Agent-based simulation of freight transport between geographical zones

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Abstract

We present TAPAS-Z, which is an agent-based freight transport analysis model for simulation of decision-making and transport activities. TAPAS-Z is a further development of a simulation model called TAPAS, and it has improved support for simulation of transport in large geographical regions. It is based on the principles that shipments are simulated for chosen supplier-consumer relations in a geographic region, and that the geographic locations of suppliers and consumers are randomly varied for each shipment. In TAPAS-Z, one supplier represents all real-world suppliers in a geographic zone, and one consumer represents all real-world consumers in a zone. In that way, TAPAS-Z is able to capture some of the diversity in freight transport that is caused by the varying geographic locations of senders and receivers, and which is important when assessing the impact of transport policy and infrastructural measures.

Keywords: Multi-agent-based simulation, MABS, Freight transport modeling, Zone-based freight simulation

1 Introduction

Freight transportation is known to cause both positive and negative effects on society. Positive effects typically relate to economy and social welfare, while negative effects mainly relate to the environment. Public authorities, in the role of policy makers, wish to plan for a transport system that contributes positively to the development of society and has reduced negative impacts. There is therefore often a wish to reach certain goals, such as obtaining a transport system that enables trade between regions and countries, and lives up to emission targets. Goals are often conflicting, and obtaining a transport system in which positive and negative effects are in balance is far from easy.

Different types of transport policy and infrastructural measures can be used to influence how transport activities are chosen and executed. Before implementing a set of measures, it is important to be able to accurately predict what will be the environmental, economic, logistical, and societal consequences, so that both undesired and desired effects can be highlighted. In the process of planning a transport system, decision-makers in public authorities are often supported by different types of computer-based analysis models. They typically use macro-level freight transport analysis models, such as SAMGODS (Swahn, 2001; de Jong and Ben-Akiva, 2007), SMILE (Tavasszy et al., 1998) and TRANS-TOOLS (Rich et al., 2009), when trying to predict the impact of different types of transport policy and infrastructural measures.

Recently, a few agent-based models for analysis of transport policy and infrastructural measures have been suggested, e.g., INTERLOG (Liedtke, 2009) and TAPAS (Holmgren et al., 2012b). Multi-agent-based simulation (MABS) is able to model the complexity of a transport system by explicitly modeling decisions made by different actors involved in transportation, their interaction, and time aspects (including timetables, and time-differentiated taxes and fees). It has been argued that this is important for being able to accurately analyze the impact of transport policy and infrastructural measures, and that it makes MABS more powerful than traditional approaches to freight transport analysis (Holmgren et al., 2012b).

A disadvantage with agent-based models, as with micro-level models in general, is that they are only able to model a limited number of entities (e.g., vehicles and decision-makers) in a scenario. It would take a considerable amount of time to set up and run scenarios with a large number of entities that are modeled on a micro-level. However, it is often desirable to analyze transport in larger regions when trying to predict the impact of different types of transport policy and infrastructural measures. This would require large scenarios to be analyzed, and a lot of time would need to be spent collecting input data.

The work presented in this paper is built around the idea that it might be beneficial to let one agent in an agent-based freight transport analysis model represent several real-world entities (typically decision-makers). In such a way, it would be possible to model arbitrarily many real-world entities, while still being able to benefit from the advantages of agent-based modeling. For example, it would be possible to let a supplier agent represent arbitrarily many real-world suppliers.

We present TAPAS-Z, which is an agent-based freight transport analysis model for simulation of decision-making and transport activities. TAPAS-Z is a further development of another agent-based model (TAPAS, Holmgren et al., 2012b). TAPAS simulates shipments in chosen supplier-consumer relations, and the choices of, e.g., route and transport mode are estimated for each shipment using agent technology. TAPAS-Z adds to the functionality of TAPAS the possibility to simulate shipments between geographical zones, not only in particular supplier-consumer relations. This is achieved by modeling at most one supplier and at most one consumer per zone, whose geographical locations (within the zone) are randomly varied throughout the simulation process. One supplier agent represents all randomly generated suppliers in a zone and one customer agent represents all consumers.

