ABSTRACT

This thesis explores how multi-agent-based simulation can be used for transport policy analysis. Transport policies are often used as a means to reach governmental goals, such as environmental targets to reduce the impact of transportation. To predict how transportation is influenced by policies, public authorities often make use of simulation models. A structured review of such models is made focussing on important transport chain characteristics. We argue that to properly predict the actual environmental, economic, and logistical effects of transport policies, the logistical decisions made in transport chains must be modelled appropriately. Such decisions, e.g., concern the choice of producer and traffic mode, planning of transportation, production, and terminal handling. The review concludes that models currently used for transport policy analysis fail to capture many of these characteristics. We argue that agent-based models have the potential to include these aspects since they are able to explicitly model the actual decision making in transport chains. We have identified a set of generic roles in transport chains where each role is responsible for certain decisions. A multi-agent-based simulator, TAPAS, has been developed in which these roles are modelled as agents. Thus, the decision making in transport chains and its influence by the application of transport policies are captured. The decisions lead to the execution of the logistical operations which in turn have consequences on the logistics, economic, and environmental performance.

The usage of TAPAS is illustrated by presenting two scenarios based on real world transport chains. Simulation experiments of the scenarios have been performed where different types of transport policies are introduced. The simulation results are analysed, e.g., by comparing the results to similar studies and by sensitivity analysis of input parameters. To facilitate the validation and generalisation of simulation results we suggest making use of typical transport chains and roles characterised by, e.g., product type and geographical locations. The type of studies that TAPAS can support are described and compared to studies typically made with traditional models. Transport policies which are relevant to examine are described and their potential influence on transport chains are analysed. The possible usage of TAPAS is discussed and related to different types of users. Public authorities can, e.g., use TAPAS to complement studies using traditional models. This can improve the accuracy of the simulation results by the inclusion of more logistical aspects. Large companies are another type of user which, e.g., can use TAPAS to analyse new market segments, such as new product types or new consumers, where historical data is not available. Some of the validation and verification of TAPAS and the simulation results have been made through interviews with experts of modelling and practitioners in industry. Also, the study of the usage and types of studies relevant for TAPAS is supported by the interviews.
Transport policy analysis using multi-agent-based simulation

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Finally, I would like to thank my family, mum, dad, Sandra, and Jonas, for always being there for me. And Simon has given me all his support and encouragement.
Preface


The thesis is more or less related to the following papers:


Control Policies, 11th World Conference on Transport Research (WCTR), Berkeley, USA, June 24-28, 2007.


The thesis is a continued work of the licentiate thesis, and the chapters in the thesis are mainly based on the following publications besides the licentiate thesis:

- Chapter 2 is based on paper VII, and to some extent paper X. When specific cases of transport chains are mentioned, this information comes from contacts with companies mainly via the projects.
- Chapter 3 is based on paper VII and to some extent V.
- Chapter 5 is mainly based on XIII and IX, and to some extent paper II.
- Chapter 6 is based on paper VIII and XII.
- Chapter 7 is mainly based on paper VIII, and to some extent paper X. The chapter is also based on interviews with experts in policy and transport modelling, as well as practitioners in transport chains who are connected to the project East West Transport Corridor and Effects of governmental control policies on transportation chains: A micro-level study.
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Chapter 1

Introduction

Transport policies are often used as a means to reach different governmental goals, such as decreasing the environmental impact of transportation. Predicting the actual effects of different transport policies is difficult due to the many logistical decisions which take place in transport chains and the many interactions between the actors in transport chains. In this thesis we examine how it is possible to make use of multi-agent-based simulation for transport policy analysis in transport chains. We begin by describing the problem domain and the methods used, and research questions are formulated. Contributions and the outline of the thesis are finally given.

1.1 Background

Freight transportation has both positive and negative effects on society. Transportation enables the movement of goods over great distances, allowing products to be consumed far from their production site. Thus, transportation contributes to the economic growth of a society, which can lead to increased welfare. At the same time, transportation has negative effects on society. For instance, transportation can cause emissions to be released into the atmosphere (carbon dioxide, sulphur dioxide, etc.) which are claimed to be very likely to cause climate changes such as global warming (Bernstein et al., 2007), and to cause acidification, eutrophication and many different health problems (Elvingson, 2001). Transportation can also cause traffic congestion, infrastructure wear, noise and accidents, which incur costs for a society. According to the European Environment Agency (EEA, 2004), the transportation sector is one of the largest contributors to several environmental problems. Especially road transportation continues to increase in the EU (European Commission, 2004; EEA, 2008) as well as in many other areas. The increase of transport demand is for example claimed to be caused by longer transport distances which are the result of logistical restructuring such as centralisation and production in countries with lower production costs (Rodrigue et al., 2001; McKinnon and Woodburn, 1993). Companies have taken these measures mainly to reduce operative costs (Rodrigue et al., 2001).

Society, represented by public authorities, wants to maximise the positive effects of transportation which contribute to economic growth, while at the same time minimising its negative effects. To reach governmental goals such as environmental targets, public authorities make use of transport policies.
Transport policies can be economic policies such as taxes and fees, and regulative policies such as bans and requirements. Governmental goals can aim at different geographical scales, for example the regional, national or global level. Transport policies on the regional or local level can also correspond to measures for improving the competitiveness of transport companies (e.g., port infrastructure investments and timetable synchronisation). Therefore, we choose to have a rather broad view of transport policies to also capture such policies, while still focusing on transport policies aimed at reaching governmental goals (for reaching environmental targets). The focus in the thesis is on transport policies aimed at reaching environmental goals.

Predicting the probable effects of transport policies is important in order to decide which policy to apply to reach governmental goals. To understand how transport policies influence freight transportation, we need to understand the mechanisms behind transportation. Freight transportation occurs when there is a demand for transportation of products to a customer, such as a retailer. The customer interacts with the actors in a transport market and in a product supply market. The actors negotiate, communicate, and make several decisions concerning how to meet the product demand. The decisions range from the choice of product supplier, what type of traffic mode and vehicle to use, and which transport route to take; to planning of potential transhipments, the size of consignments and when they should be delivered, etc. We call these types of decisions logistical decisions.

According to the Council of Supply Chain Management Professionals (CSCMP, 2005), logistics concerns the flow of goods and how the flow is planned, implemented, and controlled. The aim of logistics is to reach an efficient and effective solution which meets customer requirements. The logistical solution and the performed logistical operation can be described in terms of measurements which show how effective and efficient certain operations have been performed. The types of measures we deal with here have to do with economic, logistical, and environmental performance. Economic performance mainly concerns the cost of the transport chain actors as a consequence of logistical operations, in relation to income. It can also concern the taxes and fees paid by the actors to public authorities. In this thesis quality, resource utilisation, and transport indicators all under logistics performance. Maintaining high quality is crucial in order to meet customer demand, while resource utilisation and transport indicators are mainly related to efficiency aspects. Environmental performance concerns the environmental impact of transportation. Since transportation’s actual impact on the environment is very difficult to capture (see, e.g., Bernstein et al. (2007)), its performance is measured in terms of indicators such as the amount of emissions released into the atmosphere, energy usage, etc. Environmental performance is mainly of interest for public authorities due to its impact on society. However, companies often account for the environmental performance of transportation and point out measures taken to
improve their environmental performance in order to gain a competitive advantage due to their environmental consciousness (Welford, 1998). Different types of performance are thus of interest for both public authorities and the different actors in transport chains.

Figure 1.1 summarises the relationship between product demand, transport policies, transport chains, and effects. Product demand as well as transport policies influence transport chains. The actors in transport chains make decisions concerning how to make use of available infrastructure and resources to meet product demand. The consequences of the transport policies, product demand, and the decision making in transport chains, are the performed logistical operations, which can be described in different types of effects. We include economic, environmental, and logistical effects, which the public authorities are interested in. The effects can be evaluated in relation to governmental goals. If the actual effects do not correspond to the desired effects, such transport policies may be revised. The transport chain actors are also interested in the effects of transport policies, and the effects can potentially influence product demand and decision making in transport chains. The feedback from the effects of transport policies is illustrated with thinner arrows in the below figure. The focus of the thesis is on the relationships illustrated by the thicker arrows, not on the influence of the feedback. However, we consider the system when the decision making of the actors in transport chains has been stabilised after some time and the actors have found the best way to behave. Thus, the thinner arrow illustrating the feedback to transport chains can be considered as being taken into account.

Figure 1.1. Illustration of the relationships between product demand, transport policies, transport chains, and effects. The transport chain is the studied context, where the thicker arrows pointing towards the transport chain box illustrate input (influence), and the thicker arrow pointing away from the transport chain box illustrates output (consequence). Feedback is illustrated with thinner arrows and is not the focus of the thesis.

To analyse the probable effects of transport policies, simulation models are often used. In traditional models for transport policy analysis, that is, macro-level
models, the characteristics of an entire population are modelled. The characteristics are averaged together, and the model can be used to simulate changes in these averaged characteristics for the whole population. Current simulation models are therefore suitable for an analysis of aggregate transport movements. However, they fail to capture the complex and detailed decision making in transport chains and the interactions between the actors as described above. For instance, logistical restructuring which influences transport demand and detailed decisions concerning the planning of consignment size, consideration of timetables and time of delivery are not captured in traditional models. To deal with these issues, we suggest making use of multi-agent-based simulation (MABS) for transport policy analysis. MABS enables the modelling and simulation of the behaviour of individual entities (in terms of agents) and their interactions and can thus increase the level of realism by including more detailed aspects of transport chains. We believe that MABS can be used to bridge the gap between high-level transport policy making and detailed decision making in transport chains.

According to Parunak et al. (1998):

“...agent-based modeling is most appropriate for domains characterised by a high degree of localisation and distribution and dominated by discrete decision. Equation-based modeling is most naturally applied to systems that can be modeled centrally, and in which the dynamics are dominated by physical laws rather than information processing.”

Since the transportation domain includes the above characteristics, it seems appropriate for agent-based modelling. Research has also successfully been conducted to apply agent technology to transport logistics; see Davidsson et al. (2005a) for a review of applications.

With MABS, the simulated entities are modelled and implemented in terms of agents (Davidsson, 2000). A typical characteristic of software agents is that they are autonomous, which enables the agents to take their own initiative without external influence. Different types of agents with different goals and functions can be modelled and simulated with MABS, which enables us to capture the heterogeneity of individuals. The agents included can also have different perceptions of their environment. In MABS, the agents interact in a structured way according to interaction protocols. An application of MABS can include more or fewer characteristics typical and appropriate for MABS. For instance, the behaviour of the modelled agents can be more or less advanced and adaptive. However, a general characteristic of MABS is that it is appropriate to use for simulating group behaviour of different types of interacting entities when the outcome is difficult to predict due to the emergent (or causal) nature of the system (Davidsson, 2000).

There are examples of applications of MABS for policy making. Downing et al. (2001) for example have used MABS in the context of climate policy and
climate change. Downing et al. used an agent-based integrated assessment model to simulate issues like drought, flood, etc., where the social relations that support the effectiveness of exhortation are described. Downing et al. (2001) argue that MABS is well-suited for this purpose since agents represent the behaviour of different actors (in this context policy makers and households) and the interaction between the agents can therefore be described and evaluated. Also, since MABS can represent different grains, connections to macro-level models can be made.

Another example of an application of MABS is presented by Klügl and Bazzan (2004) where the traffic domain is examined. They have studied the route decision behaviour of commuting drivers with MABS. Klügl and Bazzan have, for instance, examined how traffic forecasts in the route decision process of the drivers influence the overall traffic situation. They argue that traffic can be suitable studied with MABS due to the social properties of the system where inter-related decisions and actions lead to the outcome.

1.2 Research questions and research methods

In this section, the research questions addressed in the thesis are presented and the research methodologies used to study them are described. Further discussions of the research questions and the methodology can be found in the following chapters in the thesis; see the outline in Section 1.3.

The main research question in the thesis is:

How can MABS be used for analysing the effects of transport policies?

This broad question concerns the examination of how MABS can be used for transport policy analysis in transport chains. The types of effects we focus on are economic, environmental, and logistical effects which can be used to evaluate different implementations of transport policies. To be able to answer the main research question, the following corollary research questions are formulated:

RQ1. What types of simulation models exist today for transport policy analysis and which aspects do they capture?

A review is made in which existing models aimed at transport policy analysis are analysed. To facilitate a structured analysis, a review framework has been developed for capturing these important characteristics of transport policy analysis which the models represent. The models have been classified according to the review framework. Based on the classifications, the models have been analysed concerning how well they capture different transport policies, effects, logistical decisions, etc., pointing out strengths and weaknesses of the models. From this analysis we concluded that MABS seems to be a promising approach, but that it has not yet been used for our purpose. Therefore we examine how MABS can be used for transport policy analysis.
RQ2. Which logistical decisions in transport chains are appropriate to include in an agent-based model to capture the effects of transport policies?

We suggest to model roles which appear in transport chains that are important to represent in order to capture the effects of transport policies. These roles are responsible for different logistical decisions. A model of logistical decisions and roles in transport chains has been developed partly based on how transport chains are described in the literature today, but also by including our extended scope of transport chains. The model has been validated by describing a real-world transport chain according to the model, and this description has been validated through interviews with practitioners in transport chains. The next step is to suggest how this model of logistical decision making can be represented using MABS.

RQ3. How can MABS be used to model the decision making in transport chains, while capturing the effects of transport policies?

This research question is related to the development of a simulation model called TAPAS which can be used for transport policy analysis in transport chains. TAPAS is an example of a tool which can be used for transport policy analysis with MABS. Logistical decisions have been modelled in TAPAS and the roles in transport chains are represented as software agents. Simulation experiments of real-world scenarios of transport chains have been performed to illustrate how TAPAS represents the decision making in transport chains. The simulation results, and consequently TAPAS, have been validated through interviews with experts and practitioners. The simulation experiments and their validation have also contributed to the verification of TAPAS. Information of the scenarios has been collected from the organisations which constitute the transport chains we studied. The scenario formulations have been validated in interviews. The validity of TAPAS and the reliability of the simulation results have been discussed in interviews with experts of transport modelling and policy analysis as well as with practitioners in transport chains. Mainly project partners have been interviewed, and the interviews are mainly face-to-face and semi-structured where pre-defined questions were discussed. Moreover, the simulation experiments are analysed by relating our studies to similar studies, as well as with sensitivity analysis, to show the validity of TAPAS.

RQ4. Which types of studies concerning transport policy analysis are relevant to make with MABS?

This research question is rather broad and concerns several issues. We have examined which types of questions can be studied with our simulation model TAPAS. TAPAS is a concrete example of a tool aimed at transport policy analysis with MABS. The possible usage of TAPAS in a real-world context and possible types of users are also related to this research question. Moreover, issues of scenario formulation, validation, and generalisation of simulation experiments are part of the question. These issues are discussed in the thesis.
based on literature and interviews with experts and practitioners in transport chains. Simulation experiments of relevant scenarios of real-world transport chains illustrate the usage of TAPAS and examples of possible analysis of the simulation results are presented.

The main research question is thus addressed through a set of corollary research questions where the usage of MABS is examined. Arguments are presented for the appropriateness of making use of MABS for transport policy analysis as opposed to traditional approaches. The examination of the usage of MABS has mainly been made through the simulation model TAPAS aimed at transport policy analysis with MABS which has been developed in relation to the thesis. The usage of TAPAS has been addressed by presenting different types of questions relevant to study, discussing scenario formulations and issues of validity, as well as bringing up possible users and for which purposes TAPAS can be used. TAPAS and the simulation results have been validated and verified through interviews with experts and practitioners in transport chains as well as through output analysis of the simulation results.

The methods which have been used are thus MABS and modelling, literature analysis, case studies and interviews. The main methods which have been studied and used are MABS and modelling, while literature analysis, case studies, and interviews are supportive methods which have been used to motivate and validate the approach.

1.3 Contributions and outline

The contribution of the thesis is mainly an examination of how MABS can be used for transport policy analysis in transport chains. This relates to the development of a model of roles and logistical decisions in transport chains, the development of a simulation model for transport policy analysis purposes, scenario formulation, dealing with validation and verification issues, performing simulation experiments, analysing questions relevant to study, as well as reviewing simulation models for transport policy analysis.

In Chapter 2, key concepts in the thesis are described such as transport chains and transport policies, as well as the possible effects of transport policies. The characteristics of transport chains are described by explaining what constitutes a transport chain according to current literature and the scope of the thesis. RQ2 is addressed by describing which logistical decisions are made in transport chains according to our scope of transport chains. Common transport policies are described in a structured way, deducing how logistical decisions can potentially be influenced by different types of transport policies. RQ4, concerning which kinds of studies are relevant and interesting to make with TAPAS, is therefore addressed. Chapter 2 also contributes to answering RQ3, since the characteristics of transport policies which need to be captured in a simulation model are described. The effects of transport policies are expressed as transport chain
performance, why the performance of the logistical decision making and the logistical operations in terms of economic, logistics, and environmental performance is described.

A review of freight models for transport policy analysis is presented in Chapter 3, that is, RQ1 is addressed. The review is made according to a review framework covering important characteristics to capture in models for transport policy analysis. In order to capture the effects of transport policies in models, different transport policies and their properties are of course important to represent, as well as different types of effects. Since the effects of transport policies are a consequence of how the logistical operations are performed, and thus how the logistical decision making is performed, a number of logistical decisions important to model are deduced. We conclude that to properly capture the actual effects, detailed decisions which are important to represent, for instance decisions concerning the choice of producer, terminal, and transport operator, as well as planning of transportation, production, and transhipment, should be modelled. The planning concerns the product quantity and the time when the operation should be performed. Moreover, we conclude that it is important to represent transport policy effects in terms of changes in transport demand. RQ2 concerning which logistical decisions should be captured is thus dealt with in Chapter 3.

Traditional macro-level models do not capture all characteristics in the review framework, for instance, not all aspects of planning. However, there is a tendency today to include more detailed logistical decisions to improve the transport policy analysis. Agent-based models have the potential to represent characteristics important for transport policy analysis; for instance, the possibility to model individual entities as agents enables to better capture the actual decision making in transport chains. Agent-based models are further reviewed, for instance, by analysing which of the defined roles in transport chains the models capture. Thus, RQ3 concerning how MABS can represent the decision making in transport chains is also studied in Chapter 3.

In Chapter 4, RQ2 is addressed by presenting a model of the generic roles which we distinguish in transport chains and which responsibilities these roles have, in other words, which logistical decisions are made by the roles. The model captures ordering, choices and planning related to transportation, choices and planning related to product supply, as well as coordination between these functions. This enables the modelling of various constellations of transport chains and to represent roles as software agents. The application of the model to a real-world transport chain shows that the model seems reasonable.

In Chapter 5, a multi-agent-based simulator called TAPAS is presented and motivations are given for why this type of model is appropriate for transport policy analysis, that is, RQ3 is mainly addressed. The logistical decisions included in the model are based on the decisions discussed in Chapter 2, 3, and
4, then the results from RQ2 are used. The roles in transport chains presented in Chapter 2 are represented as decision making agents in the model, where each role captures certain logistical decisions. The decision making agents determine how the logistical operations are simulated. The vehicles, products, etc. are modelled as passive entities. MABS enables us to capture realism due to the ability to represent the decision making and interactions between the roles in transport chains and the consequences of this in terms of the performed logistical operations and its performance. The characteristics of TAPAS are analysed according to the review framework used in Chapter 3. The classification shows that TAPAS captures most of the characteristics important for transport policy analysis, such as detailed logistical decision making, changes in transport demand, etc.

In Chapter 6 the usage of TAPAS is illustrated by presenting two scenarios relevant to transport policy analysis. These scenarios are used for simulation experiments. RQ4 is dealt with by presenting concrete examples of the usage of TAPAS. The two scenarios are formulated based on real-world transport chains and the simulation results are analysed, for instance by comparing the results to similar studies and by sensitivity analysis of input parameters. The simulation experiments and the results have also contributed to the validation and verification of TAPAS. The results have been validated in interviews with experts of transport modelling and policy analysis as well as with practitioners in transport chains. The simulation results in terms of effects of transport policies seem to be reasonable. Based on the simulation results, TAPAS seems to properly model the logistical decision making.

Chapter 7 includes a general discussion of the usage of MABS for transport policy analysis by discussing the general usage of TAPAS, RQ4 is thereby addressed. Questions which are appropriate to study with TAPAS are listed showing what kind of studies TAPAS can deal with. This is compared to questions which are typically studied with traditional macro-level models. The conclusion drawn from this comparison is that TAPAS enables us to answer more types of questions due to the possibility of capturing more transport chain characteristics. Finally, the possible usage of TAPAS is discussed and related to different types of users. Public authorities can, for instance, use TAPAS to complement studies using traditional models. This can improve the accuracy of the simulation results by the inclusion of more logistical aspects. Large companies are another type of user which can use TAPAS to analyse new market segments, such as new product types or new consumers, where historical data is not available.

Moreover, RQ4 concerns important issues to consider when making use of MABS for transport policy analysis. Therefore, issues important to consider when formulating scenarios are discussed in Chapter 7; for instance, measures to take to facilitate validation and generalisation of simulation results. As always, when individual cases are studied (here individual transport chains),
generalisation of the results is important to consider. To deal with this issue, we suggest making use of typical transport chains and roles, characterised by product type and geographical location, representing certain market segments. Another important issue to consider when modelling on the micro-level is the requirement of large amounts of data which can be problematic to collect, due to companies’ reluctance to share key cost components describing their economic situation.

Chapter 8 concludes the work. Possible ways of continuing the research are outlined. An examination of how MABS can be used for transport policy analysis in transport chains is dealt with in the thesis. Therefore, a model of roles and logistical decisions which appear in transport chains has been developed as well as the multi-agent-based simulator TAPAS. The appropriateness of TAPAS for transport policy analysis is analysed and illustrated with simulation experiments. Further, we have dealt with the validity of TAPAS. However, since transport chains can be organised in many ways and have varying characteristics, there is a need to further examine the appropriateness of the usage of TAPAS in more transport chain scenarios. Examples of ways to continue the development of TAPAS are also presented, which mainly relate to validation issues and possibilities to further develop TAPAS.
Chapter 2

Background

The purpose of the thesis is to examine how it is possible to analyse the effects of transport policies. Therefore, we need to have an understanding of how transport policies influence the domain, i.e., transport chains. Transport chains are introduced by describing transport chains and its components, which actors that are involved, which decisions that are taken, etc. After we have introduced transport chains, transport policies are described. Different types of policies are discussed and how transport policies influence the decisions in transport chains. Finally the effects as a consequence of transport policies are described by discussing performance of transport chains as a consequence of the decision making in transport chains.

2.1 The transport chain domain

In its simplest form, we regard a transport chain as the movement of products from a producer node to a customer node. In the producer node there is a factory where some kind of product refinement takes place, such as manufacturing, assembly, mining, etc. It is also possible that there are products in inventories, e.g., in connection to the producer node, or intermediate inventories. A customer node can for instance be a retailer, factory, customer inventory or end-consumer, where the demand in the customer node can be driven by a need to maintain inventory levels, a need for raw material in production or requirements for products from the end-consumer. To transport the products from the producer to the customer node there is a need for transport resources, such as trucks, ships, rail wagons, airplanes, load carriers, etc., and link infrastructure in terms of roads, railways, pipelines, etc. It can also be necessary to make use of node infrastructure such as sea ports, distribution centres, etc.

The single producer-customer relationship is part of a larger transport network where several producer nodes, customer nodes, inventories, link and node infrastructures co-exist. We call this network structure a transport chain when only one step from a production or refinement to another is included. The producer and customer nodes in a transport chain are part of the overall supply chain, where the supply chain includes the whole chain from raw material to end-consumer, i.e., many refinement steps are included. In supply chains the focus is mainly on the refinement processes of the product, while in transport chains the focus is more on the movement of goods.
Traditionally when transport chains are considered, the demand is regarded as a transport demand between a customer node and the producer node. This can be opposed to the demand in supply chains where the demand is a product demand. In our scope of transport chains we consider a product demand, i.e., the transport demand is not predetermined. See Figure 2.1 for the different focuses of supply chains and transport chains.

2.1.1 Characteristics of traffic modes

The logistical operations which take place in transport chains are influenced by many different aspects. For instance, the characteristics of the logistical alternatives have to be considered. Characteristics of different traffic modes, e.g., concerning their cost structures, are important to consider. Rail transportation is for instance typically cost-effective on longer transport distances due to the low variable costs, e.g., due to low energy consumption, especially for electrically powered trains. The fixed costs are instead high (at least in Sweden) due to feeder transport, shunting, terminal handling, planning and administration, etc. (Nelldal et al., 2005). Road transportation has higher variable costs, e.g., due to the fuel consumption, driver costs, tyre cost, and wear cost, but lower fixed costs. When comparing road and rail transportation, rail transportation is typically more competitive than road transportation on longer distances, and road transportation is regarded as more competitive on shorter distances. In studies by Nelldal et al. (2005) it is showed that rail transportation in Sweden is more competitive than 51 tons trucks on distances larger than around 425 km (under the assumption that the transport quality is the same). Waterborne transportation typically has a similar cost structure as rail transportation with low variable costs, and air transportation is a bit similar to road transportation even if both the fixed and the variable costs are rather high (Stock and Lambert, 2001). Pipeline typically has low costs, especially the variable costs. Intermodal transportation is another traffic mode alternative which is the “movement of goods in one and the same loading unit or vehicle that uses successively several modes of transport without handling of the goods themselves in changing modes” according to the definition of The European Conference of Ministers of Transport (2001). Intermodal transportation can, for instance, start with road transportation from the producer node, continue with waterborne or rail transportation, and end with road transportation to the customer. Intermodal transportation typically takes advantage of the low variable costs on longer transport distances of rail or waterborne transportation, but still being more flexible due to the combination with for instance road transportation. However, the coordination of intermodal transportation is normally more complex than uni-modal transportation, for instance it requires more handling of the product as well as interaction with several actors (Woxenius, 1998).
Figure 2.1 Example of a supply chain and its relation to transport chains.
There are thus other important characteristics of traffic modes than cost aspects that need to be considered. Other characteristics are for instance reliability, flexibility, speed, geographical spread, dependence of infrastructure, appropriateness for product types, etc. Typically the more expensive modes are faster, why the time the capital is tied-up for transportation is short, and they also have a better reliability than the traffic modes with lower costs.

In the following section the decision making made by the actors in transport chains concerning how to perform the logistical operations are introduced.

2.1.2 Actors, interactions, and decision types in transport chains

Often when transport chains are described in the literature it is described as having a buyer of the logistics services (e.g., transportation) and a provider of the logistics services (see, e.g., Liedtke et al. (2004). The logistics service buyer sets the prerequisites for the logistics service provider since the buyer decides what to buy. The logistics service provider can for instance be a road haulier or a rail operator, and typically tries to plan its vehicles as efficient as possible while meeting the customer requirement. For instance Lammgård (2007) also includes the (product) customer as an actor in transport chains, but point out that the buyer and the provider are the core actors.

As mentioned above, in supply chains the focus is more on what happens with the product, i.e., the production or refinement steps in the chain. Therefore producing companies, such as manufacturer, retailer, and mining companies are main actors in supply chains together with the customer. In models of the decision making actors in supply chain, hierarchies of actors similar to the logistics service buyer-provider relationship can sometimes be distinguished (see, e.g., Strader et al. (1998)).

In some contexts a coordinator actor is defined as an actor which should have the overall responsibility of the transport or supply chain (Gustafsson, 2008), (Huge Brodin, 2002). Hugo Brodin summarises that the actor which could manage the overall management of the logistics system is the actor that is the most powerful within the system. The importance of power for characterising the transport or supply chain is often pointed out in the literature.

When there is demand for products in a customer node, the actors within the transport chain have to decide how to meet this demand by planning and executing the transportation and production. The actors are part of the decision making process where decisions for instance regarding from which production node the products should be taken, which traffic mode that should be used, whether the vehicle should be loaded with several orders, if products should be transhipped during the transportation, etc. To reach these decisions there is a need for communication and negotiation between the actors since they do not all
have the same information of the product demand, which vehicles that are possible to use, special requirement, etc. This communication is highly dependent upon the relationship between the actors, e.g., in terms of if the relationships are characterised by a high degree of trust and willingness to share information for instance regarding costs, if the relationships are sporadic or continuous, which actor that has the most power, etc. For instance, the relations between the buyer of logistics services and the provider of logistics services can range from deep and multi-year relationships where a single provider is designated, via frequent logistics service buyers having basic agreements based on tariffs with several logistics service providers which they use selectively, to occasional logistics service buyers (Andersson and Norrman, 2002). As an example, according to a study made in 1999 (Henriksson and Persson, 1999) only 26% of Swedish transport buyers had contracted one transport provider, while 53% had three or more contracts.

The decisions taken within transport chains can be described and categorised in several ways. One common way is to describe the decisions according to the time horizon. Strategic decision making typically involves long-term decisions concerning determining what to do, while tactical deals with medium-term issues of setting up an action-list, and operational how to conduct the work set out in more specific terms, i.e., short term issues (Shillo and Vierke, 2000). Operational decisions can also include ad-hoc solutions and disturbance handling during the logistical operations. Examples of strategic decision types can be where to locate distribution centres; tactical decisions can concern deciding which policy to make use of for production and transportation; and operational decisions can involve scheduling of each and every transport and the controlling function of monitoring and ad-hoc planning. However, describing decision making according to the time-horizon can sometimes be imprecise since different persons have different ideas of which decisions are represented in the different decision types.

