacing the vehicular emissions characteristics.

Tested with integrated real-world use case All components developed in the package project will be tested in a joint real-world Berlin regional scenario. This will ascertain that all model components work together, and provide insights about the sensitivities of the combined model system.

Software open-source available Software developed or modified during this project will be made available via `http://github.com/matsim-org`. We will also make core routines, which may be used outside MATSim, available separately; `http://github.com/jsprit/jsprit` is an example of such a separate library that came out of a past project and will also benefit from the present project.

3.4 Anticipated total duration of the project

36 months

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