In the next section we briefly describe the TAPAS simulation model, followed in Section 3 by a presentation of the TAPAS-Z model. Then, in Section 4 we briefly describe a simulation study in which TAPAS-Z was used together with the TRANS-TOOLS model. The paper is concluded in Section 5 with a discussion.

2 TAPAS

TAPAS (Holmgren et al., 2012b) is an agent-based model for simulation of decision-making and activities in transport chains. An important purpose of TAPAS is to provide functionality for impact assessment of various types of transport policy and infrastructural measures. It has a 2-tier architecture, with a physical simulator and a decision-making simulator (see Fig. 1). Physical entities (e.g., links and vehicles) and their activities are modeled in the physical simulator, and six transport chain decision-makers are modeled in the decision-making simulator as agents. An agent is often described as a system that is situated in some environment and that is capable of autonomous action in that environment in order to meet its design objectives (Wooldridge and Jennings, 1995).

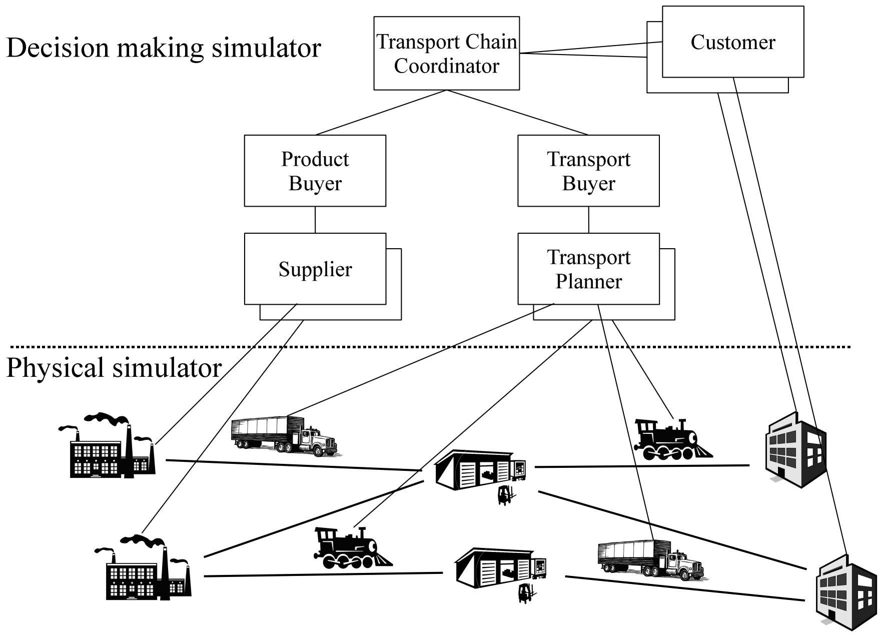

Fig. 1: Architectural overview of the TAPAS and TAPAS-Z simulation models.

Production and transport activities are driven by stochastic consumption for a number of consumers, which gradually builds up demand for products. To fulfill a consumer demand, the agents participate in a process that includes ordering of products and a transport solution, selection of which resources and infrastructure to use, and planning of how to use the resources and infrastructure. The process, which is represented as an interaction protocol (see, Holmgren et al., 2012b), starts when a customer agent sends an order request, and it ends when products and a transport plan have been booked. Ordering occurs when the inventory level for a consumer falls below the so-called order point. The order size is determined by minimizing the total cost for inventory holding and ordering, according to the principles of the Wilson (EOQ) model (Wilson, 1934). Production and transport activities are planned in the physical simulator based on the decisions taken by the agents involved in the ordering and planning process introduced above.