McKinnon and Woodburn (1993) present four hierarchies of decision making, which are connected to the time perspective. The first level is connected to the logistical structure, i.e., the node infrastructure and resources (factories, terminals, etc.), the second level is connected to the pattern of the trading links, the third level is connected to the planning of transportation, and the fourth level is connected to the allocation of vehicles to transport tasks. The first two levels concern mainly long-term decisions, while the latter levels concern decisions in a shorter time-horizon, thus the higher levels narrow the scope for how it is possible to make the decisions at the lower levels. The largest changes of the number of ton kilometres, i.e., the amount of goods transported in tons times the transport distance in kilometres, can be achieved at the higher decision levels, why these levels are important to consider. The third and fourth levels mainly influence the number of vehicle kilometres, i.e., the transport distance in kilometre for vehicles.
The decisions made within our extended scope of transport chains are ordering, choices, and planning. The ordering decisions concern *product* and *transport ordering* and concerns when and how much to order. The choice (or selection) decisions concern choosing which infrastructure and resources to use. This concern the *production node choice* and *inventory choice* which are made in order to choose from where the requested products should be supplied from, i.e., if the products should be produced or taken from inventories. The *vehicle type choice* concerns which vehicle type that is used to transport the products from the producer node or inventory to the customer. This also includes resources related to the usage of the vehicle, such as load carriers and personnel. The *route choice* concerns which route that is used to transport the products with the vehicle to the customer. The route choice therefore includes the links that are used and potentially also which terminals that are passed. When the choices are made, there is a need for planning how to perform the logistical operations in an efficient way by considering time and product quantities, and taking into account restrictions of the infrastructure and resources. The *production planning* concerns deciding how much to produce and when to produce it. The *inventory planning* concerns deciding how much products to replenish and when to do it. *Transport planning* concerns deciding the consignment size, possibly coordinated with other consignments, and when to transport, potentially based on existing timetables. *Terminal planning* concerns deciding the transhipment quantity and when to tranship the products. These types of decisions are further discussed in Chapter 4.

### 2.2 Transport policies

Transportation of freight and people is a vital component for the society we are living in. It generates economic growth and welfare which the society wants to encourage. At the same time, the society has a wish to reduce the negative effects of transportation, such as environmental impact. Transport policies, such as taxes, fees, and regulations of transportation, are a means to encourage, guide, control or force the members of the society towards certain goals. Transport policies can exist at different levels, for instance at a global, national, regional or local level. An example of such policies is a global regulation of emission standards in vehicles, a national tax for using all road infrastructure in a country, or restriction for which time of the day it is possible to drive heavy trucks in a city. In this section we mainly focus on transport policies concerning governmental goals regarding *environmental targets* on a national level, but policies, or measures, which are of interest for only parts of the society, such as a region or a transport chain, are also relevant, but not further addressed in this section.

Well-implemented policies should signal what is the best alternative. According to, for instance Engström et al. (2001) and Delucchi (2003), efficient transport policies should be directly coupled to the activity that they are supposed to
influence. Whitelegg (1993) claims that the best alternative for public authorities should be the most profitable (e.g., in monetary terms) for the transport chain actors, as well as the alternative with minimum environmental impact. However, it is difficult to achieve such precise transport policies and the actual effects of transport policies are difficult to predict (Rodrique et al., 2001).

So far transport policies within the EU have mainly aimed at technology improvements through emission standards, etc. (EEA, 2004; Blinge and Lumsden, 1993), which have decreased the harmful air pollutant emissions (EEA, 2008) such as sulphur dioxide, nitrogen oxide, etc. However, due to increased transport demand, the greenhouse gas emissions from transportation has not been reduced as much as the society as a whole according to the planned pace to reach the environmental targets of year 2020 (EEA, 2008).

One typical governmental goal, for instance within the EU, is the wish to include the external costs of transportation into fees and taxes. Today the external costs are not fully internalised, at least not in the EU (European Commission, 2001; ECMT, 1998), which is particularly apparent for road transportation, and especially for heavy road transportation (Friberg et al., 2007a; Hesselborn and Swahn, 1998). To internalise the external costs, the marginal cost principle is often applied, which implies that for each added entity, for instance vehicle kilometre, the costs for this extra entity should be included in the transport price. Transport policies which for instance depend on the number of vehicle kilometres are appropriate when applying the marginal cost principle since they depend on the amount of transport. If the marginal cost principle is perfectly implemented, it will make the transport market fair, i.e., the actual costs for transportation are paid, according to ECMT (1998). Since the behaviour of transport chain actors is influenced by the costs the actors experience, the decisions taken by the actors will probably change if the external costs are internalised into fees and taxes. Therefore, when deciding upon transport policies, the economic perspective of the actors in the transport chain has to be taken into account so that the preferable behaviour of the transport chain actors actually is encouraged by the transport policies.

The purpose of this section is to describe relevant transport policies aimed at governmental goals concerning environmental targets which may have an impact on the behaviour of the transport chain actors. Furthermore, the relations between transport policies and decisions in transport chains are examined.

2.2.1 Description of relevant transport policies

Governments have different goals which they want to achieve, for instance they typically want to reduce the environmental impact from transportation. We consider emissions, congestion, noise, land use, and accidents as environmental effects. Another consequence of transportation which governments typically want to decrease is infrastructure wear, mainly due to the high costs related to
this. There are also positive effects from transportation which governments want to increase with transport policies, such as accessibility of different geographical areas. These are the main goals directly related to transportation which we consider. The marginal cost principle is another governmental goal as mentioned above which is related to the external effects since it is the costs for the external effects that should be internalised. We regard the marginal cost principle as part of the goals of the external effects. Another wish of governments is to ensure tax income. The value added tax is a tax which is typically aimed for this goal, however, the other transport policies we consider here do not have tax income as it primary goal, why we choose not to deal with it further. The tax is equal for all actors in the transport chain, i.e., the tax is neutral for the actors in the transport chain. Also, we are mainly interested in policies which aim at influencing the transport chain actors in a certain direction.

There are several types of transport policies which public authorities use depending on which goal they want to reach and how they want to influence the behaviour of transport chain actors. The major types of transport policies we consider are regulatory transport policies and economic transport policies. Regulatory transport policies are laws and regulations, such as regulations of speed and vehicle sizes. The regulatory transport policies are set up to concretise goals specified by the public authorities, and the actors are forced to act in a certain way. Economic transport policies are for instance different kinds of taxes, fees, subsidies, subventions or other kinds of monetary tools to reach a specific goal. We see infrastructure investments as a type of subvention since public authorities choose to support certain investments. For instance, public authorities can support investment of infrastructure of traffic modes with less environmental impact than other modes1.

Traditionally, taxes are used as income to the state, but they can also be used as incentives toward certain governmental goals. We are mainly interested in the latter type. Characteristic for economic transport policies is that they give incentives to the actors to act in support of goals specified by the public authorities, i.e., they are free to act how they want, but there is a monetary advantage to act in accordance of the governmental goals. Furthermore, information and education can also be seen as transport policies. They are important, especially to reach an understanding in the society of the purpose of the transport policies when the policies are implemented (Wandén, 1997). However, information and education are outside the scope of this work.

---

1 Private companies may also be interested in investing in infrastructures, e.g., an industry track to a factory. However, we are mainly interested in public policies.
**Figure 2.1.** Overview of how Table 2.1 and Table 2.2 are organised. Transport policies are divided into policies which are regulatory (Table 2.1) and policies which are economic (Table 2.2). The regulatory and economic transport policies can concern the usage or ownership of different types of resources and infrastructure. Economic transport policies can also directly concern infrastructure.

Even if transport policies are divided into economic and regulatory transport policies, there are no clear bounds between them. Regulatory policies define the limits for economic transport policies, for instance by legislation. Economic transport policies are therefore tightly bound to regulatory policies. Also, regulatory transport policies can lead to fees for those that do not follow the regulations (Wandén, 1997).

In Table 2.1 and Table 2.2 we list different kinds of transport policies which are economic and regulatory respectively in the context of freight transportation. The focus is mainly on transport policies within the EU countries; however, the types of transport policies also exist in other countries. The transport policies are further divided into usage or ownership of resources. A tax or fee can also be described as variable or fixed. Normally the fixed taxes and fees are the long-term costs that only change rarely, whereas variable taxes and fees change more frequently (Button, 1993). A fixed tax or fee corresponds to a tax or fee for owning a resource which is ready to be used. A variable tax or fee correspond to a tax or fee for using the resource and depends on how it is used. Transport
policies are also grouped according if the transport policy concerns resources or infrastructure. Resources we consider are mainly vehicles and its related resources such as load carriers, personnel, and fuel. However, policies which concern production resources, such as factories, and inventories also influence transport chains. Infrastructure can be link infrastructure such as roads and railways, and terminals (node infrastructure) such as ports and distribution centres. See Figure 2.1 for an illustration of the division of transport policy types. The transport policies are further described under transport policy and goal. We describe the goals of transport policies as reducing infrastructure wear (infra), emissions (emission), congestion (congest), noise (noise), and accidents (accidents), and increase and maintenance of accessibility (access). An example is tax income to governments. If the transport policy is a tax or a fee, we describe the basis, which is the property that determines the size of the tax or fee. The basis depends on how the transport policy is implemented; therefore the cost basis mainly serves as giving examples of possible cost bases. The traffic mode that the transport policy concern is also indicated in the tables (the waterborne mode is denoted sea in the tables), and when necessary the transport policies are commented to further describe the transport policy. Table 2.2 is partly based on tables in Engström et al. (2001) where economic transport policies in Sweden are described.

<table>
<thead>
<tr>
<th>Transport policy</th>
<th>Usage/ownership</th>
<th>Resource/Infrastr.</th>
<th>Goal</th>
<th>Mode</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Design requirements of vehicles</td>
<td>Ownership</td>
<td>Vehicles</td>
<td>Infrastructure wear, safety, emission</td>
<td>All</td>
<td>Coupled to emission and noise requirements since new vehicles have to fulfil these requirements.</td>
</tr>
<tr>
<td>Emission and noise requirements</td>
<td>Ownership</td>
<td>Vehicles</td>
<td>Emission, noise</td>
<td>Road, air, sea</td>
<td></td>
</tr>
<tr>
<td>Speed limits</td>
<td>Usage</td>
<td>Link infra.</td>
<td>Accidents, noise, emission</td>
<td>Road, rail</td>
<td>Speed limits can depend on the size of the vehicle.</td>
</tr>
<tr>
<td>Restrictions or bans of transport</td>
<td>Usage</td>
<td>Link infra.</td>
<td>Emission, congestion, noise</td>
<td>Road, air, rail</td>
<td>In certain areas (towns, countries, etc.) there are restrictions of transport volumes, certain vehicle types etc.</td>
</tr>
<tr>
<td>Fuel requirements</td>
<td>Ownership</td>
<td>Fuel</td>
<td>Emission</td>
<td>All</td>
<td></td>
</tr>
</tbody>
</table>

Table 2.1. Regulatory transport policies.
<table>
<thead>
<tr>
<th><strong>Transport policy</strong></th>
<th><strong>Usage/owner</strong></th>
<th><strong>Resource/Infrastr</strong></th>
<th><strong>Goal</strong></th>
<th><strong>Basis</strong></th>
<th><strong>Mode</strong></th>
<th><strong>Comments</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Vehicle tax</td>
<td>Owner</td>
<td>Vehicles</td>
<td>Infra, emission</td>
<td>Weight, fuel type, emission class</td>
<td>Road</td>
<td>Differentiated in, e.g., in Sweden and Germany.</td>
</tr>
<tr>
<td>Sale tax for vehicles</td>
<td>Owner</td>
<td>Vehicles</td>
<td>Emission</td>
<td>Emission class</td>
<td>Road</td>
<td>Sometimes differentiated, e.g., Sweden.</td>
</tr>
<tr>
<td>Scrappage fee and premium</td>
<td>Owner</td>
<td>Vehicles</td>
<td>Emission</td>
<td>Same fee for all trucks.</td>
<td>Road</td>
<td></td>
</tr>
<tr>
<td>Vignette</td>
<td>Usage</td>
<td>Link infra.</td>
<td>Infra, emission</td>
<td>Emission class, no. of axles</td>
<td>Road</td>
<td>A (often) yearly road fee to use the vignette road network, e.g., the Eurovignette.</td>
</tr>
<tr>
<td>Congest. fees</td>
<td>Usage</td>
<td>Link infra.</td>
<td>Congest, infra</td>
<td>Time of day</td>
<td>Road</td>
<td>Used in London and Oslo etc.</td>
</tr>
<tr>
<td>Tolls</td>
<td>Usage</td>
<td>Link infra.</td>
<td>Infra</td>
<td>Vehicle size, special transport</td>
<td>Road, rail</td>
<td>Tolls for the usage of certain motorways, tunnels or bridges.</td>
</tr>
<tr>
<td>Kilometre tax</td>
<td>Usage</td>
<td>Link infra.</td>
<td>Infra, congest, emission</td>
<td>Emission class, driven km, time of day, location</td>
<td>Road</td>
<td>Exist today in, e.g., Germany, Austria and Switzerland.</td>
</tr>
<tr>
<td>Track fee</td>
<td>Usage</td>
<td>Link infra.</td>
<td>Infra, accident, emission</td>
<td>Energy source, per net ton km</td>
<td>Rail</td>
<td>Sometimes differentiated, e.g., in Sweden.</td>
</tr>
<tr>
<td>Sea port and airport fees</td>
<td>Usage</td>
<td>Node infra.</td>
<td>Infra, accident, noise, emission</td>
<td>Gross tonnage, goods, emissions, safety, ship properties, noise</td>
<td>Sea, air</td>
<td>Sometimes differentiated, e.g., oil tankers can get a discount if the ship has double hull or double bottom, e.g., in the port of Stockholm.</td>
</tr>
<tr>
<td>Fuel tax</td>
<td>Usage</td>
<td>Fuel</td>
<td>Emission</td>
<td>Fuel properties, fuel type</td>
<td>Road</td>
<td>In some countries fuels that have a high environmental performance do not pay fuel tax, e.g., in Sweden.</td>
</tr>
<tr>
<td>Maintain. of infra.</td>
<td>Owner</td>
<td>Link and node infra.</td>
<td>Access, environ</td>
<td></td>
<td>All</td>
<td></td>
</tr>
<tr>
<td>Infra. invest</td>
<td>Owner</td>
<td>Link and node infra.</td>
<td>Access, environ</td>
<td></td>
<td>All</td>
<td></td>
</tr>
</tbody>
</table>

Table 2.2. Economic transport policies.

The purpose with Table 2.1 and Table 2.2 is not to completely cover all different types of existing transport policies, but to give an overview of common transport policy types which exist today, and exemplify how they can be implemented. There exist some surveys of existing transport policies in Europe in the context...
Design requirements of vehicles can for instance be length regulations, maximum load restrictions, etc. The goals with design requirements are often to reduce the environmental impact, infrastructure wear, and the risk of accidents. Larger vehicles imply that more freight can be loaded on the vehicles, which can lead to fewer vehicle kilometres per transported freight (McKinnon, 1998). However, larger and heavier trucks can also imply a higher impact on the environment and a higher risk for accidents, and larger trucks can also increase the competitiveness of road transportation in relation to for instance rail transportation for certain product segments, which potentially can cause more environmental impact. Another issue is that different vehicle restrictions in different countries can make it more difficult to plan transportation efficiently. As an example, in Sweden and Finland trucks with a capacity of maximum 60 tons (and a maximum length of 25,25 metres) are allowed, while in Norway and Denmark the restriction is 50 tons, and in the rest of Europe 40 tons (and a maximum length of 18,75 metres) (European Commission, 1996). Therefore, if a 60 tons truck is fully loaded in Sweden, the truck cannot drive fully loaded in for instance Norway.

Restrictions and bans of transportation can imply that certain types of trucks are banned from cities, for instance in some larger cities in Sweden. It can also imply that air transportation is forbidden over certain areas during nights. Another example is resting time regulations of truck drivers which have an important influence on how it is possible to perform road transportation. For instance, certain routes are less attractive for certain road operators if it implies that the time limit for driving without resting is just reached. It is also possible that the route choice depends on the resting times, which might make the resource usage less efficient.

Since an effective transport policy should be closely coupled to the actual environmental impact, as well as where the impact takes place, it is desirable to have a transport policy which affects the length and location of the transport (Engström et al., 2001). Such transport policies are for instance economic policies of the usage of resources and infrastructure. As an example, the kilometre taxation has a potential to have a positive impact on the environment since it influences the number of vehicle kilometres, i.e., the variable costs. Kilometre taxation gives incentives to reduce the number of vehicle kilometres, i.e., to increase the vehicle utilisation, and in some cases also supports a modal shift. If the cost for transporting goods on the road is too high, other traffic modes such as rail transportation might be considered. Kilometre taxation has for instance been introduced in Switzerland, Austria, the Czech Republic, and Germany in various settings. In Switzerland the kilometre taxation affects all roads and depends on weight, emission class of the vehicle and vehicle kilometres, and the fee is coupled to the external costs. In Germany only the
motorways are taxed, and the tax depends on the number of axles, the emission class of the vehicle and vehicle kilometres. Other countries within the EU are also considering introducing kilometre taxation, such as Sweden (see, e.g., Liechti and Renshaw (2007)).

Another type of road fee that is used in Europe is vignettes, for instance the Eurovignette. The Eurovignette is a yearly fee for heavy trucks (i.e., trucks with a total weight of at least 12 tons) in Sweden, Denmark, Belgium, Luxemburg and the Netherlands for using the Eurovignette roads. The Eurovignette fee is differentiated on the number of axles and the emission class.

Taxes and fees sometimes interrelate. As an example, currently in Sweden the fuel tax (i.e., the tax on energy) on diesel is lower than on petrol, but the tax for diesel vehicles is higher, which means that there is an incentive it to use diesel vehicles if the vehicle is used a lot.

Infrastructure investments concern transport link infrastructure (railways, roads, and pipelines) and terminals (ports, distribution centres, etc.). Public authorities can use infrastructure investments to encourage certain transport alternatives, such as rail transportation, by improving rail infrastructure so that the competitiveness of rail transportation is improved. The most common purpose of infrastructure investments is to maintain a sufficiently good transport infrastructure which supports the transport demand. When public authorities consider investing in transport infrastructure, a trade-off between the costs for the infrastructure and the benefits (e.g., better accessibility) has to be considered, i.e., a cost benefit analysis is usually made. Infrastructure investments can have diverging goals, e.g., the public authorities want the new infrastructure to be used (i.e., increase the traffic), while they at the same time want to decrease the environmental impact from transportation. For instance Jonsson and Johansson (2003) claim that infrastructure investments contribute to increased road transportation volumes, which in turn cause increased negative environmental effects. Infrastructure investments are sometimes initiated by private actors, for instance investing in an industry track.

The actual consequences of transport policies vary. Current implementations of transport policies whose goal is to reduce the environmental impact, affect the environment in a positive direction, but the effect is seen as small (Engström et al., 2001). For instance, the effect of fuel taxes is seen as small since the transport price sensitivity is fairly low (Engström et al., 2001; Bleijenberg, 1998). The transport price has to increase with the double to have an effect, according to some studies (McKinnon, 1998). There are different opinions on how transport policies should be implemented to be efficient. Some claim that transport policies which encourage a shift to techniques with a better environmental performance are most probable to have an effect (Hesselborn and Swahn, 1998). Others claim that transport policies that encourage a modal split,
for instance kilometre taxation, would have an influence in the direction of the transport policy goal (Johansson et al., 2003).

2.2.2 Influence of transport policies on decisions

As mentioned in the beginning of Section 2.2 the societal goals with transport policies often concern reducing negative impact of transportation (such as environmental impact and infrastructure wear) and to internalise the external costs. Moreover, public authorities also want to ensure a tax income with fiscal policies. How well the societal goals are achieved depends on how the actors in transport chains are influenced and consequently change their decision making, which results in the logistical operations. Therefore it is important to capture the changed decision making of transport chain actors as a consequence of transport policies. In this section we examine how the transport policies discussed in the previous section potentially influence the decisions in transport chains brought up in Section 2.1.2. When the decisions in transport chains are influenced, all related decisions are indirectly affected in some way; however, we focus on the main direct influence.

Transport policies can influence both the choices of infrastructure and resources as well as the planning of how to make use of the resources. The choices are mainly influenced when the characteristics of the possible alternative to choose among have been changed due to influence on the available resources or infrastructure. As an example, if vehicle regulations concerning for instance the vehicle capacities have been introduced, the vehicle choice will be influenced since the set of vehicles that now is possible to choose has changed. The planning is mainly influenced by economic incentives to increase the resource utilisation or to use the infrastructure at a specific time of the day.

Regulation of infrastructure

Regulation of infrastructure influences for instance the route choice since there may be restrictions on when it is possible to make use of the infrastructure. For instance it may not be possible to meet the customer demand due to time restrictions if a certain route is chosen.

It can also influence the planning of the usage of the infrastructure since there for instance may be a need to start the transport earlier if for instance the speed limits have been set lower.

Regulation of resources

Regulation of resources influences the investment of resources, and therefore the vehicle choice is influenced since the set of resources which are possible to make use of is influenced. This type of regulation also has the potential to influence the choice of producer node and inventory.
When the resource characteristics are regulated it is possible that this also will influence the transport, production, and inventory planning, for instance with how much freight it is possible to load on the vehicles.

**Taxes/fees of infrastructure**

Taxes or fees on the infrastructure mainly concern the usage of the infrastructure and is therefore mainly connected to the planning. Such taxes and fees can influence in many different ways, for instance incentives can be given to encourage which time of the day the transport is performed on the link or node infrastructure. Also, due to the higher cost of transportation incentives are given to make use of the vehicles more efficiently.

Taxes or fees on the infrastructure can also be differentiated depending on for instance the resource characteristics, e.g., the truck size, why it also is possible that the choice of the resources, e.g., vehicle choice, is influenced by the taxes or fees. The route can also be influenced by taxes and fees which are differentiated on different parts of the infrastructure. Also, if there is a considerable increase of the transport costs for the actors in transport chains, e.g., in terms of road charges, it is possible that a production node or an inventory closer to the customer is chosen to decrease the transport distance. This influence has been observed in the opposite direction where low transport costs in relation to the production costs have given incentives to many companies to make use of production nodes with lower production costs despite a long transport distance.

**Taxes/fees of resources**

Taxes and fees of resources can influence the choice of which resources that are used since it is possible that investments of for instance vehicles can be influenced as a consequence of a vehicle tax which is higher for a specific vehicle type. Such taxes or fees can also influence in the shorter term, for instance influencing the choice of fuel due to a higher fuel tax. Following the same reasoning as above, if the transport costs increase considerably, for instance, due to higher fuel taxes, producer nodes or inventories which are located closer to the customer might be chosen.

Taxes and fees of resources give incentives to make use of, e.g., vehicles more efficiently by more efficient transport planning. Better vehicle utilisation is for instance encouraged. Moreover, the transport planning is indirectly influenced by the taxes/fees if another type of vehicle is chosen due to the policy.

**Subvention of infrastructure**

Subventions of infrastructure, such as infrastructure investments, influence the choice of routes and terminals since new infrastructure is possible to choose or since the characteristics of the infrastructure that is appropriate to choose is changed.
It is also possible that investments or maintenance of infrastructure can shorten the times on the link infrastructure or in terminals, why the overall transport times can be shortened. If the time savings are considerable it may also result in revised timetables due to the possibility to, e.g., depart and arrive earlier, why the time of the production, transportation, replenishment, and terminal planning is influenced.

<table>
<thead>
<tr>
<th>Decision</th>
<th>Regulation of infrastructure</th>
<th>Regulation of resources</th>
<th>Tax/fee of infrastructure</th>
<th>Tax/fee of resources</th>
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<td>Production node choice</td>
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<td>Route choice</td>
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<td>Production planning</td>
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<td>Terminal planning</td>
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<td>Inventory planning</td>
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</table>

Table 2.3. Overview of which decisions transport policies potentially can influence.

The main influence transport policies can have on decisions in transport chains is illustrated in Table 2.3. The purpose of the table is to summarise the relationships between transport policies and decisions in transport chains and to give suggestions of relations to further study and verify.

2.2.3 Examples of transport policies to further study

Some examples of transport policies which we find interesting to further study and which also currently are discussed by public policy makers are listed here:

- **Kilometre taxation** is a variable tax which has the potential to be closely coupled to the actual impact of the transport. It has already been implemented in several countries, and there are discussions to introduce the tax in several European countries. For instance, it is interesting to study for which levels of the tax it is possible that there will be a modal split from road transportation to for instance rail transportation. The price sensitivity of transportation can then be studied. Moreover, the effects of different types of differentiations of a kilometre tax could be
studied, such as a differentiation between rural and urban areas and between week days and weekends.

- **Combination of transport policies.** The correlation between different types of economic transport policies, e.g., combinations of fixed and variable taxes or fees, is interesting to further study. As an example, the implementation of a kilometre tax in Sweden is discussed as well as possible adjustments of other taxes or fees to reach the goal of the marginal cost principle. To not impose too much taxes and fees, a suggestion is to reduce the vehicle tax and abolish the Eurovignette (Ministry of Finance, 2004).

- **Road tolls or congestion fees** also have a potential to influence several choices and types of planning in transport chains. Both transportation of people and freight are often influenced. The fees exist in several countries in various settings, and several cities also consider introducing congestion fees, for instance Stockholm.

- The levels of **fuel taxes** are relevant to study in order to investigate how sensitive transport operators are to increased fuel taxes. Several researches (McKinnon, 1995; Engström et al. 2001), state that the transport price is not very price elastic. However, Brand et al. (2002) have showed with the STEEDS model that a higher fuel tax appears to be effective to slow down the increase of carbon dioxide emissions from transportation. This and the price elasticity for different businesses are relevant to further study.

- Today there is a **tax exemption of aviation and shipping fuel** since the air and waterborne transportation is highly international. It is be interesting to study what the effects would be if this exemption is taken away.

- **Design requirements on vehicles** influence the possibility to utilise the vehicle fleet. Studies have been performed on the effect of an increase in the maximum weight of trucks (McKinnon, 2005) and it is interesting to compare the results. It is possible that the design requirements within the EU will be harmonised to have the same requirements in the whole EU.

- **Cabotage.** It is interesting to study what the effects would be in for instance the EU if the regulations for cabotage are changed, for instance to remove the trade restrictions.

### 2.3 Performance

The purpose of the thesis is to examine how it is possible to model the effects of transport policies. Therefore we want to describe the effects which are the consequences of transportation, which in turn are a consequence of the decision making in transport chains. The effects are on both the societal level and on the company level, why both types of effects are discussed. To capture the effects of
transport policies, we describe different types of performances of the logistical operations in transport chains in this section.

The performance of a logistical solution can be expressed in several ways. Mentzer and Konrad (1991) define performance as:

“In essence, performance measurement is an analysis of both effectiveness and efficiency in accomplishing a given task. All evaluation is in relation to how well a goal is met.”

Different types of performance measurements are relevant for different purposes. The most common means to reach efficiency include cutting costs and increase incomes (Mentzer and Konrad, 1991; Meidem, 1995). According to Meidem (1995) the most important factors influencing the logistics performance are delivery service and logistics costs (concerning warehousing and transport). Delivery service can for instance be lead-time and on-time delivery (Forslund, 2007). These types of performances are mainly of interest for the companies in transport chains since they wish to maximise their profit, while meeting the customer requirements. Public authorities are often interested in the environmental performance of transportation since they typically wish that the impact from transportation is reduced, but companies also have an interest in having a low environmental impact.

In this section different types of performances are described. We divide the performances into environmental performance, economic performance, and logistics performance.

2.3.1 Economic performance

When economic performance is considered we divide it into economic performance of interest for the public authorities and economic performance of interest for companies. Public authorities have several societal goals which they strive towards, for instance welfare, little environmental impact to reach a sustainable society, as well as a sustainable business climate. The public authorities can make use of transport policies, e.g., taxes and fees, to give incentives to the actors in transport chains in which direction the public authorities wish the actors to act. The income to the public authorities from the taxes and fees is also used to reach societal goals, for instance to finance new transport infrastructure. The environmental effects from transportation are discussed in the previous section, and from a societal perspective these effects causes costs, for instance human health related costs. External, or indirect, costs denote costs which are not directly coupled to the costs for the transport chain actors, but which appear as a consequence of transportation since it causes different kinds of costs for the society. There exist several types of external costs, for instance infrastructure costs (wear and deformation costs), congestion costs, emission costs, noise costs and accident costs (European Commission, 2001). Today a common view is that the external costs of transportation should
be internalised, i.e., included in the price for transport (European Commission, 2001). Internalising the external costs implies that the one that causes the negative external costs also has to pay for it, normally this is done with taxes and fees. The external costs have to be valued and an economic valuation is always a judgment. Different persons value the environmental impact differently, as an example some claim that particles are the most severe environmental problem, while others claim that the carbon dioxide is the most important problem. Some researchers even claim that environmental evaluations can not be done without the participation of politicians when there are value conflicts (Richardson, 2003).

Valuations of the external costs are sometimes used when the effects of transport policies are evaluated (Estreen and Hesselborn, 2005). There are several methods for estimating these external costs, such as:

- ExternE (Bickel et al., 1997), which estimates the external costs resulting from the supply and use of energy, i.e., air pollution;
- UNITE (Bossche et al., 2000), which estimates the external costs of infrastructure costs, supplier operating costs, transport user costs, accident costs, noise costs, and air pollution costs; and
- ASEK (Friberg et al., 2008), which estimates the external costs of accidents, emissions, carbon dioxide, and noise among other things, to be used for socio-economic calculations of both transportation of freight and people.

According to Estreen and Hesselborn (2005), a consensus within the EU is going towards the usage of ExternE for valuations of emissions to air. Typically, when estimating the environmental external costs, the amount of the externality, in this context the negative environmental effect, for instance in terms of emissions, is first measured. Then the environmental impact of the externality is evaluated, such as the human health effects of such amounts, and finally the environmental impact is valued in monetary terms. One important result of these estimations is the external costs in relation to vehicle kilometres. Since the methods of estimation differ, the result of the estimates may vary (Estreen and Hesselborn, 2005).

Internal costs are costs which are paid by the actors in transport chains, and as discussed earlier in this section the costs can be described as fixed and variable costs. In this context, fixed costs are for instance costs associated to owning a vehicle, while the variable costs are connected to the usage of resources. We assume that the actors in transport chains are driven by the desire to increase profit, i.e., to reduce costs and to increase income (Drewes Nielsen et al., 2003).
2.3.2 Logistics performance

The logistics performance occurs as a consequence of the performed transportation and production. Such performances are for instance quality performance, resource and infrastructure utilisation, and transport efficiency. The quality performance mainly concerns effectiveness, i.e., how well the task has been accomplished in relation to the goal, and can for instance be punctuality, keeping lead-times, and maintaining inventory levels (i.e., avoiding stock-outs). When the performance of transport chains is discussed, quality aspects are always implicitly included in the concept. If the customer demand is not satisfied, good environmental and economic performance become meaningless. Therefore, maintaining a sufficiently high quality performance is important. The product quality is crucial in transport chains. As an example, some products require relatively fast transport directly after they have been produced since they are perishables. Some product types also require handling at certain temperatures and some are sensitive to shock. Furthermore, the reliability of the time of delivery is often crucial for the customers, e.g., to be able to plan the proceeding product handling.