The process of conducting a simulation study with TAPAS includes determining which transport policy and infrastructural measures to study, defining geographical scope, setting up scenarios, collecting input data, running simulation experiments, and analyzing output data. In a typical study, a base scenario is compared to scenarios that represent different transport policy and infrastructural measures. An overview of how to use multi-agent-based simulation for analysis of transport policy and infrastructural measures is provided in (Holmgren et al., 2012c).

3 TAPAS-Z

TAPAS is built on the main idea that shipments are simulated for supplier-consumer relations, which here refers to pairs of suppliers and consumers that represent senders and receivers of freight. Suppliers and consumers are represented by supplier and customer agents. For each shipment, these supplier and customer agents interact, as briefly described in Section 2, in order to decide and agree on the terms for transport. When analyzing freight transport in some geographic region, it is typically important to model as much as possible of the diversity of freight transportation. Transport-related choices may be influenced, e.g., by the geographic locations of senders and receivers, and by commodity types. By studying transport in multiple relations, TAPAS can be used to indicate what choices of, e.g., route, mode, vehicle type, and shipment size, are expected to be made under different conditions.

In TAPAS, it is theoretically possible to model all supplier-consumer relations in arbitrarily large regions, and to study all shipments in those relations. However, for large scenarios, this would be practically impossible due to the large amount of time that would be required for setting up and running TAPAS. In addition, huge amounts of data describing companies involved in transport activities are typically needed as input. Data collection is time consuming, and some companies might not even be willing to share information.

Even though the TAPAS model has limitations when it comes to setting up and running large scenarios, it has some features that we consider important to have in a freight transport analysis model. TAPAS is considered powerful as it explicitly models consumer demand, as well as the decision-making of individual actors involved in freight transport and the interaction between decision-makers. In addition, it captures aspects of time when estimating choices.

To further build on the strengths of TAPAS, we have extended it into TAPAS-Z, which is a model with improved support for modeling transport in large regions. Most of the functionality is identical in TAPAS and TAPAS-Z, in fact, they use the same decision-making simulator and the same decision-making process (see Section 2). In addition, TAPAS-Z is based on the main TAPAS principle that shipments are simulated within supplier-consumer relations in a geographic region. It should be mentioned that TAPAS allows studying the choice of supplier, but in TAPAS-Z, this functionality is currently not considered. The geographic region is represented as a number of disjoint zones, each of which is represented by one logistic terminal. All modeled real-world suppliers and consumers in a zone are located in the catchment area of the logistic terminal representing that zone. In the model there is (at most) one supplier and (at most) one consumer in each zone, which are represented by one supplier agent and one customer agent respectively. For each new shipment in a relation, the exact geographic locations of the supplier and the consumer are randomly generated within the catchment areas of their respective zones. Hence, one supplier in the model represents arbitrarily many real-world suppliers, and one consumer represents arbitrarily many real-world consumers. TAPAS-Z's additional functionality of randomly varying the geographic location of the supplier and consumer in a zone enables simulation of shipments between geographical zones. As a supplier-consumer relation in TAPAS-Z represents transport between two zones, it can equivalently be referred to as a zone-zone relation.

As mentioned above, TAPAS-Z simulates shipments between suppliers and consumers with varying geographic locations. An important reason for modeling the diversity of supplier and consumer locations is to be able to create a better overview of transport in a region. A consequence of using a zone-based approach, is that the output can be generalized into total flows in the region by making use of aggregated historical, current or estimated future flows between zones. The availability of flow data that can be used to generalize the TAPAS-Z output, is an important factor when determining which zone structure to use.

Just like TAPAS, TAPAS-Z needs accurate input data describing all modeled entity types, e.g., vehicle and commodity types, in order to produce high quality output. The sources of input data are case specific, and may include companies active in the studied region and information collected to be used in other models. As it is often difficult to obtain information about real world companies, e.g., concerning where they are geographically located, TAPAS-Z makes use of a stochastic model for locating suppliers and consumers around logistic terminals. Suppliers and consumers are assumed to cluster around logistic terminals, and distances between a terminal and the suppliers and consumers around that terminal are modeled using an exponential distribution. In that way, closer distances are generated with higher probability than larger distances. However, large distances are truncated since an exponential distribution may generate arbitrarily large distances. The directions of suppliers and consumers relative to terminals are generated using a uniform probability distribution.

The transport network is represented as a directed graph with a set of nodes, i.e., suppliers, consumers and other connection points (e.g., terminals where modal changes may occur), which are connected using directed links. Each link corresponds to exactly one transport mode, and two nodes may be connected by multiple links representing different modes. The availability of transport alternatives between nodes is typically determined by studying real-world transport network descriptions. The network is designed in such a way that road transport is enabled directly between a supplier S and a consumer C, which in the example in Fig. 2 gives approximate distance $a' + d' + d'' + a''$ or, via their local terminals (T_S and T_C), $c' + b' + d' + d'' + b'' + c''$. The latter case typically occurs when freight is transported by rail or sea between T_S and T_C, and by road between S and T_S, and between T_C and C. Another possibility is road transport from S to T_R and from T_C to C, and rail or sea transport from T_R to T_C (distance $a' + d' + d'' + b'' + c''$).

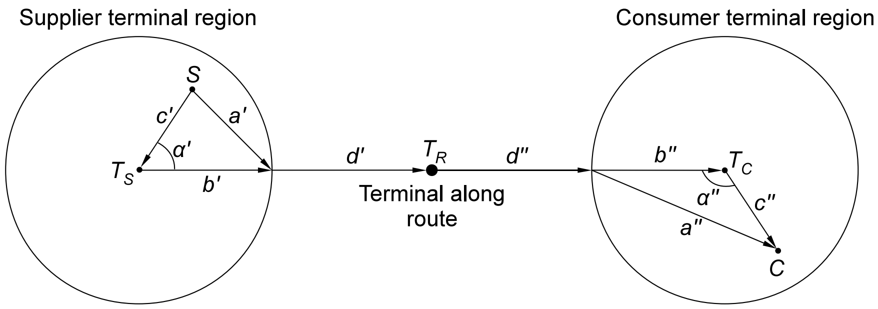

Fig. 2: Illustration of distances for different routes from a supplier S, via a terminal T_R to a consumer C. Transportation may occur, e.g., via terminals T_S and T_C ($c' + b' + d' + d'' + b'' + c''$) or direct by road ($a' + d' + d'' + a''$).

In a scenario containing a number of zone-zone relations, TAPAS-Z studies a large number of shipments between suppliers and consumers, which have varying geographic location. The number of simulated shipments in each zone-zone relation needs to be large enough to be able to show how choices tend to be made. For each simulated shipment, TAPAS-Z estimates choices of, e.g., route, mode, vehicle type, and shipment size, which are influenced by the location of the supplier and consumer. For each relation, the output can be aggregated into percentages for different choices, e.g., regarding how different transport modes and routes are selected. These percentages can then be used to generate total transport volumes, e.g., for routes and modes in a particular relation. This can be achieved by multiplying the percentage of a certain choice with the available (estimated or real) freight flow in that relation.