Resource and infrastructure utilisation is mainly a measure for efficiency, i.e., how well the transport and production resources are used in terms of space, time, weight, etc. in relation to the goal, and how well infrastructure such as terminals and link infrastructure is used. For instance, it is possible to have high vehicle utilisation if load consolidation or backloading are used, and flexible customer requirements and cooperation between the transport chain actors can also facilitate the planning of the transport and production which can cause more efficient usage of the vehicles (see, e.g., Blinge and Lumsden (1993).

A common way to capture the amount of transportation is to measure the ton kilometres, or the transport work, i.e., the amount of goods transported times the transport distance. The transport work does not by itself describe the performance of transportation well since the concept is imprecise. A short distance shipment can for instance show the same results in ton kilometres as a lightly loaded, long distance one. Therefore, the measure traffic work, or vehicle kilometres, i.e., the transport distance for one vehicle, is often used in relation to the transport work. The ratio between transport work and traffic work is called transport efficiency (Drewes Nielsen et al., 2003).

2.3.3 Environmental performance

Most often when environmental impact from transportation is considered, impact on the nature is considered, for instance impact from emissions (carbon dioxide, sulphur dioxide, etc.) which are claimed to be very likely to cause climate changes such as global warming (Bernstein et al., 2007), acidification, eutrophication and human health problems (Elvingson, 2001). The actual impact depends on if the emissions occur in the atmosphere or in the water, and for
instance where in the atmosphere the emissions occur. Moreover, the impact can be global, regional, and local. Another type of impact on the environment is land use which for instance causes land barriers.

The environmental impact of transportation depends on many aspects, such as the energy source (e.g., oil, biomass), the energy carrier (e.g., diesel, ethanol, and electricity), the traffic mode, and the vehicle and engine type. Moreover, the driving style, topography, weather, speed, if the transport takes place in a rural or urban area, etc. influence the environmental impact.

Since a societal perspective mainly is taken in the thesis, we have a rather broad perspective of what is included in the environment. We also include the human society we all are living in as the environment, why effects such as congestion, noise, and accidents which to a large extent influence humans also are considered. The environmental impact is in many cases linear, for instance in terms of amount of emissions or road wear as a consequence of transportation. However, there is also non-linear impact such as congestion.

Since the actual environmental impact is difficult to distinguish due to complex relations in the nature and society (Bernstein et al., 2007), the environmental impact is often expressed in measurable indicators describing the environmental performance of transportation. Such performance measures can for instance be gram emission per vehicle kilometre, kWh energy per vehicle kilometre, etc. The Swedish Network for Transport and Environment (NTM) has developed methods to calculate the energy usage and emissions to the atmosphere from transportation in Sweden (see http://www.ntm.a.se/), and there is also work-in-progress to also include international transportation in the calculation methods. There exist other methods for calculating the environmental performance of international transport chains, such as studies from Denmark (Danish Ministry of the Environment, 2002; Danish Ministry of Transport, 2000).

There are different ways to improve the environmental performance of transport chains. McKinnon (2003) points out three ways to reduce the environmental impact.

1. reduction of the total number of ton kilometres
2. reduction of the total number of vehicle kilometres on the roads, i.e., a modal split to traffic modes with better environmental performance
3. reduction of the number of vehicle kilometres, i.e., increase the vehicle utilisation

Reduction of the total number of ton kilometres is connected to transport efficiency as discussed previously. It can be reduced by restructuring the logistical structure, such as changes of which inventory facility or factory that is used (McKinnon and Woodburn, 1993).
According to, e.g., McKinnon (2003) and Backman (1997), a large-scale modal split from road to traffic modes with a better environmental performance is not very realistic since only some goods volumes have the prerequisites to change mode. Traffic modes have characteristics that are appropriate for certain types of products, e.g., road transportation is typically a flexible alternative that is appropriate on shorter distances and for products that require high reliability. There is a wish within the EU to transfer volumes from road to rail and waterborne transportation in order to reduce the environmental impact of road transportation (European Commission, 2001). A modal shift from pure road transportation to intermodal transportation where the main distance is rail or waterborne transportation, also normally reduces the environmental impact (Lammgård, 2007).

Measures to increase the vehicle utilisation can lead to improved environmental performance of a transport chain (Blinge and Lumsden, 1993). However Rodrigue et al. (2001), among others, claim that higher vehicle utilisation does not always lead to an increased environmental performance. For instance, centralisation which often leads to reduced costs and higher vehicle utilisation often increases the environmental impact due to longer transport distances (Wu and Dunn, 1995; Rodrigue et al., 2001).

As discussed in Section 2.2, public authorities often have a wish to reduce the environmental impact. Many companies also wish to reduce its environmental impact (Björklund, 2005; Lammgård, 2007). Companies can for instance be competitive if they choose to have a more “green” image (Welford, 1998). Some companies want their suppliers to show that they work actively with reductions of the environmental impact (Welford, 1998). They might therefore prefer suppliers or transport operators which take environmental aspects into consideration when choosing whom to contract. Sometimes there is also a correlation between cost-effective actions and good environmental performance. For instance, rail transportation is cost-efficient on longer distances (Nelldal et al., 2005) and it also has a low energy usage compared to other modes, as discussed in Section 2.1.1.

2.3.5 Aspects of performance trade-offs

There are many situations where performance improvements, e.g., environmental performance, lead to better performance of another types of performances, such as economic performance. However, sometimes good environmental, economic and logistics performance does not coincide. For instance, if there is a wish in a transport chain to have a very high quality performance, the costs for the transport chain actors are often higher than if the quality performance is not as high.

Since the importance of the three performance aspects discussed above is valued differently by different actors, a trade-off is needed to maintain a sufficiently
good performance for all three performance aspects. To facilitate the trade-off between economic and environmental performance, the environmental performance can be expressed in monetary terms. As discussed above, the environmental performance can be expressed in monetary terms, but it is also possible to make estimations of quality performance to include all three aspects in a monetary trade-off. As an example, Friberg et al. (2008) has included quality aspects such as estimations for the risk of delay in their model for analysing effects of transport policies.

2.4 Concluding remark

In this chapter an overview of what constitutes transport chains concerning actors, decision types, etc. is presented. Transport policies are described and its influence on logistical decisions in transport chains is illustrated. Finally, the effects of transport policies are discussed in terms of economic, environmental, and logistics performance of the performed logistical operations in transport chains.

Predicting the effects of transport policies is important to implement transport policies which have the desired effects. Public authorities often make use of simulation models to analyse the probable effects of transport policies. Therefore, in the next chapter a review of freight models appropriate for transport policy analysis is presented.
Chapter 3

Review of freight models

In this chapter a review of models that potentially can be used for studying the effects of transport policies is presented.

3.1 Scope of review

The purpose of the review is to examine which type of model that is appropriate to use when analysing different types of effects of transport policies. The model needs to represent certain properties to fully be able to estimate possible effects of transport policies. For a schematic figure of how we regard the cause and effects of transport chains, see Figure 3.1. First of all, we want the decision support system to be able to answer questions such as:

“What will the effects E be if transport policy P is introduced?”

Figure 3.1. Schematic figure of the context of the cause and effects in transport chains.

When transport policies are introduced common goals are to reduce the negative external effects and to internalise the external costs (see, e.g., Button (1993)). However, the public authorities usually also want to have a sustainable business climate to maintain economic growth, why for instance the public authorities wish that the internal costs are kept at a reasonable level. There are therefore different types of effects E from transport policies which we want to capture in a model. Environmental effects are important to capture, which we here refer to as emissions, congestion, noise, accidents, and land use. These effects have different types of impact on the environment, as brought up in Chapter 2. Other
effects are economic effects such as costs for the actors in a transport chain, i.e., internal costs and incomes to the public authorities from taxes and fees. Another example of an economic effect is external costs which are costs for the society as a consequence of the environmental effects and other negative effects of transportation, such as infrastructure wear, are also an economic effect. Finally, we want to capture logistical effects which are effects as a consequence of transportation. Such effects are related to the resource and infrastructure utilisation, i.e., how well the resources (vehicles, producer nodes, and storages) are utilised in terms of time, space, weight, etc., as well as how well infrastructure such as terminals and link infrastructure is used. (See Chapter 2 for a description of how we regard transport chains.) As an example, public authorities who have invested in new railway infrastructure wish to estimate how well the new infrastructure actually is used. Moreover logistical effects include quality aspects of the performed transportation such as punctuality and product quality. Logistical effects can also be described as transport efficiency, i.e., the ratio between transport work (ton kilometres) and traffic work (vehicle kilometres). A summary of the effects are given below:

- Environmental effects
  - Emissions
  - Congestion
  - Noise
  - Accidents
  - Land use

- Economic effects
  - Incomes to the public authorities
  - External costs
  - Internal costs

- Logistical effects
  - Resource and infrastructure utilisation
  - Quality
  - Transport efficiency

To capture the effects it is necessary to know which resources (vehicles, production nodes, and storages) and infrastructure (terminals and link infrastructure) that are used to meet the demand. The effects from the usage of the vehicles depend on vehicle characteristics such as traffic mode, fuel type, weight, and emission factors of the vehicle. To find the actual effects from how the resources are used on the infrastructure there is a need to capture the
planning of the resources and the infrastructure. The planning concerns how much (quantity) and when (time) to transport, produce, replenish, or tranship and with which resources and infrastructure. The time when it is possible to transport is influenced by whether the planning is determined by timetables or not.

To capture transport policy $P$ a number of aspects have to be included in the model. The transport policies we consider are economic and regulative policies, and the policies can concern the usage or the ownership of infrastructure and resources, see the previous chapter. Infrastructure can be terminals (e.g., ports, transhipment locations, and distribution centres) and link infrastructure (e.g., roads and rails), while resources are vehicles and factories. To capture the usage or ownership of the infrastructure and resources in more detail a number of properties have to be included. Vehicle characteristics which influence for instance the environmental effects and external costs of transportation are important to capture. To be able model time-differentiated transport policies, speed regulation on certain links, timetable synchronisation when timetabled transportation is used, etc., there is a need to include time in the model. Other examples of time-related policies are resting time restrictions of truck drivers which influence how it is possible to make use of the vehicles.

Besides the above deduced aspects there is also a need to include the demand for a product type in a consumer node. The product demand includes a specific time period and a certain product quantity. To meet this demand there is a need to obtain the products, e.g., by production, refinement, mining, etc. from one or several producer nodes or simply to take the products from a storage. The need to transport the products from the producer node/s, or storage, to the consumer node is called transportation demand, and this transportation demand includes a time period for when the product quantity need to be delivered at the consumer node when transported from a specific producer node or storage. We assume that it is possible to influence the transportation demand with transport policies, i.e., from where the products are being transported, but not the product demand. Therefore we regard the transportation demand as not known in transport chains. The product demand is the more general form of demand, while the transportation demand is fixed when the consumer nodes and producer nodes or storage are determined.

Below is a summary of which desirable properties (or descriptive indicators) that should be captured to model effects of transport policies, i.e., when and how much to produce and transport (demand), which resources and infrastructure to use (resources and infrastructure), and how to use the resources on the infrastructure (planning):

- demand
  - product
  - transport
resources and infrastructure
- production nodes
- storages
- vehicles
- terminals
- link infrastructure

Planning
- Quantity
- Time

To capture the demand for products and transportation, which resources and infrastructure to use, and how to use the resources on the infrastructure, there is a need to capture the underlying decisions. Decisions concerning the demand for products and transportation are product order and transport order decisions. Decisions related to which resources and infrastructure to use are production node choice, storage choice, traffic mode choice, vehicle type choice, and route choice. The route choice includes deciding upon which links to use. Decisions regarding how the production resources are used are planning of quantities to produce at a certain time. Decisions of how the storages are used are planning of the quantity and when to replenish. Decisions concerning how the transport resources are used are consignment size, time, and load coordination. The planning of the consignment size is typically influenced by the vehicle capacities and the total product demand of other transport orders in the same geographical area. The time when the transport is performed can either be determined as a consequence of the transport demand, or as a consequence of existing timetables. When timetables are used to determine the time, the timetable can also be regarded as the frequency. Time refers to dynamic time, i.e., the evolvement of time is captured in terms of time-steps where the status of the system changes. Load coordination concerns coordinating several transport orders on one vehicle and can for instance be load consolidation where several consignments are loaded together, or when the return transport of the vehicle is considered and for instance is loaded, i.e., backloading. Decisions concerning how terminals are used are planning of intermodal or uni-modal transhipment between vehicles, i.e., which quantity and at which time this product quantity is transhipped. These decisions are the main decisions which cover the properties outlined above. Below is a summary of the decisions which are desirable to include in the models:

- ordering decisions
  - product order decision
    - order size
- time
  - transport order decision
    - order size
    - time
- choices
  - production node choice
  - storage choice
  - traffic mode choice
  - vehicle type choice
  - route choice
- planning
  - production planning
    - produced quantity
    - time
  - inventory planning
    - replenished quantity
    - time
  - transportation planning
    - consignment size
    - time
      - timetabled
      - demand-driven
    - load coordination
  - terminal planning
    - transhipped quantity
    - time

Other descriptions regarding the cause and effects relations in transportation have been made by for instance Drewes Nielsen (2003) and in Richardson (2005). In the former distinctive steps are presented which go from changes in the prerequisites, which imply changes in the logistical structures and result in transport indicators showing how the transport is planned and performed. These steps have consequences on the actual environmental and societal effects.
Richardson has illustrated complex relationships between market forces, transport policies, the prerequisites for road transportation, and the actual environmental and societal effects. The reasoning in the above studies is similar to our perception, i.e., that the effects from transport policies and other changes in the prerequisites for transport chains can be deduced from previous decisions and transport indicators.

3.1.1 Selection of models

Models which are included in the review are models that can answer the main question in the beginning of the chapter. The types of models we are interested in are freight models, i.e., they should be able to capture transportation of freight, and models which enable transport policy analysis, i.e., the purpose of the models should mainly be descriptive. Also, we want the models to be able to capture traffic mode (or possibly vehicle type) choices as well as route choices. Two main types of models are included. First, typical models which are used today, or whose aim is to be used, for transport policy analysis, are selected. Second, models which capture several of the planning decisions defined above. The focus of this review is on transport-related choices, but a few representative models which focus on supply chain decisions are also reviewed (these models focus mainly on production- and inventory-related decisions) since they include several planning decisions relevant in transport chains and since transport chains are part of supply chains. Moreover, the main geographical scope of the review is on regional, national and international level, but a few interesting models on the urban level are also included. The aim of the review is not to fully cover all models which fit into the selection requirements since there already exist similar model reviews, see for instance Williams and Raha (2002) and Friesz (2000) for reviews of models used for public policy analysis, and see Davidsson et al. (2005a) for a review of agent-based models in traffic and transportation. Instead we intend to give some examples of each category of models, why several models are left out since they resemble the included models. The focus is to capture different modelling approaches and to especially include promising approaches which include many of the defined decisions, or have the potential to include these decisions. We could also have chosen to include general purpose simulation tools such as Arena. However, in this review we focus on specific models aimed at transport policy analysis. The reviewed models and the references describing the models are given below. When a name is given to the model, this is used; otherwise the main reference is used.

- **SAMGODS** (Bates and Swahn, 2004), (SAMPLAN, 2001)
- **SMILE** (Tavazssy, 1998)
- **SLAM** (SCENES consortium, 2000)
- **STEEDS** (Brand et al., 2002)
Examples of similar models which have not been included in the review are ASTRA (ASTRA Consortium), NEMO, SISD, WFTM, and EUFRANET (Williams and Raha, 2002) (traditional macro-level model), and Swaminathan et al. (1998), Krishnamoorthy and Mondal (2006), Kwon et al. (2005) (typical supply-chain models on the micro-level).

3.2 Framework for describing the models

To examine how well the models capture the decisions and effects important for policy analysis in transport chains, the reviewed models are classified according to a framework presented in this section. First, general issues concerning the problem description, the implementation approach and the results are brought up. Then, parameters which are important to capture in the models according to the defined decisions and effects are included. In the review it is indicated if these parameters serve as input or output to the model since this illustrates the type of model.

3.2.1 Problem description

Domain

The domain of the models can be transport chains or supply chains, see previous discussions in Chapter 2.

Policy analysis

The aim of the reviewed models is to function as decision support systems for policy analysis. The policy analysis can concern public policies, which include
analysis of how well public policies succeed in meeting societal goals, such as sustainability or economic growth. The effects of different implementations of public policies can be studied with these models. Such purposes are referred to as **public policy analysis**.

Policy analysis can also concern analysis of measures aimed at improving the performance of transport chains. The goal can for instance be to reduce the transport costs or to reduce the lead-time, which is of great interest for transport chain actors, but which also public authorities can have an interest in. Such purposes are referred to as **private policy analysis**.

**Purpose**

Models can be described as mainly *descriptive* or mainly *prescriptive*. Descriptive models are typically characterised as models which aim is to study certain scenarios and results. Examples of questions might be: Given a certain situation (the current situation), what would the effects be if a transport policy would be introduced? Prescriptive models have another focus; the aim is instead to find a good solution to a problem.

**Geographical scale**

The geographical scale indicates which spatial level the model operates on. We have divide geographical scale into *international*, *national*, *regional* and *urban*.

**Traffic mode**

Traffic mode indicates which modes that are included. The traffic modes for freight transport that we consider are *road*, *rail*, *air*, *waterborne*, and *pipeline*. Moreover, if several traffic modes can be used we refer to this as *multimodal*.

### 3.2.2 Implementation approach

**Level**

Simulation models can be divided into macro-level models (e.g., equation-based models) and micro-level models (e.g., agent-based models) (Parunak, 1998). Micro-level models include detailed information of individual transports and are therefore fine-grained. The transport flow in such models is modelled between nodes. In micro-level models specific behaviours of specific individuals as well as the interactions between the individuals are modelled. The output from the model is thus a consequence of several inter-related events, i.e., causality is captured. The data that is used in micro-level models represents entities, and can for instance be company-specific data, but also disaggregated data.

In macro-level models the characteristics of a population are modelled. The characteristics are averaged together, and the model attempts to simulate changes in these averaged characteristics for the whole population. Statistical correlations are thus modelled. Since macro-level models mainly focus on
higher-level properties, and not particularly on individual companies and transports, the level of detail is not high. These models are therefore course-grained. The transport flow is modelled between zones. Since the data in macro-level models is aggregated, i.e., gathered together and averaged, specific properties of individual data are therefore not available. Aggregated data is often used to distinguish general characteristics, why the data can be generalised more easily than in micro-level models.

**Time**

The simulated time can be either static or dynamic. When static time is simulated, the time is not explicitly modelled why the system is represented at a particular time. When dynamic time is simulated, time-steps are modelled and the system and its entities change states as time evolves. Dynamic time enables capturing planning and scheduling where there are different prerequisites depending on the time (e.g., of the day).

### 3.2.3 Results

**Maturity**

Models can have varying degree of maturity; see for instance Parunak (2000) for a classification of the maturity of models. The maturity of the model refers to how far the development of the model has come. If design of the model has been described, but the model has not been implemented, the model is called *conceptual*. Models which have been implemented but no tests have been presented, *implemented* is used. When the model has been implemented and tested with artificial data it is referred to as *simulation experiments with artificial data*. When real data has been used *simulation experiments with real data* is used. Real data can be collected statistics, while artificial data is based on assumption.

**Evaluation comparison**

An evaluation comparison should be made when the problem has been studied previously with other approaches. If the comparison is *qualitative*, the different approaches are evaluated based on typical characteristics and functionalities. A *quantitative* comparison implies that experiments are performed when the approaches are compared. If there is no information about evaluation comparisons, this is indicated as *none*. Of course, this may imply that evaluation comparisons have been made, but that we have not found that information.

### 3.2.4 Transport policies, decisions, and effects

In the review we want to examine which transport policies, decisions, and effects that are captured in the reviewed models. The main types of transport policies are regulative and economic policies. An example of a regulative policy
is restrictions of maximum vehicle weight and an example of an economic policy is fuel tax. Infrastructure investments can be regarded as an economic transport policy, but since it is rather different from taxes and fees in its implementation, we choose to distinguish infrastructure investments as a separate type of policy. An example of an infrastructure investment is railway maintenance (see Chapter 2 for discussions of transport policies).

The decisions deduced in the beginning of the chapter are included in the review framework and in the analysis we indicate whether the decisions are made within or outside the model. If the decisions are made within the model, the decisions are output, and if the decisions are made outside the model, the decisions are input. The effects which are presented in the beginning of the chapter are also examined in a similar way as the decisions. To explore what is captured in the model, it is indicated if the effects are input or output to the model.

3.3 Classification of the models and analysis

Table 3.1 below shows the classification of the characteristics of the models and include our perception of how the models should be classified. If the information is unclear for certain model parameters, this is indicated with a question mark. Since one of the main characteristics of the models is the level, this characteristic is discussed in relation to many of the reviewed characteristics.

3.3.1 Problem description

The analysis below relates the reviewed characteristics concerning the problem description to the level of the models since it often is possible to see general tendencies related to the level.

The majority of the reviewed models address transport chains, but a few supply chain models are also reviewed since a transport chain is part of a supply chain and these models therefore include relevant characteristics. When looking at the models within the supply chain domain, the reviewed models are rather similar in their structure, input and output data, etc. The focus is often on meeting the customer requirements in terms of time and reducing the inventory levels. Since the focus is not on transportation, this is often not modelled in detail, why vehicles loaded with cargo are not modelled. In supply chain models only flow of products occurs, i.e., there are no restrictions on the availability of transport resources. The exception is Fox et al. (2000) which also include certain transport aspects, but at a course grained level.
Table 3.1 Characteristics of the reviewed models. An x indicates that the property is included in the model.

The majority of the macro-level models focus on public policy analysis which enables a high-level analysis. Some of the macro-level models which also
include more detailed decisions (see Table 3.2), i.e., SMILE, SLAM, Cube Cargo, GoodTrip, PACE-FORWARD, and TLUMIP, also include issues of private policy analysis. This is logical since the inclusion of more detailed decisions enables analysis of issues which are closer connected to issues of interest for companies. The models which have a micro-level approach are mostly aimed at private policy analysis, i.e., the possible users of the models are companies which are interested in improving the efficiency, competitiveness, etc. and therefore evaluate strategies which might improve the performance of the transport chains. Therefore it is natural that individual actors need to be modelled in order to capture detailed decisions which are of interest for the actors. Only INTERLOG and the model by Abouaïssa et al. (2002) also include public policy analysis. The focus of the latter is on evaluation of policies aimed at improving the traffic situation, such as reducing congestion.

All reviewed models include some degree of descriptive purpose; however, the supply chain models can be regarded as having a more prescriptive purpose since their goal often is to find an efficient way to coordinate the decision making along the supply chain while meeting the customer demand.

The majority of the models, especially the macro-level models, are on a national level since transport policy analysis most often are of interest for national public authorities. In some of the models the geographical scale is not mentioned, this is probably due to the private policy analysis purpose of these models where it is not of importance on which level the transport or supply chain appear.

In the macro-level models, several traffic modes are often included, which indicates that the traffic mode choice is important in these models. In the micro-level models the focus is instead mainly on road transportation. The exceptions are the supply chain models where the traffic mode is not a main issue, and Gambardella et al. (2002) where the focus is on intermodal transportation. However, the supply chain model by Fox et al. includes different traffic modes even if they appear to be modelled rather course grained. TLUMIP includes both micro- and macro-level aspects and is therefore neither a pure micro- nor macro-level model. This is for instance illustrated in the inclusion of traffic modes; road transportation is modelled rather detailed, while rail, sea and air only are modelled on a course grain where distributions of the different modes are used. The reason for this is that the majority of the transport flows are rather short (it is a regional model of Oregon, USA), why road is the only efficient mode alternative (Donnelly, 2003). Moreover, no data was available to estimate modal choices why this was not modelled in detail.

### 3.3.2 Implementation approach

Dynamic time is only implemented in the micro-level models since it is not possible to include this in macro-level models. The inclusion of dynamic time enables planning decisions to be modelled, such as the time of the transport, load
consolidation, etc. In some macro-level models planning decisions are included anyway; in more traditional macro-level models such decisions are input to the models, while the decisions are output for approaches which capture more micro-level aspects (mainly de Jong and Ben-Akiva (2007) and TLUMIP). The aim in the latter approaches is to disaggregate the aggregated data. TLUMIP and INTERLOG are micro-level models, but are implemented as Monte Carlo simulation, a static state of the system is modelled where changes over time is not captured, why we classify them as not including dynamic time.

3.3.3 Results

The review shed light upon the fact that the reviewed macro-level models are more mature than the micro-level models, which indicates that transport modelling for policy-analysis on the micro-level is a newer approach than transport modelling on the macro-level. SAMGODS and SMILE are probably the most mature models since they are currently used for public policy analysis in Sweden and the Netherlands respectively. SAMGODS is a rather traditional macro-level model, while SMILE includes more logistical aspects as discussed above. The least mature model is Abouaïssa et al. (2002) where the proposed model is still conceptual.

The majority of the reviewed models have been compared to other modelling approaches. This comparison is most often qualitative, according to the information we have got. When agent-based (micro-level) approaches are used, comparisons between, e.g., traditional operations research approaches are compared to agent-based approaches, and advantages of the latter which are sometimes mentioned are the possibility of dynamic scheduling and execution, using online systems, flexibility of the inclusion of number of agents, and the reusable structure of agent-based systems (van der Zee and van der Vorst, 2005), (Fox et al., 2000), (Strader et al., 1998), (Gambardella et al., 2002). It is argued that agent-based models are appropriate when it is possible to divide the problem domain into subtasks, which is the case for transport chains. When decision making is centralised, it is argued that operations research methods are more appropriate than decentralised methods (Strader et al., 1998). Liedtke et al. (2004) argue that agent-based approaches are suitable when modelling the transport market since the decision rules used by the actors when making decisions regarding consignment size, routing, etc. can be captured. In literature related to traditional macro-level models the advantage of including more micro-level aspects are pointed out (Bates and Swahn, 2004).

3.3.4 Transport policies, decisions and effects

Table 3.2 presents the decisions which are captured in the models.
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<th>de Jong &amp; Ben Akiva</th>
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**Table 3.2** Overview of the captured decisions. An “i” indicates that the decision is captured in the model, but that the decision is made outside the model, i.e., it is input to the model. An “o” indicates that the decision is captured and made within the model, i.e., it is output from the model.

**Ordering**

Of the reviewed models only the supply chain models include product demand as input to the models, which indicate that it is not determined exogenously from which producer the products will be transported. In the other models the transport demand is already determined and is therefore input to the models. When changes in the transport system is studied which can have an effect on the transport demand it can be problematic if the transport demand already is determined.
A problem with using origin and destination matrices (like in for instance STAN/SAMGODS) is that statistical data of transport flows in tons, volume, etc. are seldom available; instead the available transport flow statistics is expressed as trade or value flows. Therefore, the available data has to be transformed to physical transport flows, which is often done with value to volume ratios. Since changes in trade patterns is not captured with the fixed origin and destination matrices, Williams and Raha (2002) suggests to deal with this by making use of elasticity coefficients to capture future changes of transport cost and production and transportation times.

Some of the macro-level models (SMILE and de Jong and Ben-Akiva (2007)) include production and consumption flows as input instead of origin and destination flows which are more common. However, we do not classify these models as including product demand since the flows between producer and the consumer are already determined, i.e., it is not a product demand as we describe it.

**Choices**

Practically all models that aim for transport chain analysis capture the traffic mode, vehicle type, and route choice (except the vehicle type choice in SMILE and the traffic mode choice in INTERLOG). These choices were used in the selection of which models to review and these choices indicate that the focus of the models is on analysis of important transport chain aspects. The mode assignment\(^2\) in macro-level models typically depends on the amount of transport and the cost parameters associated to these volumes, as well as the available transport infrastructure. The cost parameters are values that most often are calculated and averaged for different product groups, and the assignment is based on a minimisation of the total costs. The number of product groups differs between the models. For instance, SAMGODS includes fewer product groups (12), while for instance SMILE includes more product groups (50). The more product groups that are included, the more detailed information influences the mode assignment, why the mode assignment can get more precise. The vehicle assignment is carried out in a similar way as the transport mode assignment.

In the micro-level models which include modal choice, this choice is made depending on the circumstances for the specific transport, i.e., based on time, cost, resource availability and other requirements. Fox et al. (2000) is the only supply chain model taking different traffic modes into account. However, it seems like the decision is modelled rather coursed since the decision is not further discussed.

The route choice is captured in all reviewed models; this is logical since all models include some kind of movement of products.

\(^2\) In SAMGODS the mode and route assignment are performed at the same time.
In both transport chain and supply chain models producer node choice is included, but in transport chain models the choice is captured as input, while it is captured as output in supply chain models. Supply chain models also capture choice of storages, which is not captured in the transport chain models. In supply chains this is an important decision due to the focus on the product flow in supply chains.

Planning

A general tendency is that more planning issues are included in the micro-level models than in the macro-level models due to the possibility to include more details in micro-level models. Also, planning is closely connected to dynamic time which is not possible to capture in macro-level models. The inclusion of planning decisions illustrates that the focus more is on company-level issues. In these models the aim to function as a tool for public policy analysis is also less explicit. The aim is instead more towards issues of interest for companies such as measures to increase the competitiveness of the transport chain, i.e., private policy analysis. In macro-level models the focus is more high-level, i.e., less detailed decisions are included, and the aim is explicitly towards public policy analysis.

In some of the macro-level models consignment size and load coordination are captured by letting these decisions be represented as input to the model, while they are captured as output when the models include more micro-level aspects, i.e., the decisions are explicitly modelled. SMILE, SLAM and GoodTrip include logistical families where logistical characteristics such as consignment size and load coordination of certain segments are defined and input to the models. This enables a more detailed analysis of the overall transport flow. The model presented by de Jong and Ben-Akiva (2007) is aimed to function as a logistics module to the current national model in Sweden, SAMGODS. More logistical decisions, such as consignment size, load coordination, and transhipment, are added in this model compared to the original SAMGODS model, which will increase the level of detail in SAMGODS when the two models are merged.

The time of the transport planning is captured in the micro-level models which capture dynamic time, including the supply chain models. In Abouaissa et al. and Gambardella et al. both timetables and demand-driven transportation are possible to use to capture the time for the transportation, while a pre-determined frequency determine the time in van der Zee and van der Vorst (2005).