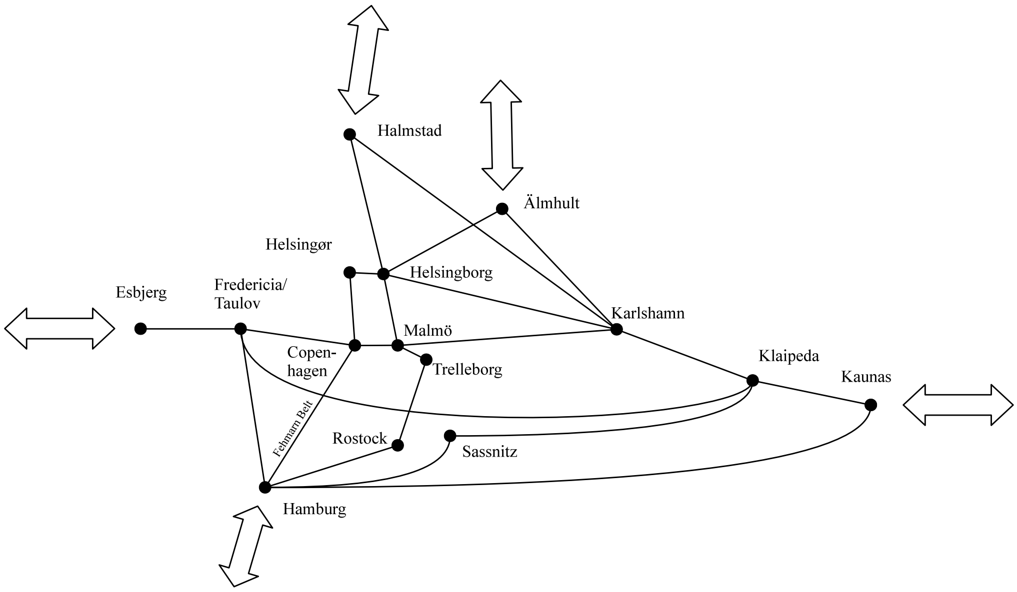

Fig. 3: Overview of the EWTC region, including modeled terminals where mode changes may occur, and connections between terminals. In the figure, each of the connections represents one or more transport mode, depending on which modes are available for that connection. The arrows represent freight flows entering and leaving the region. A complete description of the network is given in (Holmgren et al., 2012a).

4 An East West Transport Corridor simulation study

The East West Transport Corridor (EWTC) is a land-bridge for transport from China/Russia through the Southern Baltic Sea region towards the United Kingdom. In a simulation study, which is completely described in (Holmgren et al., 2012a), we analyzed transport in a geographical region referred to as the EWTC region (see Fig. 3). The TRANS-TOOLS (TT) model (Burgess et al., 2006; Rich et al., 2009) was used to estimate freight demand between zones in the studied region, and the TAPAS-Z model was used to estimate choices of route, mode, vehicle type, and shipment size. The output from the two models was jointly analyzed to obtain total freight flows for different transport modes.

An important purpose of the study was to investigate how it may be possible to achieve greener future transport in the region, and three transport policy and infrastructural measures were analyzed.

Five scenarios were included in the study: CS) Current situation, 2010; BL) Base line, 2030; BLG) BL + a distance-based road charging of 0.15 Euro/km for heavy trucks; BLHH) BL + fixed link between Helsingborg-HelsingøÃÿr; BLSE) BL + a new railway link connecting the Swedish terminals of Karlshamn and Älmhult (the SE Link). For a number of zone-zone relations in the EWTC region, and for the commodity types included in the TT model, we used TAPAS-Z for simulating a large but limited number of shipments with varying locations of suppliers and consumers. The output from TAPAS-Z was generalized into total transport flows by making use of the TT flows. In Fig. 4 we present the total amount of ton-kilometers in the region, for each of the transport modes. More detailed results are presented in (Holmgren et al., 2012a), e.g., total tons and ton-kilometers for each mode and for each connection in the network.

From the generated freight flows for the five scenarios, we observed a number of possible trends for future transport in the EWTC region. In the future, it is reasonable to expect a higher demand for rail transport than there is today. This is partly due to the fact that the costs for sea and road transport are expected to increase more than for rail transport until 2030, according to a forecast made in (McDaniel and Kyster-Hansen, 2011). For all transport policy and infrastructural measures (in BLG, BLHH, and BLSE) we observed shifts towards greener transport in the EWTC region, assuming that âĂIJgreenerâĂİ corresponds to reduced amounts of road transport. One reason is that the studied measures provide additional transport infrastructure (in BLHH and BLSE), and the kilometer tax studied in BLG gives incentives to choose greener transport as road transport in that scenario is subject to a fee.