Transhipment is captured in the models with the aim to include for instance intermodal transportation or transportation where distribution centres are used. The model by Gambardella et al. focuses on efficient terminal handling, and it is also the only model which captures the time for transhipment. The supply chain models are the only models which capture production planning and replenishment since this is one of the main issues in supply chains.
Transport policies

Table 3.3 illustrates that the more traditional macro-level models capture more types of transport policies. This is due to the focus of these models to function as a tool for transport policy analysis. Micro-level models are mainly aimed at policy analysis of private policies.

Effects

The focus of the model is possible to determine from the modelled effects, i.e., if mainly societal or mainly company aspects are captured, see Table 3.3.

Environmental effects are only included in macro-level models (except for Abouaissa (2002) which includes congestion at a conceptual level) due to the societal perspective of these models where reducing the environmental effects from transportation is an important policy goal. The most common environmental effect to capture in the reviewed models is emissions. Of course, revenues to public authorities are only included in macro-level models, as well as external costs since it is important to capture for instance due to the common policy goal to internalise the external costs.

Internal costs are included in all models since the costs which appear in transport and supply chains are crucial for how the logistical operations are performed.

Resource utilisation is captured in most of the models. In the transport chain models this mainly refers to vehicle utilisation in relation to the load capacity. Gambardella et al. (2002) also includes terminal utilisation since efficient utilisation of terminals is one of the purposes of the model. In the supply chain models mainly the utilisation of production resources are focused. A general tendency is that in the macro-level models the resource utilisation is input to the models, while it is explicitly modelled in the micro-level models (as well as de Jong and Ben-Akiva (2007)), i.e., output from the model. Vehicle load utilisation is output from Cube Cargo, however, this estimation is on a rather course grain level indicating if the vehicle is loaded in the return transport or not. The same tendency can be observed when quality aspects such as delay, reliability, product quality, etc. are captured. For instance, delay is only output from some micro-level models since it is required to include dynamic time to capture deviations from planned arrivals. In the model by Fox et al. (2000) quality aspects are both input and output. The input concerns information regarding damage rates during transportation, while the output relates to the production quality.
To capture the effects of transport policies and their interactions, Table 3.3 provides an overview of the captured transport policies and effects. An “i” indicates that the transport policy or effect is input to the model. An “o” indicates that the transport policy or effect is output from the model.

From the review it is possible to distinguish characteristics between transport and supply chain models. The focus of supply chain models is on product refinement as pointed out earlier. Transportation can sometimes be captured, but most often the complex task of connecting the consignments to vehicles is not fully captured.

### 3.3.5 Motivation for further analysis of agent-based models

The review above shows that micro-level models include more of the detailed logistical decisions in the requirement list than the macro-level models, and that these decisions are output from the models. The inclusion of dynamic time enables to better capture detailed logistical decisions. For instance, to capture timetabled transportation there is a need to include dynamic time. The models which include dynamic time and detailed logistical decisions in the review are agent-based models. Agent-based approaches are particularly appropriate when transport chains are studied due to the ability to capture heterogeneous agents, or actors, and its interactions, since an important characteristic in transport chains are the appearance of many different actors, or decision-makers. Real-world transportation is a consequence on communication, negotiations and decision-making.
making of the actors. According to Parunak et al. (1998), “…agent-based modeling is most appropriate for domains characterised by a high degree of localisation and distribution and dominated by discrete decision.”. Based on the above characteristics, transport chains seem appropriate to simulate with MABS. Research has also successfully been conducted to apply agent technology to transport logistics, see Davidsson et al. (2005a) for a review.

Agent-based models have also been applied to the research field of policy-making. For instance, Downing et al. (2001) have applied MABS in the context of climate policy and climate change where a prototype agent-based integrated assessment model is proposed for issues like drought, flood, etc. Downing et al. (2001) argue that MABS is well-suited for this purpose since agents represent the behaviour of different actors, in this context policy makers and households, and the interaction between the agents can therefore be modelled and evaluated. Also, since MABS can represent different grains, couplings to macro-level models can be done. Boulanger and Bréchet (2005) have compared six modelling approaches and point out agent-based approaches as particularly appropriate for policy-analysis for sustainable development due to its ability to simulate scientific or commonsense knowledge, to represent the environment and the included agents naturally, and the bottom-up structure enabling to capture micro-macro relationships. Another advantage of making use of agent technology is that norms have been widely used to control agent societies (Boella and van der Torre, 2005). Norms in the context of agent societies have very similar functions as (public) policies in human societies, i.e., to influence the behaviour of individuals in order to strive towards the common goals of the society. Norms are introduced at a global level in multi-agent systems in order to influence how the agents behave and interact.

Based on the above characteristics of agent-based models we choose to study these models in more detail. Even if the reviewed supply chain models do not include so many transport-related decisions, these models are interesting to review since they represent the different roles which appear in supply chains and capture the complexity between decision makers. There exist many agent-based supply chain models due to the appropriateness of making use of agent technology for representing supply chains. Only one of the supply chain models are reviewed in more detail since the models are rather similar in structure and since the focus of the review is mainly on transport chain models. Only the agent-based models of transport chains which explicitly discuss different roles included in the model are reviewed in more detail. TLUMIP is stated to be an agent-based model, but since no roles, or agents, are defined and discussed (i.e., we lack information of the agents), the model is not further analysed.
### 3.4 Classification of the agent-based models and analysis

Below the framework used for describing the reviewed agent-based models in more detail is presented. The included agents are described.

- **Included agents.** The agents included in the model are indicated by using the notation in the reviewed papers.

- **Interacts with.** The other agents which the included agents interact with are described here.

- **Decisions and actions.** The decisions and actions that the agents are responsible for are described as closely as possible to the deduced decisions in the beginning of the chapter.

- **Based on.** The decisions and actions are often based on some kind of information or policy which is described here. Examples of basis are cost, time, and resources.

- **Goals.** The included agent types have different goals. The goals of the agents indicate what the agent tries to achieve in its decision making, negotiation, etc. The aim of the ABM is often to increase the revenue, and more concrete goals can therefore be reduction of costs, shorten the lead-time, etc.

In all models decision making entities are included, and in the transport chain model by Gambardella et al. (2002) physical entities are also represented. Gambardella et al. (2002) argue that representation of (physical) entities as agents enables task-sharing which can help simulating more complex problems. The structure of the models is either hierarchical or recursive. In all transport chain models the agents are ordered in a hierarchical structure, and all supply chain models except the model in Fox et al. (2000) have a hierarchical structure. In some of the models agents are also structured in groups. This can for instance enable the representation of an organisation or a specific function within the model.

Table 3.4 (a and b) describes the agents which appear in the models and their responsibilities according to our understanding of the models. Different types of agents are included in the transport chain models. However, in general it is possible to distinguish two types of agents, even if the distinction between the roles is not always clear and they are sometimes overlapping. One agent type is more operative with exact knowledge of vehicle capacities, availability, etc., which enables it to make the detailed planning. The other agent type has an overview of possible operators and requests the operative agents for bids of certain transport tasks. The operative agent in the reviewed models also often performs the actual transportation, besides making the planning of individual vehicles.
<table>
<thead>
<tr>
<th>Strader et al.</th>
<th>Included agents</th>
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<tbody>
<tr>
<td>Supply network management</td>
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<tr>
<td>Order manager, material planner, inventory manager</td>
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<tr>
<td>Order manager, production planner</td>
<td></td>
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<tr>
<td>Production planner, shopfloor control</td>
<td></td>
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<tr>
<td>Material planner, capacity planner, order manager, inventory manager</td>
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<tr>
<td>Manufacturing system</td>
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<tr>
<td>Shopfloor control</td>
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<tr>
<td>Production planner</td>
<td></td>
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<tr>
<td>Order manager</td>
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<tr>
<td>Customer, supply chain network manager, customer, production planner, supply chain network manager</td>
<td></td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Interacts with</th>
<th>Decisions and actions</th>
<th>Based on</th>
<th>Goals</th>
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</thead>
<tbody>
<tr>
<td>Choice of supplier</td>
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<tr>
<td>Replenishment, inventory planning</td>
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<td>Inventory levels, costs</td>
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<td>Inventory information</td>
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<td>Order information</td>
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<tr>
<td>Choose appropriate supplier</td>
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<td>Meet requirements of</td>
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<td>Sent capacity utilization</td>
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<td>Supply products</td>
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<td>Produce efficiently according to plans</td>
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<td>Meet material demand</td>
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<td>Find production plan</td>
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<tr>
<td>Receive requested products to low cost</td>
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<tr>
<td>Send order, assign due dates, choice of product, supply from production or inventories</td>
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<tr>
<td>Resource availability, inventory, fiscal, lead times, production plan</td>
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</table>

Table 3.4a Included agents and their responsibilities. The supply chain model.
In INTERLOG, the interactions between the two agent types are regarded as contracts, where one agent (the shipper) can send requests to the other agent type (the forwarder) when a contract exists between the two agents. The contracts also enable a faster decision-process since the main characteristics of the transport tasks already has been decided. This reflects the reality rather well, since the transport buyer most often buys transports based on existing contracts with transport operators (Henriksson and Persson, 1999).

In the supply chain model customers and different types of production agents are captured, which illustrate the focus of different production steps. A general tendency is that in supply chain models many agents are included. Probably this also depends on the wider scope of supply chains where more actors are involved and more tasks need to be executed. In transport chains fewer agents are often included. The model by Gambardella et al. (2002), which is based on the TeleTruck model described in for instance Bürckert et al. (2002), differs from the other transport chain models since many types of agents are included, probably due to the intermodal focus of the model. This model is rather advanced and the model is implemented as a holonic agents system where individual agents can unify in a holon to enable more efficient transport planning within the holon. The holon consists of the head of the holon and the sub-agents truck, driver, and chassis agents. The head coordinates the tasks of the other sub-agents. Another reason for the inclusion of many agents is that the different characteristics of rail and road transportation are captured in the model, why different types of agents for rail and road respectively are included. For instance, in the model by Gambardella et al. rail transportation operates with timetables, while road transportation is performed on demand (demand-driven).

Even if more actors appear in supply chains than in transport chains, it seems like the agents in the supply chain models represent roles instead of actors. This can be appropriate since different roles can appear in different organisations (customer, producer, transport operator, etc.) in different types of chains. As an example, in one chain the customer might be responsible for buying the transports, while in another organisation the producer might have this responsibility. Therefore we believe it is appropriate to regard the agents as roles instead of mapped directly to a physical actor.

3.5 Concluding remarks

From the review we see that none of the reviewed models include all aspects of transport policy, decisions, and effects presented in Section 3.1. Many interesting approaches exist, and there is a trend to include more micro-level aspects in transport modelling in deployed models; examples are the Swedish national model SAMGODS which is planned to take more logistical aspects into account, the Dutch model SMILE which includes logistical aspects, etc. However, these models are still macro-level models and the inclusion of more
According to the Williams and Raha (2002), the attempts to use a micro-level approach are promising. TLUMIP (which assigns the transport flow to individual vehicle tours) performs better than the more traditional and less detailed models (Williams and Raha, 2002). Details of disaggregating aggregated data are done by disaggregating aggregated data. According to the Williams and Raha (2002), the attempts to use a micro-level approach are promising.

### Table 3.4b Included agents and their responsibilities. The transport chain models.

<table>
<thead>
<tr>
<th>Equipment</th>
<th>Forecaster</th>
<th>Forwarder</th>
<th>Intermodal coordinator</th>
<th>Terminal manager</th>
<th>Transport planner</th>
<th>Driver</th>
<th>Shipment</th>
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<tbody>
<tr>
<td>available resources</td>
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<td>meet road transport demand</td>
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<td>transport contract (time, cost, order size, etc.)</td>
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</table>
We believe that MABS can contribute to transport policy analysis by modelling roles which appear in real-world transport chains as agents, and thus increasing the degree of realism for how it is probable that transport chain actors will react as a consequence of transport policies. MABS can capture the negotiation and decision making between agents which leads to the actual transportation of products, i.e., represent causal relationships. By representing roles as agents it is possible to model different types of transport chains since roles can appear in different organisations as discussed above.

We have argued that it is important to include dynamic time to fully model important decisions in transport chains such as transport planning, for instance in relation to the requested time of delivery. MABS enables to capture dynamic time, but also other micro-level simulation techniques, such as discrete event simulation, simulate dynamic time. However, other capabilities which we are interested in and which MABS enables, such as proactive behaviour of entities which is appropriate to capture when modelling real-world actors, are not supported by discrete event simulation. Moreover, discrete event simulation does not support distributed computing and high-level programming, as opposed to MABS (Davidsson, 2000). Object-oriented simulation is related to MABS, however, there are certain characteristics which we are interested in which MABS captures, but object-oriented simulation does not (Davidsson, 2000). These characteristics are for instance i) spatial knowledge – transportation is a domain where geographical dispersion is important, ii) making use of communication languages – communication is important for representing the decision making in transport chains, iii) and possibility to capture mentalistic concepts – when modelling real-world actors it is appropriate to represent their behaviours as realistic as possible.

The review shows that agent-based modelling has been used previously to model transport chains, but only two of the reviewed models have stated a goal of public policy analysis: the conceptual model by Abouaïssa et al. (2002) and the more mature model INTERLOG. However, the reviewed agent-based models do not include decisions which are closely related to transport decisions (i.e., production, product ordering, and terminal choices), why the potential influence of transport policies on the transport demand is not possible to study with these models.

In the next chapter we suggest a model of transport chains, where decision making roles which appear in transport chains are included. The model is the basis for an agent-based simulator aimed at transport policy analysis which is outlined in Chapter 5.
Chapter 4

Roles in transport chains

Transport chains can be organised in many ways and the responsibilities therefore vary. In some cases the buyer of the transport service is the same actor as the customer, an example of this case is IKEA. In other transport chains the buyer of the transport service might be the producing company in the producer node. An example of this situation is the producer AarhusKarlshamn. In other cases it might be a third party which is contracted, for instance by the producer, to buy the transport services. An example of this situation is Volvo Logistics. The number of actors involved in the transport chain also varies; sometimes only two actors are involved, for instance a road haulier transporting clothes from a retailer’s distribution centre to its stores or a rail operator moving iron ore from a mine to a port owned by the mining company.

In the previous chapter we argued that to properly capture the complex decision making in transport chains, which influences what the effects of transport policies will be, there is a need to capture the interactions between the actors in transport chains and their decision making. In this chapter a generic model of the roles which appear in transport chains is suggested. The roles have responsibilities of different types of logistical decisions in transport chains. Hence, the focus is on the roles (functions) and not the actual companies, which enables to capture different types of transport chains organised in different ways.

4.1 A model of roles in transport chains

In this section a model of the roles which we regard as crucial in transport chains is presented. As mentioned in Chapter 2, our scope is wider than in traditional transport chains where the focus mainly is on the buyer of transport services and the provider of transport services (i.e., the transport planner). Since we also want to be able to capture changed logistical structures in transport chains, such as changes concerning which producer node, inventory, and terminal that are used, there is a need to extend the scope. Changes in logistical structures, and consequently changes in the transport demand, are also claimed to be important to capture if the negative effects of transportation is going to be reduced (McKinnon and Woodburn, 1993, EEA, 2008). Therefore we also include the customer which has a product demand as well as the terminal manager connected to terminals. We define the supply of products as consisting of the product buyer, the product planner, and the inventory planner. One reason for making use of a buyer role and a planning role for the transportation and
production parts is that we regard the decision process as including the selection (or choice) process and the planning process. In the selection process the choices concerning which transport operator and possibly terminal operator as well as which producer or inventory to make use of are considered. These choices lead to the selection of which main transport and terminal infrastructure, and which transport, production, and inventory resources that are used. In the planning process the issue of how to make use of the resources in an efficient way by planning the time a certain amount of products is going to be transported, produced, transhipped or replenished. Moreover, to coordinate the product supply part and the transport part of the chain, a transport chain coordinator is introduced. As brought up above, a coordinator function has been discussed previously in the literature for capturing the overall transport chain.

The roles presented here are the main functions within transport chains which we consider in our scope. The aim is to distinguish rather generic roles which can be used to describe different types of transport chains. Of course, not all roles appear in all transport chains, for instance, if there is no terminal in the transport chain, the role of the terminal planner is not included. Below the different roles are described in more detail explaining which responsibilities we include in the respective roles. The types of decisions included in the respective roles are explained and examples of different strategies which can be used to make the decisions are described. Both strategies to make the decisions as efficient as possible, as well as simple rules of thumbs which often are used in practice are discussed. See Figure 4.1 for the included roles and its relations. We assume that the decision making in transport chains takes place in a hierarchical fashion since it is common to model transport chains hierarchically (Gambardella et al., 2002, Heinitz and Lütke, 2007). The types of decisions included in the respective roles are described based on logistics literature and knowledge gained from interviews and contacts with companies in transport chains mainly during work in the projects East West Transport Corridor, Effects of Governmental Control Policies on Transportation Chains: A Micro-level Study, and Integrated Production and Transportation Planning within Food Industry.
4.1 Customer (C)

The customer is responsible for requesting products (components, raw material, etc.) from the transport chain coordinator. This demand stems from a wish to have certain customer inventory levels, to meet the end-consumer demand, for own production, etc. To meet this demand the customer orders products. The ordering can be made in several ways, depending on the goals of the customer. If there is a long-term relation between the customer and the producer, forecasts or plans, for which quantities will be requested over a period of time are often given to the producer to facilitate the planning of meeting the customer demand. The ordering policy has an important influence on the degree of freedom of preceding decision making. Common order policies are the \((Q,r)\) model, which determines the order point \((r)\) and order quantity \((Q)\). This implies that \(Q\) units are ordered when the inventory level is below \(r\) and the model originally assumes a stochastic demand and fixed lead-times.

The economic order quantity (EOQ) formula, or the Wilson formula, finds the optimal quantity to order to minimise the costs, is by Alstrom (2001) claimed to be the most common ordering policy in the industry to determine the optimal ordering quantity. The optimal order quantity is calculated as:

\[
Q^* = \sqrt{\frac{2CD}{H}}
\]

where \(C\) is the fixed order cost, \(D\) the demand during a period of time of the product, and \(H\) is the holding cost for one unit during a period of time. To better represent the ordering situation there exist modifications of the assumptions, for instance, a safety stock is often added (see, e.g., Alstrom, 2001).
Instead of making use of traditional customer orders based on the inventory levels at the customer like the EOQ formula, Vendor Managed Inventory (VMI) can be used. VMI implies that the product provider controls the customer inventory. This type of cooperation has the potential of making the planning of transportation and production more efficient since the information transparency between the actors enables more flexibility of the planning. Some researchers claim that VMI is especially appreciated by the customers since the customer’s inventory levels are decreased and the availability of products are better, while the producing companies do not always appreciate VMI since all customers are not always included in the VMI collaboration (Småros et al., 2003). Moreover, there are different ways of implementing VMI, for instance, VMI by direct access to customer inventory levels, or based on demand forecasts.

Connected to the ordering policy is the determination of in which time-window the customer allows the delivery. The time-window can be rather narrow, e.g., an hour, or more flexible, e.g., morning or afternoon or during a few days. The size of the time-window often depends on how the products are going to be used after delivery and inventory capacities. From a survey it is showed that customers can accept deliveries outside the time-window if the notifications of the delay are given in advance (IQ, 1999). If the products are delivered outside the time-window, the actor responsible for the transport might have to pay a penalty cost due to the breach of contract and possible income losses for the customer due to the delay. In the long run the customer may consider the transports too unreliable and thus contract another provider.

The transport chain coordinator receives information of the customer requirements, which in turn sends a proposal of how the transport chain coordinator plans to meet the customer demand. The proposal is evaluated by the customer, e.g., by considering cost and quality. Some customers may also evaluate other aspects such as the environmental performance of the proposal (Björklund, 2005). Often the communication is iterated several times before an agreement is reached.

4.1.2 Transport chain coordinator (TCC)

The transport chain coordinator is responsible for finding solutions to the demand expressed by the customer. The transport chain coordinator transforms the customer demand to a product order and a transport order and it evaluates the suggestions and information from the transport buyer and the product buyer regarding production and transportation and combines the suggestions to overall solutions which meet customer demand. An important function of the coordinator is thus to make a trade-off of the possible solutions. Of course this highly depends on requirements the customer has for instance regarding how firm the time of delivery is and how much information the customer has given the coordinator regarding the actual needs. In some cases it is reasonable to assume that the customer accepts deliveries slightly outside the time-window if
the overall price is cheaper, why this can be taken into account in the trade-off (e.g., by adding a penalty cost for deliveries outside the time-window). The information transparency between the roles influences which information the coordinator can use when making this trade-off as well as the ordering policy. An example of information transparency and a higher level of integration between the roles is VMI, as mentioned above. An example of limited information transparency is that it is common that the transport chain coordinator charges its customer a price including the transport costs which then gives no incentives to the customer to try to decrease the transport price, e.g., by increasing the vehicle utilisation (Östlund et al., 2003). There are different reasons for why there sometimes is a lack of information transparency, sometimes the reason is that the partners do not wish to share the information for instance due to lack of trust, but sometimes the reason is simply a lack of suitable IT solutions (see Davidsson et al. (2005b) for more information).

The transport chain coordinator can for instance appear in a third party logistics service provider being an actor which the customer contracts in order to find an overall solution, the role can appear in the producing company as a function within the company, or it can appear in the customer company. Huge Brodin (2002) states that it is reasonable to assume that the coordinator role is connected to the strongest actor in the transport chain.

4.1.3 Product buyer (PB)

The product buyer can be regarded as a role which makes the choice of which producer, or which inventory planner (e.g., a retailer), that should be contracted in order to meet the product demand of customer nodes in terms of the quantity of the product type that should be provided and when the products are needed. If we assume that the producer only is responsible for one producer node, this has the overall consequence that the product buyer thus makes the choice of which producer node (or producer) that should be used. The same is assumed for the inventories, one inventory planner is responsible for one inventory. The choice to order products from a producer node or from an inventory can for instance be based on a strategy where products are taken from inventories when there are sufficiently products in stock, otherwise they are produced. The product buyer can for instance appear in a producing company which owns several factories and inventories which it can make use of. Often it is connected to the organisation which hosts the transport chain coordinator.

Burke et al. (2007) point out a common decision process for choosing which producer to contract. First, possible producers which meet the requirements are defined, then the choice criteria which are going to be used are selected, and finally the alternatives received from the product planner are evaluated and the best is chosen. Wathne et al. (2001), for instance, point out some criteria which are common, such as price and relationship.
4.1.4 Production planner (PP)

The production planner is responsible for planning the production and making use of the production resources efficiently. The production planner is connected to a producer node, i.e., a node where some kind of refinement of products occurs, e.g., a factory. The production can for instance be manufacturing, assembly, etc. and the production planner mainly takes production costs, capacities, and demand into account when planning the production. There are several production strategies which can be used. Common production strategies are pull or push strategies where production is demand-driven in the former and pre-determined in the latter. Pull strategies are often chosen to decrease the inventory levels and to better capture demand variations. However, pull strategies often imply difficulties to efficiently plan the usage of transportation and production resources. Push strategies often use production and transport resources better since the planning takes place far ahead (Ahn and Kaminsky, 2005). However, push strategies are less flexible to demand variations than pull strategies why it often is more appropriate to use when the product demand is rather stable and known in advance.

When production is planned, the order quantities received from the product buyer are transformed to production quantities. The production planning such as producing continuously, in batches, or as individual items, influences how it is possible to plan the transportations from the production node, e.g., the match of the products to available resources. The choice of an optimal batch size when push strategies are used can be somewhat similar to the EOQ formula. However, here the trade-off is between production costs and inventory costs. See, for instance Riddalls and Bennett (2001) for further discussions.

4.1.5 Inventory planner (IP)

The inventory planner is connected to an inventory which for instance is located at an intermediate location (e.g., a central storage of the producing company), or in connection to a producer node. The responsibility of the inventory planner is to plan the inventories, i.e., for having sufficiently amounts of products in the inventories. Therefore the inventory planner has similar responsibilities as the production planner, except that it plans the replenishment instead of the production. An inventory planner can for instance be a retailer storing products which can be ordered by the product buyer. Different replenishment strategies can be used to maintain the desirable inventory levels depending on the characteristics of transport chain, its corresponding costs, and quality requirements. In some transport chains the main focus can be to minimise the inventory costs, while in others the focus can be on efficient transportation or production (see for instance Chang et al. (2006) for a short overview of different strategies). Inventories have different characteristics such as handling equipment and storage facilities.
4.1.6 Transport buyer (TB)

The transport buyer is mainly responsible for meeting the demand for transportation between producer and customer nodes at a certain time. In our model, the transport buyer chooses which transport planner to contract, which consequently means that the traffic mode is chosen. The choice of which vehicle type to use is also a consequence of this decision. The choice is based on the transport plans which are sent to the transport buyer on request. Since it is possible that the transport buyer contracts several transport operators, the transport buyer also has the function of coordinating different transport plans to one transport solution, i.e., an overall route is suggested containing which links and nodes that should be used. The transport buyer has got information of which nodes where production and consumption will occur, but it is also possible to make use of other nodes for consolidation and transhipment purposes, for instance for intermodal transportation. The transport buyer also takes requirements concerning the handling of the products into consideration. For instance, for product types sensitive to shock, rail transportation may not be an appropriate choice. The transport buyer makes a trade-off between the offered transport price by the transport planner, the quality of the proposal and possibly the environmental performance.

The role of the transport buyer can for instance appear in a producing company or at a retailer, depending on the type of transport chain.

Several researchers have pointed out the decision process for making the traffic mode choice, vehicle type choice, or choosing which transport operator to contract (see, e.g., Vannieuwenhuyse et al. (2003), D’Este (1996), and Bagchi and Virum (1998). The decision process is similar to the process discussed for the product buyer. From these studies some general steps can be distinguished which often appear in the descriptions:

1) definition of feasible alternatives which meet the requirements
2) evaluation of the alternatives according to certain choice criteria
3) trade-off between the alternatives according to the choice criteria

In 1) the customer requirements have to be considered, e.g., in terms of special handling requirements, and infeasible alternatives for instance due to lack of appropriate transport infrastructure are eliminated. In 2) the choice criteria are defined. According to a survey by Lammgård (2007), the most important factors when transport providers/operators are contracted are the reliability of the transport service and the price. Other important factors are trust and environmental aspects. Cullinane and Toy (2000) and SULOGTRA (2000) also point out the price of the transport service (e.g., depending on the traffic mode) and quality requirements like reliability and fast transports often have an important influence on the choice. Björklund (2005) summarises the results from several studies and states that time, cost, service and reliability are the factors
that mostly influence the mode choice. Cullinane and Toy (2000) have performed a content analysis of studies on freight route and mode choice and they conclude that most studies on traffic mode choice concern how important decision makers value certain criteria for the mode choice, i.e., the attributes that directly determine the decision process are often not considered. When the trade-off is done it is for instance possible to weight the choice criteria to facilitate the choice of which alternative is considered the best. As an example, some customers have high requirements on the reliability of the time of delivery. However, Lindau et al. (2004) state that it should not be neglected that transport contracting is still often characterised by routine.

To illustrate which aspects which have to be considered by the TB, we exemplify the traffic mode decision when it is possible to choose between two traffic modes. For certain market segments rail and road transportation are both possible to make use of. Common aspects which are considered are the cost and quality of the transportation. Even if rail transportation typically is the cheaper alternative for certain transport chains with longer transport distances, the transport quality (e.g., concerning reliability) also needs to be considered. The delivery time reliability of rail transportation is often claimed to be too poor (Rodrigue et al., 2001) and another drawback is that it is not very flexible compared to road transportation due to the dependence of rail track. Road transportation is often seen as flexible and the reliability is often claimed to be good, but of course this depends on the circumstances. For instance, congestion and accidents can lower the reliability of road transportation. In the trade-off between different aspects, there is often a minimum level of delivery reliability that needs to be reached before the cheaper alternative is chosen, i.e., time is often valued higher.

### 4.1.7 Transport planner (TP)

The transport planner is responsible for planning the transport resources in an efficient way on determined links for transport orders received from the transport buyer. The transport planner is connected to a vehicle fleet for a specific traffic mode and to a transport operator. As an example, several transport planners can be connected to one real-world transport operator. The transport planner takes the availability of appropriate vehicles, loading units, personnel, etc., into account when making its plans. For instance, the availability of vehicles and loading units appropriate for the amount and type of products are considered. The planning is mainly made based on the costs associated to the transport resources, such as fuel costs, maintenance costs and labour costs, while other requirements, for instance concerning quality, are maintained. Planning of the transport resources includes several interrelated decisions. The decisions mainly concern determining the consignment size, the time for the transport, load consolidation, backloading, as well as route planning. The decisions are closely related and in some cases they are not disjoint. A consignment is a
product quantity connected to an order (it can also be a sub-order) which is transported together between two nodes. The consignment size can therefore be the same as the order quantity if it is possible to load the products on the same vehicle. However, if the order quantity is planned to be delivered with several transports, the consignment size will be smaller than the order size. Consignment size can also be compared to a *shipment* which is the amount of products transported together between two nodes. If only one consignment is transported in one vehicle, the consignment size and shipment size are the same. However, if several consignments are transported on the same vehicle, the shipment is larger than the consignments. The time for the transport is determined by the choice of timetabled vs. demand-driven transports. This influences how efficiently it is possible to make use of the transport resources. In a longer run the transport planner also decides whether timetables are going to be used on certain transport segments, for instance if there are certain product flows which are rather stable.

Time has a great influence on the transport planning, for instance in terms of time requirements from customers, time-based costs, delays, etc. (Drewes Nielsen et al., 2003; Woxenius, 2006).

Load consolidation means that consignments from different product suppliers or to different customers are loaded in the same vehicle, which means that the transport route can include several stops. Load consolidation is mainly used to increase the vehicle utilisation (Blinge and Lumsden, 1993). If product suppliers or customers are located at different locations, the transported distance can be longer when using load consolidation than direct transportation from one product supplier to one customer. However, since several consignments are considered, the overall amount of vehicle kilometres is often lower compared to direct transportation without load consolidation. Backloading implies that the vehicle is loaded on the return journey due to a transport demand in the opposite direction, which increases the vehicle utilisation by avoiding empty runs. Backloading is sometimes difficult to achieve even if there are transport opportunities in both directions. For instance, it may be difficult to coordinate the transports, due to different vehicle requirements, cleaning requirements, customer delivery requirements or lack of overview of the transport demands.

Load consolidation and backloading are closely related. As an example, a transport solution can include a fully loaded vehicle with a consignment to one customer in one direction, and a fully loaded vehicle in the other direction, implying that backloading is used. However, it is also possible that several consignments to different customers are loaded on the vehicle when returning in the other direction, implying that both load consolidation and backloading is used. There are several strategies for determining how to plan load consolidation. Cetinkaya and Bookbinder (2003), for instance, compare two load consolidation policies frequently used in practice for the choice between transport on own account or for-hire. With the time policy consignments are transported at a certain time (this can be regarded as a timetabled transport), and with the quantity policy consignments are loaded until a certain amount of
Products are loaded. Since it is more difficult to predict the delivery time for the quantity policy, Cetinkaya and Bookbinder (2003) state that this policy can be appropriate to use if the transportation is on own account due to the more efficient vehicle utilisation in terms of space, but less punctuality.

The transport planner often wants the transport requests to be as flexible as possible to facilitate the planning of an efficient usage of the vehicles, i.e., to have a high vehicle utilisation. Large time-windows for delivery make the requirements looser and give more flexibility to the transport planner. The transport planner also wishes to manage a vehicle fleet which matches the transport demand well, so in the long run the transport planner may want to invest in transport resources with other characteristics to better meet the requirements.

Transport planners are also responsible for planning which routes the vehicles should take on the specified transport links. There exists extensive literature on how to find optimal routes for vehicles when a certain amount of goods should be transported, i.e., the vehicle routing problem, see, e.g., (Laport et al., 2000) for an overview. Some companies use software including vehicle routing capabilities, such as Route LogiX (http://www.dps-int.com/). Examples of aspects which have an influence in route choice according to the content analysis by Cullinane and Toy (2000) are cost, time, distance, speed, inventory, and damage. A similar procedure as outlined above for the choice of traffic mode, vehicle type, and transport operator can be assumed for the route choice, where certain key criteria are used in the decision making for selection among the feasible alternatives. Time and cost are also pointed out as key criteria in a study of how hauliers potentially will be influenced by a kilometre tax (see Ramstedt et al. (2007) for more information).

4.1.8 Terminal planning (TeP)

The terminal planner is responsible for planning the terminal handling, and is therefore connected to terminals. We are mainly interested in reloading activities between different vehicles due to the transport focus, but other terminal handling activities also take place which influence the overall performance of the transport chain. Such activities can for instance be shunting at rail terminals and movement of the products to different terminal areas. The planning at terminals can be complex due to for instance the planning of the terminal resources, the limited terminal area, customer time requirements, and peak hours (Henesey, 2006). Different types of terminal operators, such as sea ports, often handle the terminal planning.

In Table 4.1 below a summary of the typical decisions and actions of the different roles are presented, as well as whether the roles are connected to physical infrastructure or resources.
### Table 4.1 Overview of roles in transport chains.

<table>
<thead>
<tr>
<th>Roles</th>
<th>Decisions and actions</th>
<th>Connection physical infrastructure or resources</th>
</tr>
</thead>
<tbody>
<tr>
<td>Customer</td>
<td>Formulation of product demand, accept or reject of proposals</td>
<td>Customer nodes</td>
</tr>
<tr>
<td>Transport chain coordinator</td>
<td>Transport and product ordering, production and transportation proposal decision (including final production node choice, route choice, etc.)</td>
<td>No</td>
</tr>
<tr>
<td>Product buyer</td>
<td>Product request, suggestion of producer nodes and inventory</td>
<td>No</td>
</tr>
<tr>
<td>Production planner</td>
<td>Planning of quantity to produce and time of production</td>
<td>Producer nodes</td>
</tr>
<tr>
<td>Inventory planner</td>
<td>Planning of replenished quantity and time of replenishment</td>
<td>Inventories</td>
</tr>
<tr>
<td>Transport buyer</td>
<td>Transport request, suggestion of traffic mode, vehicle type, and overall route</td>
<td>No</td>
</tr>
<tr>
<td>Transport planner</td>
<td>Planning of consignments, time of deliveries, load coordination</td>
<td>Vehicles</td>
</tr>
<tr>
<td>Terminal planner</td>
<td>Planning of transhipment quantity and time of transhipment</td>
<td>Terminals</td>
</tr>
</tbody>
</table>

### 4.2 An illustrating example

To illustrate how the roles described above can appear in a transport chain, we present a real-world case, see Figure 4.2. AarhusKarlshamn is a producer, which produces speciality vegetable oils and fats. The producer is located in Karlshamn in southern Sweden and has customers which are spread over the world. The roles that are represented by AarhusKarlshamn are the transport chain coordinator, the product buyer, the production planner, the inventory planner, and the transport buyer. AarhusKarlshamn therefore takes the final decision of how the main logistical operations should be performed, and also decides how much products that should be taken from inventories. The transport operator FoodTankers is a tank transport provider which transports a large amount of AarhusKarlshamn’s products by truck. The role of the transport planner is represented by FoodTankers which therefore has to consider the availability of appropriate vehicles when planning the transports, determine consignment sizes, consider load consolidation and backloading possibilities, etc. Finally the customer agent is represented by the customers of AarhusKarlshamn. In Chapter 6 scenarios are presented which illustrate how the roles can appear in other types of transport chains.
4.3 Concluding remarks

In this chapter a model of generic roles which appear in transport chains is presented. The roles are responsible for different types of logistical decisions in transport chains. The model can be used for capturing different types of transport chains where the defined roles appear in different types of organisations. The application of the model to a transport chain is illustrated.

To enable transport policy analysis, we have in Chapter 3 argued that MABS is appropriate to make use of. Therefore, in the next chapter an agent-based simulator is presented which is based on the model presented in this chapter.
Chapter 5

TAPAS – Transportation And Production Agent-based Simulator

Transportation and production in transport chains and its corresponding environmental, economic, and logistics effects are a consequence of the decision making of interacting transport chain actors. In Chapter 3, advantages of micro-level models for transport policy analysis were pointed out. In particular MABS seems appropriate for capturing effects of transport policies in transport chains due to its ability to capture heterogeneous agents and its communication, negotiation and decision making. In this chapter an agent-based simulator called TAPAS (Transportation And Production Agent-based Simulator) is presented. TAPAS is based on the model of roles which appear in transport chains presented in the previous chapter. The main characteristics of TAPAS are discussed, and classified according to the review framework used in Chapter 3.

5.1 Motivation

Due to (increased) cooperation between actors in transport chains (e.g., producers, customers, transport operators) and their ability to adapt to new situations, there exists a significant flexibility of how to carry out their operations in different scenarios. We believe that more precise predictions regarding the effects of transport policies can be achieved using micro-level simulation, i.e., simulation of transport chains, which also capture the decision making of the actors in the logistical processes. Agent-based simulation models seem appropriate since they can deal with the above issues. There exist agent-based simulation models aimed at studying transport chains, see for instance Gambardella et al. (2002) and Heinitz and Liedtke (2007). However, these models assume a pre-determined transport demand, why changes in transport demand due to changes in logistical structures, etc. cannot be captured.

There are also natural connections between (transport) policies and concepts of agent technology. Software agents that interact according to certain rules are called artificial societies. Like in human societies there is a need for some sort of influence to guide the agents towards common goals (Boella and van der Torre, 2005). In artificial societies norms are used for influencing the behaviour of the individuals of the artificial society. According to Wooldridge (2002) a norm is an established, expected pattern of behaviour. Like transport policies norms can have different functions. Norms can have a regulative function, i.e., norms for what the members of the society can or cannot do. Norms can also have a
distributive function, i.e., how rewards, costs and risks are divided. Hence, the functionality of regulative norms corresponds to transport policies that are regulative, and distributive norms correspond to economic transport policies. A difference between human societies and artificial societies is that agents are programmed to follow certain norms, while you cannot be sure that humans follow norms (Boella and van der Torre, 2005). However, obviously there are several connections between norms and transport policies. Therefore agent technology seems appropriate when the consequences of transport policies are modelled since the concepts of norms can be used in order to capture the behaviour of members of the society.

Traditionally the focus in transport chain models is on the provider of transport services and the buyer of transport services (see, e.g., Lammgård (2007)); however, we extend the focus to also include production, terminal handling, and ordering, see Chapter 4. This is motivated by the fact that these different parts are highly connected. The production and terminal handling are modelled on a rather high level since the focus still is on transportation.

The decision making in transport chains is subject to both short- and long-term planning implying that the time dimension of the decisions needs to be considered when modelling transport chains. We assume that the aim of the actors in transport chains is to reach its goal in the most efficient way by local cost minimisation according to their knowledge of the environment. This is typical in transport chains where the interacting actors focus on their specific task (Drewes Nielsen et al., 2003). Virtually no exploration of potential cost savings achievable by cooperation in the transport chain is made by the agents. Due to the hierarchical decision structure with some knowledge of production and transportation alternatives, some global optimisation can occur. This appears to be rather typical in transport chains today, i.e., the overall optimality of the solution depends on the degree of shared information.

5.2 Simulation model

The agent-based simulator TAPAS is a further development of the simulation tool presented in Bergkvist et al. (2005). It uses a two-level architecture with a physical simulator and a decision making simulator (see Figure 5.1). This design is motivated by the fact that entities in the physical simulator (e.g., vehicles and products) are considered passive with no will to make decisions, while entities in the decision making simulator (the decision makers) act independently and potentially proactively. The two layers are connected by letting the decisions taken in the decision making simulator initiate the actions in the physical simulator. The hybrid architecture we present is similar to the architecture by Gambardella et al. (2002), where the decision making concerning the transport plans is modelled as an agent-based model, and the simulation of the transport
plans in the system is implemented as a discrete event simulation. See Figure 5.1 for an overview of the two-level simulator.

![Figure 5.1. Illustration of TAPAS.](image)

### 5.2.1 The Physical Simulator

The transportation network is modelled as a directed graph with a set of nodes and a set of directed links. A link, with average speed and length, is a directed connection between two nodes. A node can either be a customer inventory, a producer depot (factory) or a connection point in the transportation network. The nodes contain maximum capacities and possibility to store certain types of products, and the producer and customer nodes are connected to inventories. Further, TAPAS models a set of product types and a set of vehicles. Each product type has mass, volume, and value, and each vehicle has maximum speed, fuel type, maximum capacity, and emissions (e.g., NO₃, CO and CO₂) per distance unit. Also, a vehicle has fuel consumptions for empty and fully loaded
vehicles respectively. The actual fuel consumption is computed as a linear function of the current load. See Holmgren et al. (2007) for further details of the physical simulator.

Transportation

A vehicle has a traffic mode (road, rail, or waterborne) and can only travel links with the same mode and it is either controlled by a timetable (with fixed departure/arrival times) or by the departure time of a transport solution, i.e., be demand-driven. The road, rail, and waterborne modes are included since these modes carry large volumes of freight and for certain product segments modal shifts between them are possible. Air and pipeline can be regarded as more specialised modes used for fewer product types. Transport costs consist of

- time-based costs (e.g., driver, capital, and administration),
- distance-based costs (e.g., fuel, vehicle wear, and kilometre tax), and
- link-based costs (e.g., road tolls).

Since load consolidation is not currently (fully) included in TAPAS, a customer pays the complete transport cost when the transport is demand-driven. As offers are given at the time of booking, care must be taken for timetabled transportation to split the transport costs fairly between the buyers of transportation capacity even though no information is available about future bookings. The actual transport cost is the same as for demand-driven transportation, but the cost for a particular booking is calculated as the transport cost for the fully loaded vehicle times the customer’s share of the maximal load divided by the assumed average vehicle utilisation.

Travel times are stochastic and the time it takes for a vehicle to travel a link is assumed to follow a probability distribution which, for instance, can be lognormal (Noland et al., 1998). Vehicles are transported back after a transport task has been completed.

Production

The production is performed in factories located in the producer nodes. Each node has exactly one factory with a set of individually scheduled production lines. For each product type that can be produced there is a maximum batch size, a production cost per time unit and a batch production time given as input. We assume that production occurs in batches since it is common in production. Delays can occur since production lead-times are stochastic. They are assumed to follow a probability distribution, e.g., a normal distribution (Riaño et al., 2003).

Terminals

We define terminals as nodes where some kind of terminal handling occurs such as unloading and loading. Terminals can be producer nodes, customer nodes and
intermediate nodes used for transhipment. Times for loading and unloading of vehicles at terminals are expressed in terms of fixed and variable times. Fixed times are used for the times it take to prepare a vehicle for loading or unloading. Variable times are given for each product type and denote the times for loading or unloading one unit of a product. There are also costs for loading/unloading a vehicle that are given as cost per time unit. When the loading and unloading take place in intermediate nodes, it can both take place between vehicles with the same traffic mode as well as between vehicles with different traffic modes.

5.2.2 The Decision Making Simulator

The different types of decision makers in terms of agents that are included in TAPAS are transport chain coordinator (TCC), product buyer (PB), transport buyer (TB), transport planner (TP), production planner (PP), and customer (C). These different agents, or roles, correspond to the roles discussed in the previous chapter, except that the terminal planner and inventory planner are omitted here. The terminal planner is omitted due to the simplified modelling of the terminal handling so far. If there is a wish to model the terminal handling in more detail there are more incentives to include an agent representing the terminal handling. Inventory aspects are taken into consideration, even if they are not yet implemented as agents. Instead they are included in the physical simulator in TAPAS.

We regard the decisions which are taken by the agents as decisions when the system is stabilised after a certain amount of time when the actors have found the best way to take its decisions according to its perception of the situation.

Customer (C)

Each customer node is operated by a customer agent who is responsible for keeping the customer inventory at a reasonable level by sending order requests (to the TCC). The consumption, which for instance can occur as a consequence of production in the customer node, follows a probability distribution and takes place in the customer node, but the customer does not have exact knowledge of the consumption. However, it can access a forecast of the consumption on which it can base its ordering upon. We consider this a reasonable assumption since there often is some kind of approximate plan for how the products will be used in real transport chains.

An order request contains a customer node, a product type, a single order quantity q, and a delivery time-window. An inventory is connected to the customer node; however, it is possible to set the inventory capacity to zero if no customer inventory is assumed in the specific transport chain.

The ordering behaviour is based on the principles of the EOQ (Economic Order Quantity) formula which is claimed to be the most common ordering principle used in practise (Alstrom, 2001), see the previous chapter. With EOQ, the
calculation of the order quantity q is based on fixed order (transport) cost, inventory holding cost, and the forecasted demand, but the presence of different vehicles with different transport costs makes it difficult to estimate this quantity. Instead, we let the order request contain a number of different quantities. For the offers (one for each q) returned to the customer, it chooses the best alternative based on the lowest marginal costs.

An issue is that the customer needs knowledge about the lead-time from order to actual delivery to deduce the order point. Such information is however inaccessible to the customer since lead-times are different for different traffic modes and dependent on departure times for timetabled transports. To deal with this problem, we let the customer use estimated lead-times (chosen as an upper bound) and safety stock levels for the different products. This corresponds to integrating the knowledge built from experience by real-world customers.

When the customer inventory level is below the order point, the customer makes an order request. The time-window in the order request is computed based on the current inventory level, planned deliveries, the safety stock level, forecasted consumption during the lead-time, the maximum allowed inventory level, the order quantity q, and current time. A general tendency is that the larger the estimated lead-time is, the higher will the inventory level of the order point be, why the ordering probably will be made more often. Another consequence of a larger estimated lead-time is that the maximum inventory level probably has to be increased, which will cause a larger time-window. However, the time-window depends on many parameter settings, why it is difficult to draw general conclusions.

Details of how the order quantity, the order point, and the time-window are computed can be found in Holmgren et al. (2007).

*Transport Chain Coordinator (TCC)*

The TCC has a central role and it is responsible for receiving order requests, sending product and transport requests and receiving the corresponding proposals. For an order request from a customer it finds the cheapest offer (via requests to the TB and the PB) for production and delivery for each order quantity and sends order proposals back to the customer. We assume that the TCC has to know the possible producer alternatives before it can request transport alternatives.

*Product Buyer (PB)*

The PB operates between the TCC and the PP:s and is responsible for handling production related communication with these decision makers. When a product request is received it forwards it to all PP:s and when the production proposals are returned, it sends them back to the TCC for further processing. It also takes care of product bookings received from the customer via the TCC. If the role of the PB is extended in TAPAS it would also be possible that it would select
which production alternatives which are the best and send these selected alternatives to the TCC.

*Production Planner (PP)*

Each production node is operated by a production planner. Upon the reception of an order request from the PB, it creates a production proposal with a cost and the earliest time when the products can be ready for pickup. The modelled production strategy is therefore of make-to-order type which is commonly used in practice (Stevenson et al., 2005). It is assumed that the products can be produced and scheduled for pickup later but not earlier than this time. At the reception of a booking message (of a production previously given as a request), it communicates the booking to the factory.

The production the PP plans is primarily regarded as some kind of manufacturing, assembly, etc. However, since the production and production planning so far is modelled on a rather generic level it is also possible to regard the “production” as other types of product supply, such as replenishment of inventories. In the model of roles which appear in transport chains described in Chapter 4 the inventory planning is regarded as a separate role, but in TAPAS this function is so far modelled in the same way as the production planning.

*Transport Buyer (TB)*

The TB is responsible for compiling transport solutions from producers to customers to fulfill order requests initiated by customers and communicated to the TB via the TCC agent. The problem of creating an optimal transport solution from a production node to a delivery node contains the following complicating factors:

1. The capacities of the vehicles are restricted.
2. Some vehicles follow timetables, while others do not.
3. Delivered products must be unloaded at the customer inventory inside a time-window.
4. Previous bookings must be considered before booking new transports and productions.

The problem of how to find the cheapest transport solution can be seen as a shortest (cheapest) path problem (see, e.g., Gallo and Pallottino, 1988) in the transportation network, with additional constraints for handling timetables and time-windows. We were unable to find any existing research on how to address the problem, and therefore we had to develop and implement our own customised search algorithm.

For a transport request containing a producer node, a customer node, a product type, an order quantity, and a delivery time-window, the TB uses a set of precompiled transportation paths between the production node and the delivery
node. It can be regarded as reasonable that the TB has knowledge about characteristics of available transportation paths from its experience in the business. For each link in each path, the TB sends a transport request to all TPs, containing a start node, an end node, the requested product type, and quantity and some time interval which is calculated from the earliest possible production time and the preferred delivery time-window.

The time-window consists of one preferable time-window, but late deliveries within a wider time-window are also allowed. The wider time-window is determined by adding a constant to the preferable time-window. Deliveries within the wider time-window are penalised with a delay cost, modelled as an increasing cost function. The wider time-window allows for more flexibility of how possible transport solutions are searched for by letting the TB make a trade-off between delay and transport cost.

After the receipt of all requested link transport proposals, the TB combines them into one transport proposal for each precompiled path using a tree-based search algorithm. The best path proposals are then sent for evaluation to the customer via the TCC. Details about how transport proposals are created and selected can be found in Holmgren et al. (2007).

Transport Planner (TP)

Each TP controls a vehicle fleet of one traffic mode which operates some set of network nodes. Upon the reception of a transport request between two nodes, it generates proposals for the requested product and quantity with departure and arrival times inside the requested time-window. Since vehicles controlled by timetables have fixed departure and arrival times which are repeated within a certain frequency, and demand-driven transportation only departs when they are booked, the corresponding transport proposals are different. For a timetabled transport, a transport proposal is generated for each departure with departure no earlier than the start of the interval and arrival no later than the end of the interval, and for demand-driven transports, the TP generates one proposal, containing the actual travel time (without departure and arrival times), for each vehicle type in the fleet. The cost returned to the TB includes all costs associated with the transport.

So far load consolidation for demand-driven transportation is not modelled in TAPAS, but this is an important issue to study further. Complex transport planning of the coordination of different customer orders is therefore not fully modelled yet. Moreover, when comparing the TP role described in Chapter 4 to the TP in TAPAS, the latter do not include any route planning so far since the TB sends requests for specific links.
Figure 5.2. Interaction diagram.
**Interaction Protocol**

In this section the communication framework aiming at matching valid transport and production proposals to fulfil a customer order is illustrated. When we developed the interaction protocol we had to deal with a number of challenges.

– Transport and production cannot be booked simultaneously, one must be booked before the other,

– a production cannot be booked without matching it with a valid transport and vice versa,

– the computations needed to find the cheapest combination of production and transportation that fulfils the order might be very time consuming.

In the communication framework, where a negotiation requires two steps, a production is booked before a transport, but bookings are preceded by production and transport requests to assure valid overall solutions. See Figure 5.2 for the interaction diagram. Observe that only one production planner and one transport planner are shown to increase the readability of the diagram. See Holmgren et al. (2007) for further details of the interaction protocol.

**Comments**

In a simple transport chain there is only one agent per agent type, i.e., it is not possible to choose between for instance different TPs. There is often several transport and production alternatives, why several TPs and PPs exist, and several customers can also be connected to a transport chain. It would also be possible to include several TCCs where each TCC is connected to a PB and a TP, i.e., including a complex transport network.

**5.3 Implementation**

TAPAS is implemented as a discrete event based simulator in the Java 1.4 language. It has been argued that time-based simulation is more appropriate for MABS to take advantage of the distributed approach (Davidsson, 2000). However, we choose an event-based approach to avoid slowing down the simulations. In a similar application an event-based approach has also been used (Gambardella et al., 2002).

The decision making simulator is implemented as a multi-agent system with software agents representing decision makers. Agent platforms provide means for developing multi-agent systems and are claimed to facilitate and minimise the time for developing the systems (Wooldridge, 2002). There exist different types of agent platforms, e.g., TuCSoN and DESIRE, having different characteristics (Bordini et al., 2006). Often agent platforms support communication, coordination, debugging, and testing. Based on these characteristics we choose to make use of an agent platform, specifically the Java Agent DEvelopment Framework (JADE) platform (Bellifemine et al., 2007).
JADE supports distributed simulation and supply a library of FIPA interaction protocols.

Simulated activities (loading/unloading, departures, arrivals, etc) are all represented by events, which are scheduled in an event list. An activity is actually represented by two events, a start activity event and an end activity event. At the start of a simulation activity (triggered by a start activity event), the execution time of the activity is determined (possibly stochastic) and the end event is created and scheduled. Further, if an activity cannot be started when a start activity is scheduled, e.g., since it might be waiting for some other activity to finish, then it must wait for the blocking activity to terminate before trying again.

We have outlined several advantages of implementing our model as an agent-based system. However, there are of course drawbacks. For instance, running a multi-agent system is often rather resource intensive, for instance, due to the many interactions between the entities. Making use of an agent platform is argued to facilitate the development of multi-agent systems; however, when developing TAPAS we have also experienced its limitations. The main problem when developing TAPAS has been the limitations when developing advanced communication protocols, such as the protocol for the transport buyer. See Holmgren et al. (2007) for further discussions.

5.4 Characteristics of TAPAS

In this section characteristics of TAPAS are discussed as well as further possibilities of development. The characteristics of TAPAS have been discussed with experts of transport modelling. See Appendix for a more structured overview of the interviews.

One of the main characteristics of TAPAS is that it has the potential to capture realism of transport chains better than traditional macro-level models. This is due to a number of characteristics. Roles in transport chains are represented by heterogeneous agents in TAPAS, i.e., tasks are distributed to the agents. The agents have different responsibilities and goals, and they also have different information of the system which they use when performing their tasks. Cause and effects are captured in a natural way where the decision making of the agents and its negotiations and communication, etc. through interaction protocols lead to the performed logistical operations and the effects of these operations.

To get a better overview of the characteristics of TAPAS in relation to the classified models in Chapter 3, TAPAS is also classified according to the review framework presented in Chapter 3, see Table 5.1, 5.2, and 5.3.
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Table 5.1 Characteristics of the reviewed models. An x indicates that the property is included in the model.
Table 5.2 Overview of captured decisions. An “i” indicates that the decision is captured in the model, but that the decision is made outside the model, i.e., it is input to the model. An “o” indicates that the decision is captured and made within the model, i.e., it is output from the model.

Table 5.1 shows that TAPAS is the only simulation model of transport chains which makes use of dynamic time, and which usage has been illustrated with simulation experiments. (Simulation experiments with TAPAS are presented in the preceding chapter.) These characteristics illustrate that TAPAS enables to capture changes in the environment as the time evolve. Therefore time is an important property which is considered in the decision making of the agents. This is especially important when capturing more detailed planning decisions and it also increases the realism of the modelled transport chains. Gambardella et
al. (2002) is the model which is most similar to TAPAS and our purposes, but they do not present any simulation results. TAPAS is also one of the few models which have made a quantitative evaluation comparison (see the following chapter), however, one reason for this can also be that such comparisons have not been published in literature we have studied.

When comparing the decisions captured in TAPAS to the reviewed models in Chapter 3 (see Table 5.2) it can be seen that TAPAS is the only model which both captures product ordering and transport ordering decisions. This illustrates the extended scope than traditionally taken in transport models. TAPAS is also the only transport chain model which models the choice of producer node. This is an important characteristic since it enables to capture changes in logistical structures. For instance, this enables to study the effects of outsourcing or effects of a significant increase in transport costs on the choice of producer node. If the aim of public authorities is to introduce transport policies which reduce the amount of transportation, e.g., in terms of ton kilometres, this ability is important to include. This ability is also a consequence of the extended scope of transport chains.

<table>
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<tr>
<th>Policy</th>
<th>SAMGODS</th>
<th>SMILE v.1</th>
<th>SLAM</th>
<th>STEDS</th>
<th>Cube Cargo</th>
<th>GoodTrip</th>
<th>PACE-FORWARD</th>
<th>TLUMIP</th>
<th>deJong &amp; BenAkiva</th>
<th>Abouaissa et al.</th>
<th>INTERLOG</th>
<th>Gambardella et al.</th>
<th>Fox et al.</th>
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Table 5.3 Overview of captured transport policies and effects. An “i” indicates that the transport policy or effect is input to the model. An “o” indicates that the transport policy or effect is output from the model.
TAPAS is the model which captures most of the choice types in the review framework. The only choice that is not captured is inventory choice, i.e., the decision regarding whether to get the requested products from an intermediate inventory. This choice is only captured in the supply chain models.

TAPAS is the only model which captures the different planning decisions in the review framework. However, some of the planning decisions are so far implemented with a simplified behaviour. For instance inventory planning only considers the possibility to replenish and to take products from inventories in transhipment nodes, customer nodes, and producer nodes. Hence it is not possible to make use of intermediate storages so far in order to make use of replenishment strategies. Moreover, load coordination so far implies that it is possible to load several consignments on the same timetabled vehicle and that it is possible to make use of backloading. Load consolidation for demand-driven vehicles, for instance to solve routing problems, are not implemented so far.

Table 5.3 illustrates that TAPAS captures all transport policy types in the review framework, like the macro-level models, which indicate the purpose of transport policy analysis. TAPAS captures environmental effects in terms of emissions, and economic effects in terms of incomes to public authorities and internal costs. Moreover, TAPAS is the only one of the reviewed models which captures all types of logistics effects.

<table>
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<tr>
<th></th>
<th>Abousse et al.</th>
<th>INTERLOG</th>
<th>Gambardella et al.</th>
<th>Fox et al.</th>
<th>van der Zee et al.</th>
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Table 5.4. Modelled transport chain roles in the reviewed models.

The majority of the roles defined in the previous chapter are implemented as agents in TAPAS, see the summary in Table 5.4; however, the terminal planner and inventory planner are so far not implemented as agents. Inventory aspects are taken into consideration, even if they are not yet implemented in terms of an agent. Instead they are included in the physical simulator of TAPAS.
Transhipment is also considered, but is not implemented in terms of a terminal agent due to the currently rather simplified functionality.

5.4.1 Further possibilities of TAPAS

There are several possibilities to further develop TAPAS. Some examples of further development are discussed in this section.

Behaviour of agents

So far the decision making of the agents is mainly based on cost minimisation strategies. Since time-based costs are included, speed and frequency are accounted for. It is also possible to include other aspects in the decision making. Examples of other parameters except cost which have an important influence are network coverage, current cooperation, reliability, risk of product damage, as well as risk of accidents. These parameters could be captured in different ways, e.g., in monetary terms (see, e.g., (Friberg et al., 2008)). Moreover, the project partners in the East West Transport Corridor project have validated that environmental performance is a relevant performance indicator which they wish to take into account. In a future version of TAPAS it would also be possible to capture more long-term costs of the transport chain actors, such as vehicle taxation, in the decision making. Then long term issues such as investment decisions can be taken into account. Furthermore, the search process of the PB for finding appropriate product proposals can also be improved.

Capturing more types of decisions, e.g., load consolidation decision, enables to represent more fleet management issues which are crucial when the utilisation of the resources are examined. This would enable to study effects of measures to improve the performance in transport chains, e.g., by more flexible time-windows of delivery. If load consolidation is properly captured, this also enables to better model the types of transport chains where this is a major issue. Examples of such transport chains are piece goods transportation (e.g., with Schenker). Another suggestion of further work is letting the TP plan the routes to a greater extent.

Including more advanced behaviour in the agents is another suggestion for how TAPAS can be further developed. For instance, more sophisticated optimisation algorithms can be integrated in the agents to improve the quality of their decisions. This can possibly make the system prescriptive rather than descriptive, and open up for the usage of TAPAS for studies which are of more interest for the transport chain actors rather than public authorities. Another way to include more advanced behaviour in the agents is to allow the agents to learn from experience, e.g., customer agents regarding lead-times and safety stock levels. It would also be possible to make other agents than the customer to take initiatives on communication between the agents. For instance, if the agents make use of VMI, the transport chain coordinator may control the customer
inventory levels and initiate the transport and product ordering at certain order points.

**Agent types**

TAPAS can also be further developed by enabling the usage of different types of the respective agents, i.e., different decision strategies. For instance, different types of ordering strategies are used by different types of customers, why the possibility to choose among a set of decision strategies would enable to better capture different types of roles in transport chains.

TAPAS does not currently capture all identified roles defined in the generic model of transport chains presented in Chapter 4. Therefore, including these roles, i.e., the terminal planner and the inventory planner, in terms of agents would enable for capturing more types of transport chains. Simple inventory and terminal behaviours are currently modelled in the physical simulator.

**Interacting agents**

Another possible extension of the work is to study different ways of interactions between the agents, i.e., to experiment with other interaction protocols. For instance, allowing agents to initiate and respond to messages outside the presented interaction framework is interesting to examine. As an example, the production buyer might suggest an order quantity that fits one producer. The means of communication and negotiation differs in different types of transport chains (Andersson and Norrman, 2002), why this would allow for capturing these differences.