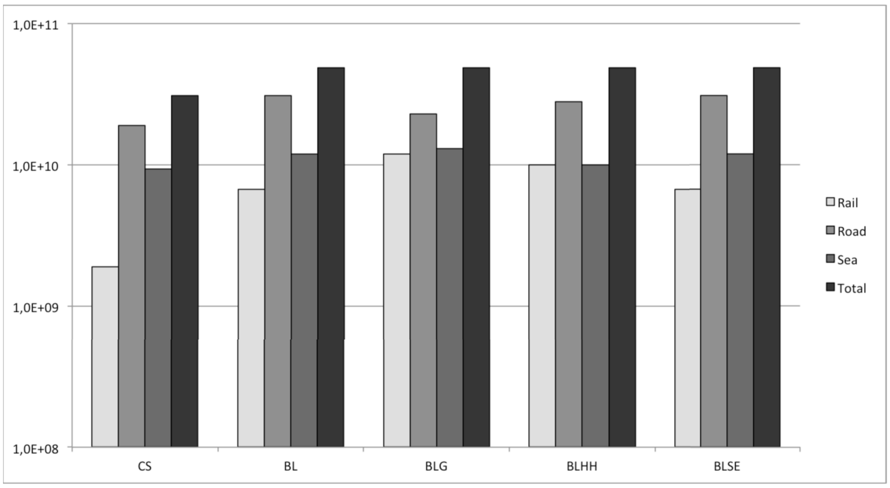

Fig. 4: Total transport work (ton-kilometers) between terminals, for each of rail, road and sea (ferry), for each of the five studied scenarios. Note that the scale of the y-axis is logarithmic.

5 Concluding remarks

We have presented TAPAS-Z, which is an agent-based model for simulation of transport between geographical zones. TAPAS-Z is a further development of the TAPAS model, and it utilizes the advantages of TAPAS at the same time as it adds features for improved modeling of transport in large geographic regions. It is based on the principles that shipments are simulated for supplier-consumer relations in a geographic region, and that the geographic locations of suppliers and consumers in a geographical zone are stochastically located in the catchment areas of logistic terminals. In the model, one supplier represents all real-world suppliers in a geographic zone, and one consumer represents all real-world consumers. In that way, we have managed to capture, in an agent-based model, some of the diversity that characterizes freight transportation, and that is important to capture when assessing the impact of transport policy and infrastructural measures. TAPAS-Z has been validated through expert opinions and it has been used in a simulation study concerning transport in the Southern Baltic Sea (see Section 4). By varying the locations of suppliers and consumers for each shipment, it was possible to capture more of the diversity of freight transport in the EWTC region than would have been possible if transport was studied only in chosen supplier-consumer relations.

We describe TAPAS-Z primarily as an agent-based model; however, it also integrates features from the macro-level modeling paradigm. In the model, one consumer is used to represent arbitrarily many real-world consumers in a geographic zone, which share inventory, consumption pattern, and ordering policy, even though they are geographically separated. Decisions of when to order are therefore taken centrally, and decisions about how much to order is taken based on the location of the supplier and the consumer, which are specific for each shipment. Future work includes elaborating further on issues related to the integration of modeling paradigms.

TAPAS-Z does not include functionality for modeling intra-zonal freight flows, but the zones can be made arbitrarily small in order to model more of the freight flows as inter-zonal flows. However, modeling a large number of small zones could have a negative impact on the execution performance. An alternative approach would be to extend TAPAS-Z, so it contains functionality for studying transport inside zones, as well as between zones. Another direction for the further development of TAPAS-Z is to include (in the agents) the variation of some of the characteristics of the modeled real-world actors. This may be important because these variations may influence the decision-making.

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