An advantage of the agent-based approach is that it is possible to give the agents different perceptions of the environment (in this context the transport chains). This can represent the realistic situation that different roles in transport chains have different information concerning resources, costs, etc. An issue which is important in transport chains is in which degree the actors share information between each other, i.e., the degree of visibility. For instance, if the roles appear within the same organisation there is probably a higher level of transparency than if the roles are spread between different organisations. A measure for improving the performance of transport chains is increasing the visibility in a transport chain. Since improving the efficiency of transport chains might be of interest for public authorities, this is relevant to further study.

**Functionality of the physical simulator**

To capture more functionality in TAPAS, more details in the physical simulator can be included. As an example, the transshipment activities at the terminals can be explicitly simulated. Another example is to simulate intermodal transportation by also simulate the loading units. This would enable to study the flow of empty containers as well as issues of availability of feasible load units. In the current version of TAPAS, multimodal transportation is considered, i.e., the loading units are not explicitly captured.
Moreover, external aspects influencing transportation are relevant to include. As an example, to simulate other traffic on the links would allow us to study the effects of link congestion. This would enable to study capacity issues such as congestion at peak hours on certain infrastructure.

The deterioration rate of the products over time is also planned to be implemented in TAPAS. This enables us to analyse possible waste of products for instance due to long transport times or inventory levels at producers or customers which are set too high.

Performance of simulator

There are also possibilities to improve the performance of TAPAS, for instance by a more efficient route selection method and make TAPAS run in a GRID environment.

5.5 Concluding remarks

In this chapter the agent-based simulator TAPAS which has been developed is described. Whereas traditional approaches rely on assumed statistical correlation between different parameters, TAPAS relies on causality, i.e., the decisions and negotiations that lead to the performed transportation and production. The aim of TAPAS is to have a generic structure which enables to study different types of transport chains of different types of organisations, collaborations, etc. We have chosen to implement certain decision strategies in the agents which we regard as common for many transport chains.

The characteristics of TAPAS are discussed and presented with the review framework. Since TAPAS uses an agent-based approach, the decision making in transport chains is naturally represented by the inclusion of decision making agents. Moreover, the extended transport chain scope enables to capture more important logistical decisions, such as producer node choice, which enables to capture logistical restructuring. Since dynamic time is captured, the modelling of detailed aspects, such as planning decisions, is enabled. This increases the realism of the modelled transport chains.

The typical characteristics of TAPAS show that TAPAS has many of the characteristics typical for MABS. TAPAS has the possibility to take advantage of more MABS characteristics, which are outlined in the chapter. For instance, it is possible to extend the behaviour of the agents as well as the included agents and to develop the interactions between the agents.

In the next chapter the usage of TAPAS is illustrated by formulating scenarios of transport chains which are used when performing simulation experiments. Validation and verification of TAPAS are dealt with in the following chapters since this is connected to the examination of TAPAS.
Chapter 6

Scenarios and simulation results

The usage of TAPAS is illustrated in this chapter with scenarios and simulation experiments. The scenarios have been defined in collaboration with the project partners in the East West Transport Corridor project (http://www.eastwesttc.org/). Many of the companies in the project exist along the transport corridor. In the project a transport corridor between China and northern Europe, via the Baltic Sea states, is studied. The transport corridor is interesting since it is possible that increased goods volumes will be transported via the Trans-Siberian railway in the future, i.e., in the transport corridor, instead of with container ships directly from China to northern Europe which is currently the most common way. It is interesting to analyse the prerequisites of the corridor and predict possible effects, such as traffic mode and route choice, of different types of transport policies on the corridor. Another purpose with illustrating the usage of TAPAS is validation and verification of TAPAS. Two main scenarios are presented in this chapter, where the first scenario is a simplified version of the whole transport corridor, and the second scenario represent the whole corridor.

The scenarios illustrate how it is possible that the roles in transport chains presented in Chapter 4 appear in some of the companies in the East West Transport Corridor project, see Figure 6.1. The two main scenarios are very similar; the difference is mainly that more actors are involved in the scenario of the whole corridor than in the basic scenario. It is possible that a customer company along the East West Transport Corridor has a strong position and includes the roles of the customer, the transport chain coordinator, the transport buyer, and the product buyer. The producing companies in the corridor would then be represented by production planners, while the road, rail, and sea operators would be represented by transport planners. The sea port operators as well as a terminal operator in a transhipment node are represented by terminal planners.
6.1 Basic East West Transport Corridor scenario

The first scenario concerns a transport corridor between the Baltic States and UK, which is a part of the larger transport corridor between China and northern Europe. In this scenario we are interested in studying the effects a kilometre tax on Swedish trucks will have in this international and intermodal transport chain. The target interest group of the scenario studied would be public authorities in Sweden. In this section the scenario will be described followed by the simulation results and the analysis of the results.

6.1.1 Scenario

The scenario consists of several possible transport alternatives for transportation of 20 ft ISO-containers (i.e., TEU containers) from Kaunas in Lithuania to Harwich in the UK. The considered transport links are:

- Rail transport from Kaunas to Klaipeda.
- Road transport from Kaunas to Esbjerg.
- Sea transport from Klaipeda to Karlshamn.
- Rail transport from Karlshamn to Esbjerg (electrical locomotives from Karlshamn to Taulov, diesel locomotives from Taulov to Esbjerg).
- Road transport from Karlshamn to Esbjerg.
- Sea transport from Esbjerg to Harwich.

See Figure 6.2 for an illustration of the three transport alternatives, or routes, in the scenario. Route 1 is the considered East West Transport Corridor.

1. Kaunas (train) Klaipeda (ferry) Karlshamn (train) Taulov (train) Esbjerg (ferry) Harwich
2. Kaunas (train) Klaipeda (ferry) Karlshamn (truck) Esbjerg (ferry) Harwich
3. Kaunas (truck) Esbjerg (ferry) Harwich

The containers contain goods with medium value, such as furniture or kitchen appliances. The producer is assumed to be located in Kaunas, and the customer is assumed to be located in Harwich, where there is a customer inventory. In general, we have tried to use real-world data from companies which possibly can use the corridor as much as possible, but when it has not been possible we have used some of the data from a study called the Scandic Bridge pre-study made on transport alternatives from Klaipeda to Esbjerg, i.e., a part of the transport corridor (CTT – DTU & SDU, 2004). The analysis in the Scandic Bridge study is made with a GIS (Geographical Information Systems) tool. Since we are able to use more detailed data in our simulation experiments than in the pre-study, we have chosen to use real-world data when possible, and averaged data from the Scandic Bridge study when we have not been able to find data. The data is therefore collected from the companies participating in the East West Transport Corridor project when possible.

The assumptions and data that we have used in this scenario:

- **Product type.** The product value is 20000 euro/TEU, and the acceptable lead-time for the customer to get the products is 18 days. The inventory holding cost is 0.50% of the product value per day. The weight of one container is 11 tons and the volume capacity of the container is 39 m³.

- **Consumption.** There are consumption opportunities every third day and the average consumption is 3 TEUs.
- **Order behaviour/quantity.** The product demand is not fully known to the customer. However, there is a forecast of the demand, in terms of a probability distribution, of which the customer has access. The probability distribution used here is a Poisson distribution. When the customer inventory level is below the inventory level of the order point, the customer makes a request of 1, 2 and 3 TEUs, and when it has received the proposals, it chooses the cheapest feasible alternative based on transport costs and the inventory holding costs during transport. Hence the consignment size is not fixed. See Holmgren et al. (2007) for further details.

- **Time-windows.** As explained in the previous chapter, the customer calculates a preferable time-window for delivery, but also accepts late deliveries within a wider time-window if it is economically preferable. In this scenario the trade-off is made by setting a penalty cost of 1440 euro/day for late deliveries.

- **Inventory levels.** The initial inventory level is set to 15 TEUs. Therefore there is no need to warm up the simulator. The safety stock level in the customer storage is 4 TEUs and the maximum storage level is 40 TEUs.

- **Production.** The principle used for modelling the production is make-to-order. The focus is not on production in this case, why the production lead-time is assumed to be short, less than a day. The production cost is also not the focus since there only is one production node, why the production cost is low. See Appendix for further information.

- **Links.** Road link distances have been collected from an online roadmap service ([http://www.viamichelin.co.uk](http://www.viamichelin.co.uk)). Rail link distances have been estimated based on the road link distances. Sea link distances have been averaged based on transport times and average speeds of the ferries.

- **Time assumptions.** We have tried to make reasonable transport times assumptions based on information from some transport operators operating on transport links in the scenario. When we have not been able to find accurate information we have used data from the Scandic Bridge pre-study (average speed assumptions). In intermodal nodes (Klaipeda, Karlshamn, Esbjerg and Kaunas) we consider loading and unloading. The loading times are based on information received from the port of Karlshamn in the transport corridor, and this data is then used in all nodes. In the scenario the trains and ships are transported according to timetables, while trucks are not restricted to timetables. The timetables are based on existing timetables concerning transport times, see Appendix. See mode specific time details below.

- **Cost assumptions.** The cost assumptions are mainly based on the cost information from transport operators along the East West Transport
Corridor and more general costs partly found from Sveriges Åkeriföretag (http://www.akeri.se/). Fuel prices have been collected from the European Commission and EuroStat (2005) and Swedish fuel tax levels from SPI (http://spi.se/) and (Ministry of Finance, 2004). We assume that the costs which occur from production to consumption are the costs which the customer pays to receive the required products and hence the estimated profit of the logistics service providers is included. (See Section 5.1.1 for a description of the cost parameters.) We have not been able to find real-world data for all detailed cost parameters and transport alternatives. Instead we have tried to get the overall costs as accurate as possible. An administrative order cost is used to indicate the additional cost for each shipment and links used (de Jong and Ben-Akiva (2007) use a similar cost component). Since we do not have any basis for this cost component, the administrative order cost is assumed. Since no producer node choice occurs in this basic scenario, the production cost is of no interest, and it is therefore assumed to be low. Loading and unloading costs in the intermodal nodes are based on costs at the port of Karlshamn. See mode specific cost information below.

- **Vehicle characteristics.** The vehicle characteristics, such as dimensions, capacities, energy usage, and emission factors, are based on vehicle characteristics collected by NTM (2005). Default vehicle load factors for the train and ship transports from NTM (2005) are used for cost calculations, as well as calculations of the environmental performance.

- **Sea transportation.** Currently there are only RoRo ferries on the links Klaipeda–Karlshamn and Esbjerg–Harwich. Therefore we assume that the containers are transported on mafi, i.e., a small wagon used for pull on and off the ferry, or on a driverless trailer chassis. The total costs for the two ferry lines are based on the costs used on the Klaipeda-Karlshamn link, but the share between distance- and time-based costs are not known. The average speed is estimated based on the timetables and the vessel characteristics.

- **Rail transportation.** Since the studied scenario is part of the larger transport corridor from China, rail transportation between Kaunas and Klaipeda is part of rail transportation on the Trans-Siberian railway. The transport costs for transportation on the Trans-Siberian railway are assumed to be lower than the costs for rail transportation in Sweden and Denmark due to the long distance. It is difficult to find timetables of the departures between Karlshamn and Esbjerg, but there exist timetables on the Swedish part of the link. The transport times highly depend on the type of rail transportation, such as wagon load systems and system freight trains. In this scenario we regard the type of rail transportation as a type of wagon load system, where shunting takes place, why the average speed is rather low. Also, we assume that the trains between
Karlshamn and Esbjerg cannot use a high average speed since the transportation takes place during the day when the railways are rather congested. Therefore the assumed average speed between Karlshamn and Esbjerg is based on the rather low average speed information for European railways (European Commission, 2001). In the scenario there is a need for a change from electrical locomotives to diesel locomotives in Taulov since the railway between Taulov and Esbjerg is not electrified. We assume shorter transhipment times in Taulov than in the intermodal nodes.

- **Road transportation.** The road toll for trucks when passing the Öresund Bridge and the Great Belt Bridge is included (see [http://osb.oeresundsbron.dk/](http://osb.oeresundsbron.dk/) and [http://www.storebaelt.dk/](http://www.storebaelt.dk/)). The driver cost is assumed to be lower for the road transportation from Lithuania to Denmark due to lower salaries in the Baltic States for Baltic drivers compared to Swedish drivers. The distance- and time-based costs have been estimated based on real-world hauliers, but are not connected to a specific company. The average speed of the trucks is based on estimations made by FoodTankers. We assume a rather low speed for road transportation from Kaunas to Esbjerg since it includes resting times for the driver to reflect existing regulations.

- **Simulated time.** Around 520 days are simulated and the precision is 1 minute. We argue that there is no need for several replications since the simulation run is sufficiently long and running a longer simulation will give similar results.

In Table 6.1-6.3 some of the input data is presented.

<table>
<thead>
<tr>
<th>Connected nodes</th>
<th>Link 1</th>
<th>Link 2</th>
<th>Link 3</th>
<th>Link 4</th>
<th>Link 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Modes</td>
<td>Rail</td>
<td>Sea</td>
<td>Road, rail</td>
<td>Road</td>
<td>Sea</td>
</tr>
<tr>
<td>Length (km)</td>
<td>240</td>
<td>537</td>
<td>487, 517</td>
<td>1562</td>
<td>648</td>
</tr>
<tr>
<td>Av. Speed (km/h)</td>
<td>19</td>
<td>37</td>
<td>63, 18</td>
<td>36</td>
<td>37</td>
</tr>
<tr>
<td>Adm. order cost (euro)</td>
<td>7</td>
<td>7</td>
<td>7</td>
<td>7</td>
<td>7</td>
</tr>
<tr>
<td>Road toll (euro)</td>
<td>219, 0</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Table 6.1.** Input data for the links.
Table 6.2. Input data for the vehicle types.

* The time-based cost includes driver cost and capital cost.

Table 6.3. Loading and unloading cost and times. Costs and times are assumed to be the same for all different transport modes, except for the part of the link where diesel train is used in Denmark, where the fixed loading time is 30 min.

The assumptions above represent the base case. In the simulation experiments we study an introduction of a kilometre tax on trucks in Sweden and its effects. The tax levels that we are examining are the levels suggested by SIKA (Friberg et al., 2007a), but we have also been inspired by Ministry of Finance (2004). The suggested kilometre tax is differentiated based on the euro class of the truck (here euro class 3), as well as on the total weight and the number of axles of the truck. Different types of implementations are represented in the cases that are studied:

- **Base case.** Current situation, no kilometre taxation. The diesel tax is assumed to be 0.40 euro/l (Friberg et al., 2007a).
- **Case 1.** A kilometre tax as suggested by SIKA (Friberg et al., 2007a). A lower diesel tax is assumed, 0.30 euro/l (the minimum level within the EU (Ministry of Finance, 2004)).
- **Case 2.** A kilometre tax as suggested by SIKA. The same diesel tax as in the base case is assumed.
6.1.2 Simulation results

From these simulation experiments it is possible to see the choice of traffic mode, truck type, transport route as well as the size of the consignments. Also, performance metrics in terms of for instance amount of emissions released into the atmosphere, the total costs, and the tax income to the public authorities are possible to distinguish. The simulation results show that in the base case as well as in Case 1, road transportation in Sweden and Denmark is chosen, while there is a modal change in Case 2 to rail transportation in Sweden and Denmark. This corresponds to a change of the route choice from Route 2 to Route 1.

Case 2 also results in a change of order size. In the base case and in Case 1 where road transportation in Sweden and Denmark is chosen, the order size is 2 TEUs, while in Case 2 where rail transportation between Karlshamn and Esbjerg is chosen, the order quantities are 3 TEUs. This can be explained by the administrative order cost which makes it more profitable to order fewer but larger order quantities. An order size of 2 TEUs is chosen since the trucks which are possible to choose have the capacity of 1 TEU or 2 TEUs, and the cost per TEU is lower for the truck with the larger capacity.

![Figure 6.3](image)

**Figure 6.3.** Transport costs (euro) per TEU for the customer per case and CO₂ (kg) per TEU.

In Figure 6.3 the transport-related costs per TEU for the customer and the amount of CO₂ per TEU are illustrated. The transport costs included in the figure are therefore the distance-based costs, time-based transport costs (driver and capital costs), taxes and fees. The loading and unloading cost, the inventory
holding cost and the production cost are not included. The lowest transport costs for the customer appear with Case 2 where Route 1, i.e., rail transportation in Sweden and Denmark, is chosen. The reason for this is that rail transportation is cheaper than road transportation. Although, rail transportation is not chosen in the previous cases since choosing rail transportation leads to deliveries outside the preferred time-window. However, when the costs for road transportation increase due to the kilometre taxation, rail transportation is chosen despite deliveries outside the preferred time-window. When the transport buyer makes transport suggestions, it makes a trade-off between cost and time by adding a penalty cost for deliveries outside the preferred time-window (but still within the acceptable time-window). In Case 2, the customers benefit more when choosing Route 1 instead of Route 2, despite the penalty cost and the deliveries outside the preferred time-window. When the products are delivered outside the preferred time-window the customer is less satisfied with the service.

Concerning the environmental performance in terms of CO₂, as expected, the lowest amount of CO₂ appears in Case 2 where rail transportation is chosen instead of road transportation in Sweden and Denmark. For the results of other emissions, see Appendix.

In this scenario the total tax income for the simulated time to the Swedish public authorities from the kilometre tax and the diesel tax is largest in Case 1 when there is a kilometre tax and road transport is chosen (around 3660 euro), while it is zero for Case 2 when only rail transportation is chosen in Sweden, and very small in the base case when there is no kilometre tax (below 10 euro).

6.1.3 Analysis

The simulation experiments and results presented in the previous section have shown that it is possible to observe several effects of an introduction of a kilometre tax, e.g., concerning order quantity, mode choice, route choice, etc. when using TAPAS.

As pointed out above, the results should be regarded as illustrative examples of the usage of TAPAS. An example of a weakness in the study is that some of the cost parameters probably do not properly represent the real-world scenario. Some cost parameters we have received from companies are template values which do not represent our specific scenario, why we have estimated some cost parameters. For instance, the distance-based costs for rail transportation might be too high. When the distance-based costs for rail transportation in Sweden and Denmark were set lower (6 euro/km), Route 1 with rail transportation in Sweden and Denmark was chosen in the base case instead of Route 2, i.e., the modal split results are the same as in Case 2. However, since the aim was to illustrate the possible effects of a kilometre tax in Sweden for this transport chain, it would not have been possible to observe any modal shift effects of a kilometre tax in this scenario if rail transportation already was chosen in the base case. Of course
there exist other possible effects of an introduction of a kilometre tax, but such effects, e.g., road choice, are not possible to observe in this scenario.

Another issue is that we assume that profit is included in the cost parameters. Information regarding the profit of different types of companies is difficult to receive, why we have mainly estimated this based on price quotas.

The emission calculations are based on the methods by NTM (2005), however, since the methods and data especially for international transports are preliminary and work-in-progress (e.g., data for some of the countries are missing), the results should only be regarded as hints of possible environmental performance.

6.1.4 Relation to similar studies

Studies relevant for comparison that have been done on examining the possible effects of a kilometre tax in Sweden, and especially in southern Sweden, are Lundin (2007) and Yngström-Wänn (2007). These studies have been performed within the East West Transport Corridor project. Also, Kronbak (Sakalys et al., 2007) has studied the competitiveness of the transport corridor. There also exist other studies of the effects of kilometre taxation in Sweden, e.g., EPA (2003) and Friberg et al. (2007b).

Lundin (2007) has examined the effects of a kilometre tax on the mode choice with a model called EFM-STAN. (STAN is also a part of the Swedish SAMGODS model). Both transit transports via southern Sweden and import/export are included, and the transport alternatives we study are included, i.e., road transportation in Germany and Poland, sea transportation in the Baltic Sea, and road or rail transportation in southern Sweden. An additional rail transport alternative in Germany and Poland is assumed. The kilometre tax which has been studied is a 50% increase of the operative distance-based cost, as well as a 100% increase of the operative distance-based cost. The effects which have been observed in the study are that road transportation decrease with 9% in Sweden for the first scenario, and 19% in the second; while rail transportation increase with 5% and 6% respectively. Road transportation in Germany and Poland also increased somewhat, as well as sea transportation. The tendency in this study and our study is similar, but the modal shift effect is clearer in our scenario since we only include one type of transport chain, while Lundin simulates all transportation in the corridor. A difference is that we do not get any road transportation at all from Lithuania to Esbjerg in our scenario.

The study by Yngström-Wänn (2007) concerns the possible effects on the route choice in Sweden as a consequence of a kilometre tax in Sweden. Therefore only road transportation is included in the model. Different cases of implementations of a kilometre tax have been examined with Samper/Samkalk, mainly differentiated in various ways on different road types, or road networks. There is a wish by the Swedish Road Administration to encourage trucks to use the main highways to increase the safety. The simulations by Yngström-Wänn show that
for some of the implementations of a differentiated kilometre tax it is possible to steer over transportation to these roads. However, a negative effect of such cases is that the amount of CO₂ increases due to increased number of vehicle kilometres and the increased amounts of emissions per kilometre as a consequence of higher speed on the main road network. Cost assumptions are based on Swahn and Pyddoke (1999) where distance- and time-based costs are defined. A difference from our assumptions is that the Swedish Road Administration assumes that driver and capital costs are included in the distance-based cost, while we assume that they are time-based costs.

Friberg et al. (2007b) have also made a simulation study with SAMGODS of an introduction of a kilometre tax in Sweden. Their assumptions are similar to the assumptions made by Yngström-Wänn, but they analyse the effects on transportation in the whole of Sweden and effects of modal shifts are included. Mainly the effects regarding the traffic work and transport costs per traffic mode are analysed. Results of simulations of a kilometre tax differentiated on vehicle weight, number of axles, and euro class are compared to simulation where the kilometre tax is further differentiated on rural and urban roads. According to these simulation results, the effects of a kilometre tax are rather small, and the results show that the further differentiation on rural and urban roads does not give any large effects.

Kronbak (Sakalys et al., 2007) mainly studies the cost competitiveness of the transport corridor by comparing costs for alternative routes between Lithuania and the UK. In addition to the routes we have studied, a route which includes RoRo transport from Klaipeda to Aabenraa in Denmark, and by truck to Esbjerg, is included. The results are illustrated with isocost maps. The conclusions are that the transport alternative including road transportation in Sweden and Denmark is not competitive due to high bridge tolls. Also, it is concluded that the rail transportation costs in Sweden and Denmark have to be rather low to be competitive in the corridor (around 500 euro/2 TEU). It is possible to compare the transport costs Kronbak presents with our transport costs, but since Kronbak only studies the transport alternatives between Klaipeda and Esbjerg, the costs for the links Kaunas-Klaipeda and Esbjerg-Harwich have to be omitted. Our costs when making use of road transportation are a bit lower than the costs calculated by Kronbak: our costs are around 1410 euro/2 TEU while Kronbak’s are 1650 euro/2 TEU. Also for the rail alternative, our costs are a bit lower than the costs presented by Kronbak: our costs are 1050 eur/2 TEU, while Kronbak’s are 1200 euro/2 TEU if the competitive costs for rail transportation are used. Our costs on the rail link are 440 euro/2 TEU which corresponds to Kronbak’s conclusions of competitive rail transportation costs.

The rail transportation costs are also compared to costs presented by Wajsman (2005). Our transport costs (0,019 euro/ton kilometre) correspond well to the average transport costs by Wajsman (0,018 euro/ton kilometre). Wajsman also presents transport costs for higher value freight which probably corresponds
rather well to the product types used in the basic East West Transport Corridor scenario (0.031 euro/ton kilometre). However, since the transport costs which are presented by Wajsman are the transport costs paid by the transport buyer, transhipment costs are probably also included in these transport costs. Thus, since our transport costs do not include transhipment costs, our transport costs are probably a bit higher than the transport costs by Wajsman (especially if the rail transports are part of a wagon load system).

A general difference between the related studies above and our study is that our scenario concerns one type of transport chain, compared to the studies above which concern all transports in the area. This also explains the difference in the results; our results show clearer tendencies since the study concerns one unique transport chain.

6.2 Extended East West Transport Corridor scenario

In the second scenario the transport chain is extended to also include transports from China instead of from Lithuania. Here we study different measures which might improve the competitiveness of the transport corridor. Therefore, in this scenario possible users of TAPAS are logistics companies along the transport corridor or public authorities representing a region along the corridor, e.g., southern Sweden.

6.2.1 Scenario design

In the extended scenario which we have implemented the following nodes are added:

- producer in Shanghai
- producer in Odessa
- terminal/hub in Fredericia
- terminal/hub in Vladivostok/Nakhodka/Vostochnyy
- terminal/hub in Kaunas (no longer producer)

and links:

- ferry between Shanghai and Vladivostok
- train between Vladivostok and Kaunas/Klaipeda
- ship between Shanghai and Felixstowe

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3 Felixstowe and Harwich are next to each others, where Felixstowe is the container terminal, while Harwich is the RoRo terminal.
- train between Odessa and Kaunas/Klaipeda
- ferry between Klaipeda and Fredericia
- truck between Fredericia and Esbjerg

A number of different measures to increase the competitiveness of the corridor are evaluated.

In the first simulation study we assume that the production takes place in Shanghai. In this case, the relevant transport network is illustrated in Figure 6.4. Route 3 is the East West Transport Corridor alternative.

Thus, in this case there are six transport alternatives, or routes:

1. Shanghai (ship) Felixstowe
2. Shanghai (ship) Vladivostok (train) Kaunas (truck) Esbjerg (ferry) Harwich
3. Shanghai (ship) Vladivostok (train) Kaunas (train) Klaipeda (ferry) Karlshamn (train) Taulov (train) Esbjerg (ferry) Harwich
4. Shanghai (ship) Vladivostok (train) Kaunas (train) Klaipeda (ferry) Karlshamn (truck) Esbjerg (ferry) Harwich
5. Shanghai (ship) Vladivostok (train) Kaunas (train) Klaipeda (ferry) Harwich
6. Shanghai (ship) Vladivostok (train) Kaunas (train) Klaipeda (ferry) Fredericia (truck) Esbjerg (ferry) Harwich
In the second study we assume that there is an alternative producer situated in Odessa. In this study an additional link between Kaunas and Odessa is added, see Figure 6.5.

**Figure 6.5.** The extended scenario (two producers).

Thus, in this case there are five additional transport alternatives, or routes. In this case Route 3 is the East West Transport Corridor.

7. Odessa (train) Kaunas (truck) Esbjerg (ferry) Harwich
8. Odessa (train) Kaunas (train) Klaipeda (ferry) Karlshamn (train) Taulov (train) Esbjerg (ferry) Harwich
9. Odessa (train) Kaunas (train) Klaipeda (ferry) Karlshamn (truck) Esbjerg (ferry) Harwich
10. Odessa (train) Kaunas (train) Klaipeda (ferry) Harwich
11. Odessa (train) Kaunas (train) Klaipeda (ferry) Fredericia (truck) Esbjerg (ferry) Harwich

Similar assumptions are made in the extended scenario as in the basis scenario. Here we present some further information and clarifications of the assumptions. See Appendix for further information.

Like in the basis scenario, the timetables used in the extended scenario are based on real-world timetables when possible; in this case all timetables except timetables for rail transportation on the Trans-Siberian railway exist. For the sea link Klaipeda-Harwich, the timetable for Klaipeda-Immingham is used instead. See Appendix for timetables and other data describing the links.
- **Consumption.** For both product types, the amount of containers consumed is assumed to be on average 2 TEUs every fourth day.

- **Ordering behaviour.** There is an ordering opportunity for the customer every day.

- **Inventory levels.** The safety stock level in the customer storage is 20 TEUs, the maximum stock level is 40 TEU, and the initial stock level is 24 TEUs.

- **Product types.** In the extended scenario we include different production costs for the two producer nodes, for production in Shanghai we assume no costs, while it is 5000 euro/TEU for production in Odessa. We lack production cost information why we are just interested in the relative difference of the costs. Consequently the production costs are higher in Odessa, but the transport costs will be lower due to the shorter transport distance compared to transportation from Shanghai. We study two types of products, product type 1 with a lower value (e.g. furniture) which is 20000 euro/TEU, and product type 2 with rather high product value (e.g., computers) which is 100000 euro/TEU. The inventory holding cost for the two product types is 0,10% per day of the product value. The acceptable lead-time also differs between the product types, for product type 1 it is 40 days and 31 days for product type 2.

- **Rail transportation.** In this scenario, rail transportation in Sweden occurs mainly during night, why the speed is assumed to be higher than in the basic scenario. The rail transportation in Denmark takes place during the day, why the speed in Denmark is slower than the transportation in Sweden. However, the overall higher speed compared to the basic scenario can also be seen as depending on the different types of rail transportation solutions in the two scenarios. If the type of system in the basic scenario is a wagon load system, the system used in this scenario can be regarded as a system freight train where no shunting takes place which makes the transportation faster. Electrical trains are assumed from Vladivostok to Kaunas and Klaipeda. From Odessa to Kaunas and Klaipeda are diesel trains assumed. We assume that large trains are used on the Trans-Siberian railway, which effect emission levels, etc.

- **Cost assumptions.** Concerning the additional cost components in the extended scenario, they are collected in a similar way; the known total costs are used to estimate detailed cost components as well as used on similar transport links when there is a lack of cost information. The total costs which are known in this scenario are the rail transportation costs from Odessa to Klaipeda, and approximate sea transportation costs from China to the UK. More details of the vehicles and its costs can be found in the Appendix.
- **Simulation time.** The simulation experiments are run for about 208 days and the precision is 1 minute.

We examine four different measures to improve the competitiveness of the East West Transport Corridor, i.e., the transport alternative from Klaipeda-Karshamn-Esbjerg-Harwich, when the producer is located in Shanghai.

- **Measure 1 (M1)** An increase of the frequency of departures (trains and ferries) for the links between Klaipeda and Karlshamn, between Karlshamn and Esbjerg, and between Esbjerg and Harwich so that there is a departure each day.

- **Measure 2 (M2)** An increase of the speed of the ferries and trains on the above links. Fast ferries are assumed to be used between Klaipeda and Karlshamn, and between Esbjerg and the UK, why we assume an average speed of 74 km/h. This implies higher fuel consumption since the fuel consumption is quadratic in relation to the speed (NTM, 2005). The freight trains between Karlshamn and Esbjerg are assumed to be given a higher priority why a higher speed can be used. The higher assumed average speed is 90 km/h. Moreover, the timetables are better synchronized to reduce the transport time in the East West Transport Corridor, see Appendix.

- **Measure 3 (M3)** Shorter times in the nodes, for instance due to port infrastructure investments. The fixed loading and unloading times in the nodes are here assumed to be 30 min, instead of 150 minutes. Moreover, the customs time is assumed to be shorter when the train is leaving Russia. This will imply that the transport times for train transportation between Vladivostok and Kaunas/Klaipeda is shortened. Customs is modelled as a short link in Vladivostok and Kaunas. In the base case the customs are assumed to take three days when passing the Russian border, while in this measure the customs time is assumed to be one day instead. The timetables are also adjusted after these new prerequisites, see Appendix.

- **Measure 4 (M4)** Measure 4 is based on Measure 3, but a kilometre tax is also added on trucks in Sweden. The kilometre tax implementation is the same as the one in Case 2 in the basic East West Transport Corridor scenario, i.e., a high kilometre tax and the current diesel tax.

### 6.2.2 Simulation results

First the simulation results of the case with a producer in Shanghai are presented, followed by the results of having an additional producer in Odessa.
In Figure 6.6 and 6.7 above the proportion of TEU per route and case is illustrated. In the case with product type 1, almost only direct transportation with container ship from China to the UK (Route 1) is used. Only Measure 2 slightly
reduces the amount of containers transported directly to the customer since Route 2 (where road transportation from Kaunas to Esbjerg is included) sometimes is chosen. The large amount of direct transportation from China to the UK corresponds rather well to the real-world situation since this is mainly used today, according to project partners in the East West Transport Corridor project. In the case with product type 2 both Route 1 and Route 2 are chosen. Route 2 is the fastest of all transport alternatives. This reflects that time is valued higher for transportation of product type 2 than transportation of product type 1 since this product type requires faster transportation due to shorter lead-times. All measures increase the share of faster transportation somewhat, but the increase is rather moderate. The reason why direct transportation still is chosen is probably that certain timetabled departures match the required time-window rather well. Note that despite the measures to increase the competitiveness of the East West Transport Corridor (Route 3) it is not chosen. Probably there is a need for even greater measures to achieve more transportation in the corridor, especially regarding transport times.

**Figure 6.8.** Proportion of vehicle kilometres per traffic mode for product type 1.

Figure 6.8 and 6.9 illustrate the modal split (based on vehicle kilometres). Of course, the largest amount of vehicle kilometres is sea since direct transportation is most often chosen. When the land routes are chosen, the long transport distance on the Trans-Siberian railway is reflected in a large share of vehicle kilometres for rail. The vehicle kilometres in Europe are rather few when regarding the whole transport chain which is illustrated in the tables.
Figure 6.9. Proportion of vehicle kilometres per traffic mode for product type 2.

Figure 6.10. Transport cost per TEU and CO₂ per TEU for product type 1.
Figure 6.11. Transport cost per TEU and CO₂ per TEU for product type 2.

Figure 6.10 and 6.11 illustrate the transport-related costs per TEU together with the amount of CO₂ per TEU (note the scale of the tables). Like in the basic scenario, the transport costs included in the figure are distance-based costs, time-based transport costs (driver and capital costs), taxes and fees (i.e., the loading and unloading cost, the inventory holding cost, and the production cost are not included). In the case with product type 1, the transport costs are slightly lower with Measure 2 where Route 2 sometimes is chosen. This can be explained by the lower time-based costs due to shorter transport times on the transport links between Klaipeda and the UK. In the same way are the transport costs lower for product type 2 with Measure 1-4 due to lower time-based costs (note that the transport costs for Measure 1-4 are very similar).

The amount of CO₂ is very low when direct transportation is used since large container ships are used where the share of the total emissions of each container is rather small. When Route 2 is used the amount of emissions is of course larger, mainly due to the usage of road transportation. For information of the amount of other emissions, see Appendix.
In the case with one producer in Shanghai and one in Odessa, direct transportation from Shanghai is chosen with product type 1. For product type 2, the producer in Odessa is chosen, as well as the route which includes road transportation from Kaunas to Esbjerg, see Figure 6.12. This can be explained by the fact that product type 2 requires faster transportation (shorter lead-times), why the fastest transport alternative also is chosen. Like in the case above, short transport times are valued higher with product type 2, despite the higher production costs.

In Figure 6.13 the amount of vehicle kilometres per traffic mode is illustrated and like the previous cases, sea is of course the mode with the largest amount of vehicle kilometres. It can also be observed that the share of road transportation is larger than rail transportation with product type 2, even if the transport distances are rather similar. This is explained by the fact that more trucks than trains are used to transport the products.

Like in the case above with one producer, the transport cost is higher and the amount of CO₂ is very low (the same amount of CO₂ per TEU as the cases above) when direct transportation from Shanghai is chosen, see Figure 6.14.
Figure 6.13. Proportion of amount of vehicle kilometres per mode for the case with two producers.

Figure 6.14. Transport cost per TEU and CO₂ per TEU for the case with two producers.
6.2.3 Analysis

In the extended scenario, more characteristics have been included, and we have showed that it is possible to study effects of different product types with different characteristics regarding product value and time requirements (lead-time). We have also showed that it is possible to observe changes in the decision making of the agents and its consequences in the logistical operations due to different implementations of timetables, and times on links and in nodes with TAPAS. A case where the customer agent chooses between two producers have been included, which results in different choices depending on time requirements of the product types.

It is difficult to compare the extended scenario with other studies, since no similar studies of the same transport corridor have been made to our knowledge. Instead we examine the sensitivity of input parameters on the output.

To determine which factors that have an important influence on the output from simulations, sensitivity analysis is important to perform (see for instance Law and Kelton (2000)). We have performed a minor sensitivity analysis on certain crucial input parameters. The lead-time parameter is crucial in TAPAS since influences the possibility to deliver within the preferred time-window and also influences the order size through the EOQ principle. Another important input parameter is the product value since it influences the time cost for having the product in the system.

In this small study we examine (1) what the results are if a product type with the product value of 20000 euro/TEU (the value for product type 1) has the acceptable lead-time 31 days (instead of 40 days). Correspondingly, (2) we study the results of having a product type with product value 100000 euro/TEU (product type 2) which has the lead-time 40 days (instead of 31 days). The results from this analysis show that in (1) the modal split is the same as in the base case with product type 2, and (2) shows that the modal split is the same as in the base case with product type 1. This indicates that it is the lead-time that has a higher influence on the mode choice than the product value.

Moreover, some of the cost parameters have been difficult to determine, why we see a need to examine what the results would have been if the cost parameters are determined differently. The cost parameters which we see as the most uncertain are the costs for the rail transportation. We have got some price indications from a rail operator in Sweden, but rail transportation is complex and the template price information (which is not coupled to specific transport solutions for a specific company) for typical transport solutions such as system freight trains and wagon load system is difficult to collect. For instance road transportation is less complex since the transported units on trucks are smaller and the cost structure is less complex and the cost information is easier to collect. Also, rail operators are not always willing to share their cost information.
In the base case of the extended scenario there are two rail transportation alternatives with different cost parameters: the rail transportation in Sweden and Denmark and the rail transportation on the Trans-Siberian railway. Since no rail transportation appear in Sweden and Denmark in our simulation results, we find it interesting to focus on this transport link to see what the output would be if the transport costs were lower for this transport alternative. The driver cost, capital cost, distance-based cost, and cost for loading/unloading for train transportation in Sweden and Denmark were set to zero to examine if it was possible to get a model shift to this route. Both product types were examined. The simulations showed that this change did not have any effect on the mode choice. We conclude that the transport distance in Sweden and Denmark are too short compared to the transport distance for the whole transport chain, why cost measures on this part of the chain do not have any effects. It seems like time measures have a greater importance than cost measures in this scenario.

There are many issues that are interesting and important to further examine in the studied scenario. Examples of further sensitivity analysis are:

- examine the relationship between input parameters,
- the choice of distribution of for instance the product demand,
- the level of detail in the system,
- the effects of no inventory connected to the customer (i.e., if the inventory level is 0),
- the sensitivity of the cost parameters, e.g., the influence of the production-related costs, and inventory holding cost,
- the trade-off between cost and time in the decision making of the agents,
- the effects of timetabled vs. demand-driven transports, e.g., in terms of costs, and
- the effects of different price-elasticities.

### 6.3 Concluding remarks

The simulation experiments have illustrated what kind of studies which are possible to perform with TAPAS. Effects of different product types, vehicle sizes, timetabled vs. demand-driven transportations, etc. have been observed. Effects in terms of for instance modal split, route choice, order size, transport costs, and emissions of the actual transports are illustrated.

The studied transport chain can be regarded as a part of a larger supply chain, where components needed for producing product type 1 and 2 are transported from different suppliers to the producer in Kaunas, Shanghai or Odessa. The customer in the UK can function as a wholesaler to the end-customers, a distribution centre or a store where the actual end-consumers buy the products.
The application of the East West Transport Corridor scenario to the model of roles in transport chains has also been illustrated in this chapter.

There are several other issues which are interesting to further study in the East West Transport Corridor scenarios. A few examples are:

- Changes in prerequisites for the transport chain actors in terms of lower costs and times in the nodes. The price sensitiveness of the actors is interesting to study.

- Other types of kilometre taxation implementations, such as a tax differentiated on different types of roads, time of the day, week-day/week-end, etc.

- Different aspects of demand and consumption; e.g., a changed demand distribution is relevant to study, as well as different settings of the ordering and consumption behaviour.

- The importance of the inventory holding cost and product value in the transport chain.

- Study import/export to/from Sweden/Denmark/Lithuania via the transport corridor.

- Changed vehicle restrictions in Sweden and the EU.

- Extend the analysis of the results, e.g., by further sensitivity analysis and examine the generalisability of the results.

The scenarios and simulation results have been discussed with different types of experts (companies, public authorities, and universities) at several stages in the study. Suggestions of improvements have been brought up why the scenarios have been revised and the simulation experiments have been run again several times. Examples of suggestions of improvements which have been brought up are:

- the inclusion of an administrative order cost (has been included),

- the revision of the cost calculations for rail transportation (has not yet been done),

- the revision of the speed and the inclusion of resting times for road transport (has been included).

The problem of finding good input data is a problem which is important in micro-level models. Even if we would improve the cost calculations in the model the simulation results might not be more realistic if detailed cost parameters is not available when formulating scenarios of real-world transport chains.
Chapter 7

On the usage of TAPAS

In this chapter the usage of TAPAS is discussed. First, scenario formulation of transport chains and validation of the simulation results are discussed. This is followed by a discussion of which types of studies that are possible to study with TAPAS. They are then compared to studies which typically are made with macro-level models. The potential users of TAPAS as well as how TAPAS can be used are further discussed.

7.1 Scenarios

When setting up a scenario for transport policy analysis, the design of the scenario depends on what type of analysis the user of TAPAS wants to make. Questions to consider are for instance what type of transport policies and effects which are of interest, as well as what type of transport chain that should be studied and what type of data that should be used. The type of transport chain that is studied can for instance concern a type of product, certain real-world companies, scenarios where a modal split is probable to take place, a transport chain which have been studied previously in other types of studies, etc. Connected to the type of transport chain is the type of data to use. The data can be collected from different sources, e.g., real-world transport chains, i.e., case studies. The data can for instance be collected from interviews with companies in transport chains, or from follow-up data from the companies. Since TAPAS enables to capture detailed aspects of transport chains, it is natural to choose case specific data as input since this enables the scenario to model the reality with lots of details. However, sometimes it can be difficult to get information of cost parameters, etc., from companies since they do not want to reveal cost information due to its sensitivity in a competitive situation. Another important issue is that it can be difficult to generalise the results from case studies since they only concern a specific transport chain in a specific situation.

To avoid the problematic issue of generalisability when case specific data is used, more generic data collected from a large sample, or even a whole country, can be used when formulating the scenario. Such generic data can be extracted from national or international statistics or data from different types of surveys, etc. An advantage of making use of national or international statistics is that traditional macro-level models typically make use of statistics, which enables to compare results from studies with TAPAS and macro-level models. An issue with making use of statistics is that it is seldom available on the level of detail
which TAPAS requires, why one of the main benefits of TAPAS, i.e., to capture detailed aspects of transport chains, cannot fully be taken advantage of.

One way to both take advantage of the possibility to capture detailed aspects of transport chains and to deal with the generalisability of scenarios and simulation experiments is to define a number of categories of typical transport chains. To define these typical transport chains, typical roles which appear in transport chains can first be defined. These categories can represent certain market segments with specific characteristics. Different categories of market segments are currently used in traditional macro-level models (i.e., statistics), for instance to study different product types and its characteristics such as value and possibility to make use of certain traffic modes. Examples of such categorisations are the SITC categories (United Nations, 2006) and the NST/R commodity groups (European Commission, 2007). In Sweden, detailed statistics exist concerning the product flow in the Commodity Flow Survey, CFS (SIKA, 2006). The product flow is for instance connected to industries, load carriers, transport modes, product values, and product flows between regions. However, a drawback is that terminals are not included (de Jong and Ben-Akiva, 2007).

Several researchers have pointed out drawbacks of using current statistics. Liedtke and Schepperle (2004) identify a number of shortcomings in the European transport statistics. For instance, they argue that the NST/R (Standard Goods Classification for Transport Statistics) product categories which are used in Europe does not successfully take handling and packaging categories, sector relations, and product type relations into account. Moreover, often products are not categorised in a consistent way, since the categories are not disjoint.

In macro-level models which capture more logistical aspects (e.g., SMILE (Tavasszy et al., 1998) and SLAM (SCENES consortium, 2000)), logistical categories are used to define the characteristics of logistical segments. In these categories aspects such as consignment size, frequency, etc. are defined. As opposed to TAPAS, these logistical characteristics are input to the model; in TAPAS they are output. Categories which can be appropriate to define for TAPAS can for instance concern product types, geographical spread of the producer, consumer, and terminal nodes, decision making strategies of the roles, size and distribution of product demand. Moreover, the appearance of the transport chain actors within organisations, which can indicate the dominant functions in the transport chain, is relevant to capture. This would facilitate the analysis and improve the generality of the simulation results since the effects are coupled to certain segments.

To make suitable categorisations and gather the relevant information of typical transport chains and roles requires lots of work. Typical transport chains and roles and their characteristics (as well as data describing them) can be defined by reviewing the literature, making interviews or questionnaires to the industry, as well as studying existing categorisations. Collecting data of more detailed
categorisations can be built upon current work on collecting more detailed characteristics, such as the work with the CFS in Sweden (SIKA, 2006).

7.1.1 Example: study of haulier categories

To illustrate how it would be possible to categorise the transport chains, a (preliminary) study of how it is possible to categorise haulier types in Sweden was made. The study concerns the possible effects of hauliers as a consequence of a kilometre tax in Sweden. The analysis was made by suggesting categories of haulier types (i.e., mainly the transport planner role) which exist in the Swedish haulier market. The basis for the segmentation of the haulier categories was current categorisations of the haulier market. This was further developed by interviewing the haulier organisation in southern Sweden. The categorisation was validated through interviews with hauliers of their organisational belonging as well as their thoughts of the suggested categorisation. The hauliers were divided into five categories, see Table 7.1 for an overview.

<table>
<thead>
<tr>
<th>Type of transport</th>
<th>Total weight (ton)</th>
<th>Vehicle age (years)</th>
<th>Distance/year (km)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Martin</td>
<td>Long distance, often timetabled, LTL</td>
<td>60</td>
<td>2</td>
</tr>
<tr>
<td>Åsa</td>
<td>Regional distribution, LTL</td>
<td>18</td>
<td>4</td>
</tr>
<tr>
<td>Kevin</td>
<td>Construction, FTL</td>
<td>50</td>
<td>6</td>
</tr>
<tr>
<td>Piotr</td>
<td>Long distance, foreign vehicle, FTL</td>
<td>40</td>
<td>2</td>
</tr>
<tr>
<td>Olle</td>
<td>Wood, routed tour, FTL</td>
<td>60</td>
<td>2</td>
</tr>
</tbody>
</table>

**Table 7.1.** Overview of haulier categories. LTL – Less-than-TruckLoad. FTL – Full-Truck-Load.

The haulier types were mainly described according to their cost structures, i.e., concerning the staff cost, the variable costs, and the fixed costs, see Ramstedt et al. (2007) for further information.

This is a preliminary suggestion of a categorisation of hauliers, or the transport planner role. There are several shortcomings of the study, e.g., the sample is small and the categorisation method need to be further considered. For instance, if the sample is large, it is possible to make categories from the data by making use of clustering techniques/algorithms.

The hauliers belong to different types of transport chains with different types of customers, suppliers, etc., therefore it makes sense to extend the categorisation to also include other actors within transport chains to better capture different types of relations. A characteristic that is relevant to capture for typical customers is, e.g., ordering behaviour; for typical transport buyers the importance of the reliability of transports could be relevant to capture. Therefore
it makes sense to include the remaining transport chain roles in a categorisation. It is also possible to define categories of typical transport chains based on the relations between actors in a transport chain. For instance, typical transport chains can be based on the dominance of the customer, supplier, or logistics service provider. It is possible to extend this with other characteristics such as product types, transport distance, etc.

7.2 Validation

When appropriate scenarios have been defined and the simulation experiments have been run, the simulation results should be validated. As an example, the results of the simulation studies with TAPAS presented in Chapter 6 were mainly validated through interviews with experts in policy issues and transport modelling, as well as practitioners in transportation and logistics. The results of the simulations were also compared to similar studies (Yngström-Wänn, 2007; Lundin, 2007; Sakalys et al., 2007) as well as to existing transport chains. Moreover, the sensitivity for different input parameters was also examined in the second scenario.

The validation of the simulation results also contribute to the validation and verification of TAPAS by showing that the scenarios of real-world transport chains are possible to apply to TAPAS. The simulation results in terms of, e.g., effects of transport policies, seem to be reasonable, which indicate that TAPAS seems to behave reasonable. The simulation experiments show that it seems appropriate to include the implemented decision making agents in TAPAS. The validation of the simulation results also indicate that the implemented interaction framework seems to function well when simulating the interactions in transport chains. Validation and verification of TAPAS are also made by interviews with experts of traffic modelling and policy analysis as well as with practitioners in the industry, e.g., by discussing the appropriateness of including the decision making agents for representing transport chains.

The example above illustrates that different types of sources can be used when validating the simulation results. Expert interviews can for instance be used. This has been discussed by for instance Downing et al. (2001). They argue that agent-based approaches are well suited for validation through stakeholder participation since representation of entities in terms of agents facilitates the understanding of the model. Also, the detailed validation of individuals (agents) is enabled. Moreover, comparing the simulation results to studies of similar scenarios with other models is another way of validation. Simulation experiments with TAPAS can also be compared to observations, for instance the effects from actual transport policy implementations. There are also other types of validation that can be used, such as sensitivity analysis, analysis of confidence intervals, calibration of the model behaviour, etc. See for instance Kleijnen (1999) for work on this.
7.3 Possible studies and contexts

In this section the usage of TAPAS is dealt with in terms of studies that are possible to make and which the potential users are. The studies which are possible to make with TAPAS are related to studies which are possible to make with macro-level models. The usage has been discussed in semi-structured interviews with experts in transport modelling and practitioners in transport chains, i.e., potential users of TAPAS (see Appendix). When choosing which persons to interview, we tried to cover different types of possible users. The respondents therefore represent academia, public authorities, institutes, transport modelling consultancies, and companies. The selected companies have different functions in transport chains. The selected respondents are working with issues related to transportation and/or policy analysis.

7.3.1 Type of questions to study

In Chapter 6 the usage of TAPAS is illustrated by presenting two simulation experiments. Examples of issues which are included in the two scenarios are intermodal transportation, transhipment, time-window for delivery, timetabled vs. demand-driven transportation, etc. Several other aspects are possible to include in TAPAS and some of these aspects are illustrated in this section by relating TAPAS to traditional models for transport policy analysis. Concrete questions which can be studied are exemplified in the discussion.

The main question TAPAS as well as traditional models is able to answer is:

\[ \text{What will the effects } E \text{ be if transport policy } P \text{ is introduced?} \]

One of the main differences between TAPAS and macro-level models is that TAPAS concerns transport policy analysis of transport chains, as opposed to the focus of larger transport systems, such as transportation in a country, with macro-level models. It is possible to model large transport systems also with TAPAS. However, since large amounts of micro-level data have to be collected this may be difficult to achieve. Aggregated data are used in macro-level models which enables studies on a higher level. Therefore, the types of questions TAPAS can answer are on the form:

- What will the effects \( E \) be in a transport chain if transport policy \( P \) is introduced?

while questions answered with macro-level models often are on the form:

- What will the effects \( E \) be in a country if transport policy \( P \) is introduced?

Several types of questions are possible to study with both types of models, for instance transport policy effects on the choice of traffic mode and route. However, one important difference is that TAPAS captures more detailed
decision making in transport chains, such as planning, since TAPAS represent causal relationships. Examples of such questions are:

- How will the planning of the consignment size, the time of delivery, etc. be made in transport chain T if transport policy P is introduced?

As discussed in Chapter 3, all models which we call macro-level do not have the same characteristics. Some models have an explicit aim to include logistical aspects which appear in transport chains, for instance terminal handling and consignment size. However, such planning decisions are not modelled as detailed as in TAPAS since dynamic time is not possible to capture in macro-level models. Moreover, detailed decisions (e.g., consignment size) are represented differently in macro-level models than in TAPAS. In macro-level models the effects of a certain consignment size are captured, while the consignment size is the output from TAPAS. See Chapter 3 for further discussions of characteristics of macro-level models.

It is not only the decision types modelled in TAPAS and macro-level models which differ, the type of output is not always the same due to the possibility to capture more details in TAPAS. Since each and every transport is simulated, it is possible to compute how much freight which is loaded on the vehicle. This makes it possible to deduce the vehicle load utilisation, which enables for more precise cost calculations of the performed transports, as well as emission calculations for each transport, such as:

- What will the vehicle utilisation in a transport chain be if the transport policy P is introduced?

This enables for more accurate calculations of the environmental performance, for instance, per customer, per ton product, etc. (see Bäckström (1999) for studies on allocation methods). In macro-level models such calculations are made on an aggregated level.

TAPAS represent dynamic time, why issues including a sequence of time-steps can be captured which enables better modelling of the reality. Many transport policies are also related to time (see Chapter 2 for more examples) which are more suitable to study with TAPAS than with macro-level models. Examples of questions related to dynamic time are:

- What will the effects E be in a transport chain if a regulative transport policy concerning the resting times of truck drivers or concerning the cabotage of transport operators, is introduced?

- What will the time of arrival at the customer be as a consequence of the introduction of transport policy P?

- What will the effects E be if the regulation for which time of the day it is possible to make use of the link infrastructure in a city is changed?
Since detailed decision making in transport chains is modelled in TAPAS, it is also possible to study other issues besides public transport policies in transport chains, such as:

- Which type/s of measure/s M can be introduced in a transport chain to make it more competitive in terms of lower operative costs and/or better reliability?
- What will the effects E be in a transport chain if timetable synchronisation is introduced?
- What will be the effects E in a transport chain as a consequence of different customer order strategies or production strategies?

An important characteristic of TAPAS which influences the studies possible to make, is the extended scope of transport chains. Since the modelled demand in TAPAS is the product demand, this enables to capture changes in the transport demand due to changed logistical structures. Examples of such questions are:

- What will the transport demand and emissions be in a transport chain if transport policy P aimed at minimising the greenhouse gas emissions is introduced?
- What will the transport demand be in a transport chain if an investment in a new distribution centre is made?
- What will the new transport demand be as a consequence of a new product demand, for instance due to the introduction of a new product type?
- How will the planning be made if the product demand variations and/or production lead-time variations are high in a transport chain?
- What will the effects E be as a consequence of high seasonal variations of the product demand in a transport chain when transport policy P is introduced?
- What will the choices of producer node, route, and terminal be in a transport chain if transport policy P is introduced?

### 7.3.2 Possible users of TAPAS

In Chapter 6 where the two simulation experiments are presented, the potential users interested in the studies are pointed out. In the first scenario the potential users are public policy makers on the national level which are interested in examining the effects of an introduction of a kilometre tax for analysing the potential effects in relation to the desired effects. In the second scenario the potential users are actors along a transport corridor, or in a region. The actors can for instance be companies operating along the corridor and regional public authorities. In this section different contexts in which TAPAS potentially can...
contribute are described, connected to possible types of users. The main types of users of TAPAS that have been defined together with experts of transport policy modelling and practitioners in transport chains are the following types:

*Public authorities*

The most obvious type of user of TAPAS is public authorities interested in predicting probable effects of new implementations of transport policies. The public authorities can be on the national, regional, and global level, which consequently lead to different focuses. TAPAS can both function as an independent tool for policy analysis, and as a complement to current models. We believe that TAPAS can complement these existing models by adding more details and thus strengthen the analysis.

We believe that models such as SAMGODS and TAPAS may complement each other in different ways. Simulation results from SAMGODS can function as scenario settings, or input, to TAPAS; and simulation results from TAPAS can function as input to simulation studies with SAMGODS. Since TAPAS can capture changes in transport demand, it would be possible to use the transport demand from simulations with TAPAS for certain types of market segment as input to SAMGODS. This is interesting if there is a wish to capture restructuring effects in terms of, e.g., choice of producer node since this is not possible to capture in SAMGODS. Also, more detailed breakpoints for different logistical decisions such as traffic mode choice or route choice received from simulations with TAPAS can be used as input to SAMGODS. It is also possible to study certain types of transport chains which the model analyser knows that SAMGODS does not capture well. Such examples can be transport chains where time plays a very important role, such as dependence on timetables, or where the time of delivery is especially important to meet.

TAPAS also has the potential to contribute to the validation of macro-level models such as SAMGODS, for instance validation of price elasticity numbers (concerning, e.g., price and time) by comparing elasticities received from simulation runs with TAPAS and SAMGODS respectively. Bates and Swahn (2004) claim that there is a wish to compare the elasticity numbers used in SAMGODS with other numbers, and TAPAS can potentially provide such numbers for certain typical transport chains. Moreover, TAPAS enables to capture more detailed aspects, therefore the more detailed numbers received from TAPAS can potentially be used for certain typical transport chains. Since elasticities are claimed to be situation-specific (Bates and Swahn, 2004), this is valuable to capture with TAPAS to provide higher accuracy to studies with SAMGODS.

TAPAS can function as a pedagogical tool to illustrate possible effects of policies, or to increase the understanding for how the actors in a transport chain behave, and thus provide the possibility to make a more detailed analysis of transport policy effects. An argument for making use of TAPAS as a
pedagogical tool, instead of direct decision support for public policy making, is that it is difficult to know what actually influence the decision making in transport chains. Observations of effects of public policies have been observed before policy implementations, why it is possible that the effects of public policies are not directly the effects of the actual policy implementations, but that the *expectations* of the probable effects that have an important effect of the decision making in transport chains (see summary from interviews in Appendix). Also, SAMGODS which is aimed at public policy analysis are rather seldom directly used for decision support for how to implement transport policies. However, often it is indirectly used to strengthen the policy analysis (Bates and Swahn, 2004). If TAPAS is used for pedagogical purposes the requirements for validation may not be as high since the purpose then is to illustrate the principles of transport chains, not to show exact results.

*Large companies*

Large companies which are interested in certain market segments, for instance new markets or possible effects of logistical restructuring, might also be interested in using TAPAS. This may especially be the case if the flows are complex and difficult to analyse without a decision support system. Companies may also be interested in finding the best way to behave to increase profit as a consequence of new prerequisites, e.g., from transport policies, or they can be interested in analysing the effects of measures to improve the integration between companies along a transport chain. Ports are a type of transport chain actor which might be interested in using TAPAS to analyse measures to increase the transport volumes to the port.

Like for the public authorities, TAPAS can be used as a pedagogical tool for companies, for instance as an illustrative tool to show what the effects would be if they behave in a certain way as well as to increase the understanding of the effects of their decision making.

*Academia*

MABS is an interdisciplinary approach, why it is possible that universities are interested in making use of TAPAS as a tool for illustrating the usage of methods or approaches. Examples of methods which can be possible to study in TAPAS are algorithms used in artificial intelligence, optimisation techniques, etc.

**7.4 Concluding remarks**

In this chapter the usage of TAPAS in terms of design of scenarios and validation issues was discussed. Moreover, typical questions which are possible to study with TAPAS were compared with typical questions that are studied with macro-level models. Finally, different types of users as well as different ways of making use of TAPAS were presented.
Chapter 8

Conclusions and future work

In this chapter the contributions of the thesis in relation to the research questions is discussed. Since the work concerns a novel approach for transport policy analysis, there are of course many ways to continue the research. Some of these possibilities are presented in the second part of this chapter.

8.1 Conclusions

RQ1. In order to examine current simulation modelling practices for transport policy analysis and which aspects they capture, a review of simulation models for transport policy analysis has been made. The review is made according to a review framework covering important characteristics for transport policy analysis. To capture the effects of transport policies in models, different transport policies and their properties are of course important to model, as well as different types of effects. Since the effects of transport policies are a consequence of how the logistical operations are performed, and thus the logistical decision making, a number of important logistical decisions are identified. We conclude that to properly capture the actual effects, important decisions, such as decisions concerning the choice of producer, terminal, and transport operator, as well as planning of transportation, production, and transhipment should be modelled. The planning is dependent on the quantity and the time when the operation should be performed. Moreover, we argue that it is important to capture transport policy effects in terms of changes in transport demand.

Today mainly macro-level models are used for transport policy analysis. The focus in macro-level models is rather on traffic than on transportation (or transport chains) and the models typically cover large traffic volumes, e.g., in a whole country. However, traditional macro-level models do not capture all characteristics in the review framework, e.g., not all aspects of planning. This is mainly due to the fact that individual actors in transport chains and their detailed logistical decision making and interactions are not captured in macro-level modelling. However, there is a tendency today to include more detailed logistical decisions to improve the transport policy analysis. Some agent-based models are reviewed which are related to transport policy analysis. Agent-based models have the potential to capture characteristics important for transport policy analysis. For instance, the possibility to represent individual entities as agents enables to better capture the actual decision making in transport chains.
which therefore can increase the realism in the results. However, none of the reviewed models capture all aspects which we consider important for transport policy analysis. Thus there seems to be a need for further development of models aimed at transport policy analysis.

RQ2. A model has been developed that includes the generic roles we distinguish in transport chains and which responsibilities the roles have, i.e., which logistical decisions that are made by the roles. The model captures ordering, choices and planning related to transportation, choices and planning related to product supply, as well as coordination between these functions. This enables to represent various constellations of transport chains and to represent roles as agents. Modelling these logistical decision and the roles in transport chains enables to capture economic, logistical, and environmental effects of transport policies. The application of the model to a real-world transport chain indicates that the model is reasonable.

RQ3. To examine how MABS can be used for transport policy analysis, a simulator called TAPAS has been developed and motivations are given for why this type of simulation model is appropriate for transport policy analysis. The logistical decisions included in TAPAS are based on the decisions included in the model, i.e., the results from RQ2. Moreover, characteristics which are important to include in a simulation model for policy analysis have been deduced when common transport policies are described. The roles in transport chains are represented as decision making agents in TAPAS, where each role captures certain logistical decisions. The decision making of the agents is mainly driven by a desire minimise the costs of the logistical operations. Decision making strategies which we argue are relevant for representing common transport chains are implemented. For instance, the principles of EOQ are captured by letting the customer select the best order quantity among a set of possible quantities. TAPAS enables simulating both timetabled and demand-driven transportation with the implemented approach. The decisions of the agents determine how the logistical operations are simulated, i.e., the vehicles, products, etc. are modelled as passive entities. A conclusion from the work with TAPAS is that MABS can be used for representing the decision making and the interactions between the roles in transport chains. The consequences of this are represented in terms of the performed logistical operations and its performance. This enables to model realism in transport chains which is important to capture precise transport policy effects.

Simulation experiments of scenarios of real-world transport chains and the validation of the simulation results, contribute to the validation and verification of TAPAS. Based on the simulation results, for instance concerning the traffic mode choice, TAPAS seems to properly model the logistical decision making. Some of the validation and verification of the simulation results have been performed by relating our experiments to similar studies and by sensitivity analysis of some input parameters. Validation and verification of both the model
and the simulation results are made by interviews with experts of traffic modelling and policy analysis as well as with industrial practitioners.

An analysis of TAPAS according to the review framework shows that TAPAS captures most of the characteristics important for transport policy analysis, such as detailed logistical decision making, dynamic time, changes in transport demand, etc. However, all roles and its logistical decisions are not yet fully captured in TAPAS in terms of agents. For instance, the behaviours of the inventory and terminal planner are modelled in the physical simulator in a quite simple way.

**RQ4.** The usage of TAPAS is illustrated with two scenarios of real-world transport chains, which are used when performing simulation experiments of the consequences of various transport policy implementations. Output analysis by comparing the results to similar studies and by sensitivity analysis of input parameters is performed as illustrative examples. From the simulation experiments and analysis, we conclude that TAPAS has the potential to be used for transport policy analysis. However, further validation and verification of TAPAS are recommended.

Issues important to consider when formulating scenarios are discussed in the thesis, for instance measures to take to facilitate validation and generalisation of the simulation results. Due to the micro-level approach, TAPAS requires large amounts of data which may be problematic when a large system is simulated and large amounts of data need to be collected. When the simulated system is large, the complexity increases and complicates the validation of the simulation results. Moreover, when large systems are studied using individual cases (here individual transport chains), generalisation of the results is important to consider. We suggest making use of typical transport chains and roles, e.g., characterised by product type and geographical location, representing certain market segments.

Questions which are appropriate to study with TAPAS are listed showing what kind of studies TAPAS can deal with. This is compared to questions which are typically studied with traditional macro-level models. The conclusion from this comparison is that TAPAS enables to provide answers for more types of questions due to the possibility to capture more transport chain characteristics. Common transport policies which are relevant to study are also discussed and described in a structured way, deducing how logistical decisions potentially can be influenced by different types of transport policies.

Finally, the possible usage of TAPAS is discussed and related to different types of users. Public authorities can for instance use TAPAS to complement studies using traditional models. This can improve the accuracy of the simulation results by the inclusion of more logistical aspects. Large companies are another type of user which, e.g., can use TAPAS to analyse new market segments, such as new product types or new consumers, where historical data is not available.
Addressing the main research questions, the contribution of the thesis is mainly an examination of how MABS can be used for transport policy analysis in transport chains. This relates to the development of the model of roles and logistical decisions in transport chains and the development of the simulation model TAPAS which can be used for transport policy analysis with MABS. Simulation models common for transport policy analysis are also reviewed. Relevant questions to study with TAPAS are analysed. The appropriateness of TAPAS for transport policy analysis is exemplified by performing simulation experiments and analysing the results. The general usage is dealt with by discussing scenario formulation and suggesting how to deal with validation and verification issues of simulation results. The validity of TAPAS is dealt with, however, since transport chains can be organised in many ways and have varying characteristics, there is a need to further examine the appropriateness of TAPAS for more transport chain scenarios. Examples of ways to continue the development of TAPAS is discussed in the following section.

8.2 Future work

There are many ways to continue the work on transport policy analysis with MABS. Regarding TAPAS, the types of future work mainly concern further validation and verification as well as further development of the simulation model. Also, the exploration of the usage of TAPAS is important to continue.

8.2.1 Further validation

There is a need to continue the validation and verification of TAPAS to examine if it properly captures the most important decisions and roles in transport chains. For instance, the actual decision making of the transport chain actors can be further examined, e.g., through a more extensive interview study or questionnaires. There is also a need to perform more simulation experiments to make sure that TAPAS can represent various types of transport chains and that the simulation results seem reasonable.

The sensitivity of the results is important to further study. For instance, our implementation to find the optimal order quantity based on the EOQ formula is relevant to further examine. Since we do not consider constant demand and perfectly known fixed ordering cost, as in the traditional EOQ formula, the results (of course) become less reliable. Therefore, there is a need to further study how our implementation of the EOQ formula influences the sensitivity of the results.

8.2.2 Development of TAPAS

Possible future work concerning the development of TAPAS is outlined below. More detailed descriptions are available in Chapter 5.
- Include more aspects in the decision making, such as network coverage, current cooperation, reliability, risk of product damage, and risk of accidents.

- Improve the search process of the PB for finding appropriate product proposals.

- Capture more types of decisions, e.g., load consolidation decisions, to study fleet management issues in more detail.

- Integrate more sophisticated optimisation algorithms in the agents to improve the quality of their decisions and make the simulator prescriptive rather than descriptive.

- Include different versions of the agent types, i.e., different decision strategies. For instance, different types of ordering strategies are used by different types of customers, why the possibility to choose among a set of decision strategies would enable to better capture different types of roles in transport chains. This is also related to making use of typical transport chains and roles to facilitate the generalisation of the simulation results which is important to further examine.

- Include additional agents, i.e., the terminal planner and the inventory planner. Simple storage and terminal behaviours are currently modelled in the physical simulator. For instance, more details concerning transhipment at the terminals could be included in the agents.

- Experiment with other interaction protocols, e.g., allowing agents to initiate and respond to messages outside the presented interaction framework is interesting to examine. As an example, the production buyer might suggest an order quantity that fits one producer.

- Examining different degrees of information transparency between the agents.

- Including the deterioration rate of the products over time to enable analysis of waste of products.

- Including external aspects that affects the transports. As an example, to simulate other traffic on the links would allow us to study the effects of link congestion.

- There are also possibilities to improve the performance of TAPAS, for instance by a more efficient route selection method and make TAPAS run in a GRID environment.

8.2.3 Usage-related issues

An issue related to the usage of TAPAS is input handling. The some of the input can be difficult to collect, e.g., due to sensitive company information. Therefore, it would be relevant to instead of manually specify input parameter values, let TAPAS handle incomplete information during simulation. This can for instance be based on learning from the outcome or make use of decision rules.
There are many types of studies which are relevant and possible to make with TAPAS, see Chapter 7 and Chapter 2 for further discussions.

The possible context of usage of TAPAS needs to be further examined, e.g., how it would be possible to integrate TAPAS in a decision support system for transport policy analysis. To examine such a usage, there is a need for further interviews with possible users which would be affected.

Making use of MABS for transport policy analysis of transport chains is a promising approach due to the possibility to represent decision making actors and their interactions in a natural fashion. There are many possibilities for further improvements in order to capture more aspects important for transport policy analysis such as including more advanced behaviour in the actors.
References


Bernstein et al. (Core Writing Team), Climate Change 2007: Synthesis Report, Intergovernmental Panel for Climate Change, 2007.


CTT – DTU & SDU, *Scandic Bridge, A strategic evaluation of the time and environmental impacts from a coordinated freight transportation link to and from the Baltic Sea region*, Denmark, 2004.


Lindau, R., Woxenius, J., Edlund, P., Verkstadsindustrins logistik – en innovationssystemana-lys (The logistics of the manufacturing industry - an innovation system analysis), Report for VINNOVA, Meddelande 120,


Småros, J., Lehtonen, J-M, Appelkvist, P., Holmström, J., The impact of increasing demand visibility on production and inventory control efficiency,


Appendix

Basic East West Transport Corridor scenario

Base case: Assumptions

The same vehicle types as in the extended scenario are used, see below.

<table>
<thead>
<tr>
<th>Links (timetable)</th>
<th>Klaipeda, Karlshamn</th>
<th>Karlshamn, Taulov</th>
<th>Taulov, Esbjerg</th>
<th>Esbjerg, Harwich</th>
<th>Kaunas, Klaipeda</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mode</td>
<td>Sea</td>
<td>Rail</td>
<td>Rail-diesel</td>
<td>Sea</td>
<td>Rail</td>
</tr>
<tr>
<td>Timetables, freq.</td>
<td>7/week</td>
<td>3/week</td>
<td>7/week</td>
<td>3/week</td>
<td>3/week</td>
</tr>
<tr>
<td>Departure</td>
<td>Day 1, min 1</td>
<td>Wed (Fri, Sun), min 1</td>
<td>Thu (Sat, Mon), min 700</td>
<td>Tue (Fri, Sun), min 650</td>
<td>Mon (Wed, Fri), min 1</td>
</tr>
<tr>
<td>Arrival</td>
<td>Day 2, min 870</td>
<td>Thu (Sat, Mon), min 400</td>
<td>Thu (Sat, Mon), min 1110</td>
<td>Wed (Sat, Mon), min 360</td>
<td>Mon (Wed, Fri), min 850</td>
</tr>
</tbody>
</table>

- Production lead-time: 8 min
- Production cost: 0.1114 euro/TEU
- There is a lack of information of the emission factors for the electricity supply for railway transports in Russia and Lithuania, why the information for Poland is used.

Simulation results

Emissions (g) per TEU.

<table>
<thead>
<tr>
<th></th>
<th>NOx</th>
<th>HC</th>
<th>PM</th>
<th>CO</th>
<th>CO2</th>
<th>SO2</th>
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<td>72</td>
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<td>381</td>
<td>203900</td>
<td>161</td>
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<tr>
<td>Case 1</td>
<td>1940</td>
<td>72</td>
<td>50</td>
<td>381</td>
<td>203900</td>
<td>161</td>
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<tr>
<td>Case 2</td>
<td>465</td>
<td>16</td>
<td>17</td>
<td>9</td>
<td>43655</td>
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## Extended East West Transport Corridor scenario

### Base case: Assumptions

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<th>Link 3,4</th>
<th>Link 5,6</th>
<th>Link 7,8</th>
<th>Link 9,10</th>
<th>Link 11,12</th>
<th>Link 13,14</th>
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<td>Kaunas, Klaipeda</td>
<td>Taulov, Esbjerg</td>
<td>Kaunas, Esbjerg</td>
<td>Klaipeda, Karlshamn</td>
<td>Karlshamn, Esbjerg</td>
</tr>
<tr>
<td>Mode</td>
<td>Rail</td>
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<td>Rail</td>
<td>Rail-diesel</td>
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<td>Sea</td>
<td>Road</td>
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<td>Length (km)</td>
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<td>1500</td>
<td>240</td>
<td>81</td>
<td>1562</td>
<td>537</td>
<td>487</td>
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<td>Average speed (km/h)</td>
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<td>31</td>
<td>19</td>
<td>18</td>
<td>36</td>
<td>36</td>
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<th>Link 17,18</th>
<th>Link 19,20</th>
<th>Link 21,22</th>
<th>Link 23,24</th>
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<th>Link 29,30</th>
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<td>Klaipeda, Fredericia</td>
<td>Fredericia, Esbjerg</td>
<td>Odessa, Kaunas</td>
<td>Shanghai, England</td>
<td>Klaipeda, Harwich</td>
</tr>
<tr>
<td>Mode</td>
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<td>Sea</td>
<td>Rail</td>
<td>Rail</td>
<td>Sea</td>
<td>Sea</td>
<td>Sea</td>
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<tr>
<td>Length (km)</td>
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<td>15000</td>
<td>1950</td>
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<td>39</td>
<td>33</td>
<td>63</td>
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<td>21</td>
<td>36</td>
</tr>
<tr>
<td>Administrative order cost</td>
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<td>7</td>
<td>7</td>
<td>7</td>
<td>7</td>
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</table>

### Links (timetable)

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<tr>
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<th>Vladivostok, Kaunas</th>
<th>Shanghai, Vladivostok</th>
<th>Customs Vladivostok</th>
<th>Kaunas, Klaipeda (via Transsib)</th>
<th>Klaipeda, Karlshamn</th>
</tr>
</thead>
<tbody>
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<td>Mode</td>
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<td>Sea</td>
<td>Rail</td>
<td>Rail-diesel</td>
<td>Sea</td>
</tr>
<tr>
<td>Timetables, freq.</td>
<td>1/week</td>
<td>1/week</td>
<td>1/week</td>
<td>1/week</td>
<td>6/week</td>
</tr>
<tr>
<td>Trp time</td>
<td>17 d</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Departure</td>
<td>Thu, min 300</td>
<td>Sat, min 480</td>
<td>Mon, min 1</td>
<td>Wed, min 1000</td>
<td>Day1, min 1080</td>
</tr>
<tr>
<td>Arrival</td>
<td>Sun, min 300</td>
<td>Mon, min 480</td>
<td>Thu, min 1</td>
<td>Thur, min 400</td>
<td>Day2, min 540</td>
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</table>

<table>
<thead>
<tr>
<th>Nodes</th>
<th>Customs Kaunas</th>
<th>Karlshamn, Taulov</th>
<th>Taulov, Esbjerg</th>
<th>Esbjerg, England</th>
<th>Klaipeda, Fredericia</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mode</td>
<td>Rail</td>
<td>Rail</td>
<td>Rail-diesel</td>
<td>Sea</td>
<td>Sea</td>
</tr>
<tr>
<td>Timetables, freq.</td>
<td>1/week</td>
<td>3/week</td>
<td>7/week</td>
<td>3/week</td>
<td>2/week</td>
</tr>
<tr>
<td>Departure</td>
<td>Sun, min 600</td>
<td>Sun (Tue, Thu), min 1320</td>
<td>Day1, min 495</td>
<td>Tue (Thu, Sat), min 1125</td>
<td>Thur, min 720 (Sun, min 1200)</td>
</tr>
<tr>
<td>Arrival</td>
<td>Wed, min 600</td>
<td>Mon (Wed, Fri), min 360</td>
<td>Day1, min 765</td>
<td>Wed (Fri, Sun), 780</td>
<td>Fri, min 1110 (Tue, min 360)</td>
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</table>
## Links (timetable)

<table>
<thead>
<tr>
<th>Nodes</th>
<th>Odessa, Kaunas</th>
<th>Kaunas, Klaipeda (fr Odessa)</th>
<th>Shanghai, England</th>
<th>Klaipeda, Harwich</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Mode</strong></td>
<td>Rail</td>
<td>Rail</td>
<td>Sea</td>
<td>Sea</td>
</tr>
<tr>
<td><strong>Timetables, freq.</strong></td>
<td>1/week</td>
<td>1/week</td>
<td>1/week</td>
<td>2/week</td>
</tr>
<tr>
<td><strong>Trp time</strong></td>
<td>30 days</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Departure</strong></td>
<td>Mon, min 55</td>
<td>Tue, min 1080</td>
<td>Sun, min 1200</td>
<td>Thu (+Sun), min 720,</td>
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<tr>
<td><strong>Arrival</strong></td>
<td>Tue, min 900</td>
<td>Wed, min 514</td>
<td>Fri, min 840</td>
<td>Sat (+Tue), min 432</td>
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</tbody>
</table>

### Vehicle

<table>
<thead>
<tr>
<th>Basis</th>
<th>NTM, Scandic Bridge</th>
<th>NTM</th>
<th>NTM</th>
<th>NTM</th>
<th>NTM</th>
<th>NTM</th>
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</thead>
<tbody>
<tr>
<td><strong>Vehicle types</strong></td>
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<td>8</td>
<td>9</td>
<td>8</td>
<td>9</td>
<td>8</td>
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<tr>
<td><strong>Capacity (TEU)</strong></td>
<td>44</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td><strong>Av. vehicle utilization</strong></td>
<td>0.5</td>
<td>0.68</td>
<td>0.79</td>
<td>0.64</td>
<td>0.75</td>
<td>0.62</td>
</tr>
</tbody>
</table>

* kg/km is used for ships/ferries, l/km is used for trucks and diesel trains, kWh/km is used for electrical trains. Average fuel or electricity usage is given for ships/ferries and trains, and maximum fuel usage (on highways or rural roads) is given for trucks.

### Vehicle

<table>
<thead>
<tr>
<th>Basis</th>
<th>NTM</th>
<th>NTM</th>
<th>NTM</th>
<th>NTM</th>
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<th>NTM</th>
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</thead>
<tbody>
<tr>
<td><strong>Used on link</strong></td>
<td>27.28</td>
<td>3.4</td>
<td>11.12</td>
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<td>19.20</td>
<td>29.30</td>
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<tr>
<td><strong>Vehicle types</strong></td>
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<td>2</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td><strong>Capacity (TEU)</strong></td>
<td>6000</td>
<td>4300</td>
<td>471</td>
<td>471</td>
<td>471</td>
<td>471</td>
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<tr>
<td><strong>Av. vehicle utilization</strong></td>
<td>0.8</td>
<td>0.8</td>
<td>0.88</td>
<td>0.88</td>
<td>0.88</td>
<td>0.88</td>
</tr>
</tbody>
</table>

* kg/km is used for ships/ferries, l/km is used for trucks and diesel trains, kWh/km is used for electrical trains. Average fuel or electricity usage is given for ships/ferries and trains, and maximum fuel usage (on highways or rural roads) is given for trucks.
- The loading time above concerns most of the vehicles, except that the variable loading and unloading times are assumed to be 30 minutes for the trains on the Trans-Siberian railway and from Odessa, and the fixed loading time is 1 for diesel trains in Denmark, and 30 for the trains on the Trans-Siberian railway and from Odessa.

- Production lead-time: 8 min

**Measure 2: Assumptions**

<table>
<thead>
<tr>
<th>Links (timetable)</th>
<th>Klaipeda, Karlshamn</th>
<th>Karlshamn, Taulov</th>
<th>Taulov, Esbjerg</th>
<th>Esbjerg, England</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mode</td>
<td>Sea</td>
<td>Rail</td>
<td>Rail-diesel</td>
<td>Sea</td>
</tr>
<tr>
<td>Timetables, frequency</td>
<td>6/week</td>
<td>3/week</td>
<td>7/week</td>
<td>3/week</td>
</tr>
<tr>
<td>Departure</td>
<td>Day 1, min 750</td>
<td>Sun (Tue, Fri), min 96</td>
<td>Day 1, min 737</td>
<td>Tue (Fri, Sun), min 1141</td>
</tr>
<tr>
<td>Arrival</td>
<td>Day 1, min 1185</td>
<td>Sun (Tue, Fri), min 387</td>
<td>Day 1, min 791</td>
<td>Wed (Sat, Mon), min 227</td>
</tr>
</tbody>
</table>

**Measure 3: Assumptions**

<table>
<thead>
<tr>
<th>Links (timetable)</th>
<th>Shanghai, Vladivostok</th>
<th>Vladivostok, Customs Vladivostok</th>
<th>Vladivostok, Kaunas</th>
<th>Kaunas, Customs Kaunas</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mode</td>
<td>Sea</td>
<td>Rail</td>
<td>Rail</td>
<td>Rail</td>
</tr>
<tr>
<td>Timetables, frequency</td>
<td>1/week</td>
<td>1/week</td>
<td>1/week</td>
<td>1/week</td>
</tr>
<tr>
<td>Trp time</td>
<td>17 days</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Departure</td>
<td>Tue, min 1190</td>
<td>Fri, min 100</td>
<td>Sat, min 400</td>
<td>Tue, min 600</td>
</tr>
<tr>
<td>Arrival</td>
<td>Thu, min 1190</td>
<td>Sat, min 100</td>
<td>Tue, min 400</td>
<td>Wed, min 600</td>
</tr>
</tbody>
</table>

The loading/unloading cost (euro/min) 0.39
Variable loading/unloading time (min/unit) 1
Fixed loading/unloading time (min) 150
Simulation results

Emissions (g) per TEU for product type 1 (P1) and product type 2 (P2).

Case with 1 producer

<table>
<thead>
<tr>
<th>P1</th>
<th>NOx</th>
<th>HC</th>
<th>PM</th>
<th>CO</th>
<th>CO$_2$</th>
<th>SO$_2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base case</td>
<td>5174</td>
<td>174</td>
<td>99</td>
<td>157</td>
<td>184817</td>
<td>3139</td>
</tr>
<tr>
<td>M1</td>
<td>5174</td>
<td>174</td>
<td>99</td>
<td>157</td>
<td>184817</td>
<td>3139</td>
</tr>
<tr>
<td>M2</td>
<td>35886</td>
<td>1146</td>
<td>1392</td>
<td>4409</td>
<td>2989427</td>
<td>6103</td>
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<tr>
<td>M3</td>
<td>5174</td>
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<td>157</td>
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<td>99</td>
<td>157</td>
<td>184817</td>
<td>3139</td>
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</table>

Case with 1 producer

<table>
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<th>PM</th>
<th>CO</th>
<th>CO$_2$</th>
<th>SO$_2$</th>
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</thead>
<tbody>
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<td>32242</td>
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<td>10966</td>
<td>20253</td>
<td>46942</td>
<td>33502564</td>
<td>57896</td>
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<tr>
<td>M2</td>
<td>353330</td>
<td>11036</td>
<td>20301</td>
<td>47043</td>
<td>33587584</td>
<td>59340</td>
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<td>11358</td>
<td>16171</td>
<td>49019</td>
<td>32920618</td>
<td>41385</td>
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<td>M4</td>
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<td>16171</td>
<td>49019</td>
<td>32920618</td>
<td>41385</td>
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Case with 2 producers

<table>
<thead>
<tr>
<th>P1</th>
<th>NOx</th>
<th>HC</th>
<th>PM</th>
<th>CO</th>
<th>CO$_2$</th>
<th>SO$_2$</th>
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<td>Base case</td>
<td>5174</td>
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<td>99</td>
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<td>184817</td>
<td>3139</td>
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<td>P2</td>
<td>519336</td>
<td>16826</td>
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### Summary of interviews

<table>
<thead>
<tr>
<th>Role</th>
<th>University</th>
<th>Public authorities</th>
<th>Institute</th>
</tr>
</thead>
<tbody>
<tr>
<td>Org.</td>
<td>Blekinge Institute of Technology</td>
<td>Vägverket</td>
<td>SIKA, VTI</td>
</tr>
<tr>
<td>Name</td>
<td>Lars Emmelin</td>
<td>Sylvia Yngström-Wänn</td>
<td>Inge Vierth, Göran Friberg</td>
</tr>
<tr>
<td>Date</td>
<td>2007-06-11</td>
<td>2007-06-08</td>
<td>2007-06-19</td>
</tr>
</tbody>
</table>

**Appropriate studies**
- connection between environmental management systems and public policy making
- capacity studies
- study effects in cities during different times of the day
Operative studies:
- packaging decisions
- consignment size, frequency, empty running
Strategic decisions:
- location decisions
- product supplier choice
- change in vehicle fleet

**Interesting parameters**
- customs
- labour cost
- damage costs
- security issues (in choice between train and truck)
- arrival time important for transport operators
- timetables
- inertia
- scale advantages
- load consolidations
- elasticities
- long term effects on train and ferry frequencies
- reliability in the decision-making

**Context for possible usage**
- mainly an illustrative tool to show possibilities
- illustrate irrationality in decision making
- large companies with complex flows can be interested, as well as lobby org. and interest groups
- complement to SAMGODS
- complement to macro-level models

**Important aspects to consider**
- make sensitivity studies
- study non-linear relations
- is it really the public policies that influence the decision making in transport chains?
- do not only follow trends (e.g., CO₂)
- what is happening “behind the customer”?
- validation
- focus on some part of transport chain
- cost structures, e.g., for rail transportation
- compare TAPAS to, e.g., hybrid models

**Main advantages**
- the effects of many parameters can be studied
- relatively easy to study different scenarios
- many details
- time aspects included
- possibility to complement macro-level models by including more details

**Main drawbacks**
- rational behaviour is modelled, real-world actors do not behave rational, important to be careful with conclusions from simulation results
- complexity
- requires large amounts of input data
- requires large amounts of data

- validation
- focus on some part of transport chain
- cost structures, e.g., for rail transportation
- compare TAPAS to, e.g., hybrid models
<table>
<thead>
<tr>
<th>Role</th>
<th>Consultance</th>
<th>Producer, transport buyer</th>
<th>Transport provider</th>
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<tr>
<td>Org.</td>
<td>TemaPlan</td>
<td>AAK</td>
<td>FoodTankers</td>
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<tr>
<td>Name</td>
<td>Matts Lundin</td>
<td>Bengt Lövgren</td>
<td>Tomas Petterson</td>
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<tr>
<td>Date</td>
<td>2007-06-01</td>
<td>2007-06-04</td>
<td>2007-06-05</td>
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<tr>
<td><strong>Appropriate studies</strong></td>
<td></td>
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<tr>
<td>- mainly operative decisions</td>
<td>- mainly strategic studies</td>
<td>- mainly operational studies, e.g., efficiency studies</td>
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<tr>
<td>- quality</td>
<td>- effects of a km tax on traffic mode choice</td>
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<td></td>
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<tr>
<td>- backcasting</td>
<td>- effects of larger handling capacities in terminals</td>
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<td></td>
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<td>- new markets</td>
<td>- location decisions</td>
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<tr>
<td>- availability</td>
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<td>- location decisions</td>
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<tr>
<td><strong>Interesting parameters</strong></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>- order sizes</td>
<td>- larger time-windows</td>
<td>- load consolidation, find smooth flows</td>
<td></td>
</tr>
<tr>
<td>- consignment sizes</td>
<td>- larger order sizes</td>
<td>- possibility of empty transports</td>
<td></td>
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<tr>
<td>- empty transports</td>
<td>- increased cooperation and transparency</td>
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<td></td>
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<tr>
<td>- flows of empty containers</td>
<td>- choice of traffic mode</td>
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<td></td>
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<tr>
<td>- damage cost</td>
<td>- empty transports</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>- maybe vehicle utilization</td>
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<td></td>
</tr>
<tr>
<td><strong>Context for possible usage</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- results input to SAMGODS</td>
<td>- make simulation studies, e.g., study effects of increased cooperation and transparency</td>
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<tr>
<td>- results from SAMGODS as input</td>
<td>- make simulation studies, e.g., study possibilities of coordination of transport tasks</td>
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<tr>
<td><strong>Important aspects to consider</strong></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>- data is often a problem</td>
<td>- scenarios and input parameters should reflect reality</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- make sensitivity studies</td>
<td>- scenarios and input parameters should reflect reality</td>
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</tr>
<tr>
<td>- use indexes and elasticity numbers when presenting the results</td>
<td>- traffic mode choices</td>
<td></td>
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</tr>
<tr>
<td>- adapt TAPAS to users</td>
<td>- rather long term decisions, longer than vehicle investment decisions</td>
<td></td>
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</tr>
<tr>
<td><strong>Main advantages</strong></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>- details and logistical aspects can be considered</td>
<td>- details</td>
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<tr>
<td>- requires large amounts of data</td>
<td>- usability of TAPAS</td>
<td></td>
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<tr>
<td>- important to consider calibration</td>
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<tr>
<td><strong>Main drawbacks</strong></td>
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<tr>
<td>- requires large amounts of data</td>
<td>- important that assumptions of scenarios reflect the reality</td>
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<tr>
<td>- difficult achieve reliable results</td>
<td></td>
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<td></td>
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<td>- complexity</td>
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ABSTRACT

This thesis explores how multi-agent-based simulation can be used for transport policy analysis. Transport policies are often used as a means to reach governmental goals, such as environmental targets to reduce the impact of transportation. To predict how transportation is influenced by policies, public authorities often make use of simulation models. A structured review of such models is made focussing on important transport chain characteristics. We argue that to properly predict the actual environmental, economic, and logistical effects of transport policies, the logistical decisions made in transport chains must be modelled appropriately. Such decisions, e.g., concern the choice of producer and traffic mode, planning of transportation, production, and terminal handling. The review concludes that models currently used for transport policy analysis fail to capture many of these characteristics. We argue that agent-based models have the potential to include these aspects since they are able to explicitly model the actual decision making in transport chains.

We have identified a set of generic roles in transport chains where each role is responsible for certain decisions. A multi-agent-based simulator, TAPAS, has been developed in which these roles are modelled as agents. Thus, the decision making in transport chains and its influence by the application of transport policies are captured. The decisions lead to the execution of the logistical operations which in turn have consequences on the logistics, economic, and environmental performance.

The usage of TAPAS is illustrated by presenting two scenarios based on real world transport chains. Simulation experiments of the scenarios have been performed where different types of transport policies are introduced. The simulation results are analysed, e.g., by comparing the results to similar studies and by sensitivity analysis of input parameters. To facilitate the validation and generalisation of simulation results we suggest making use of typical transport chains and roles characterised by, e.g., product type and geographical locations. The type of studies that TAPAS can support are described and compared to studies typically made with traditional models. Transport policies which are relevant to examine are described and their potential influence on transport chains are analysed.

The possible usage of TAPAS is discussed and related to different types of users. Public authorities can, e.g., use TAPAS to complement studies using traditional models. This can improve the accuracy of the simulation results by the inclusion of more logistical aspects. Large companies are another type of user which, e.g., can use TAPAS to analyse new market segments, such as new product types or new consumers, where historical data is not available.

Some of the validation and verification of TAPAS and the simulation results have been made through interviews with experts of modelling and practitioners in industry. Also, the study of the usage and types of studies relevant for TAPAS is supported by the interviews.