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Abstract

Increasing freight transportation volumes continue to increase problems related to human health, congestion on the transport infrastructure, noise, climate changes, etc. Governments often want to minimize these negative effects, and this wish is expressed in societal goals, e.g., to reach environmental targets. An important instrument for reaching societal goals is governmental control policies, e.g., regulations, taxes and fees, which can influence the behaviour of the actors in a transport chain. Before implementing such control policies, it is crucial to predict their effects in order to make probable that it is a good measure. A review of models that consider the effects of governmental control policies on transportation has been performed which shows that macro-level models are mainly used for this purpose. However, the behaviour of the individual transport chain actors can hardly be captured in such models since the decision making actors are not modelled explicitly. Consequently, the negative effects caused by the decisions taken by the individual transport chain actors are not fully captured in these models.

We believe that micro-level models have the potential to bridge the gap between governmental policy-making and the behaviour of transport chain actors. A micro-level model based on agent-technology has been developed which captures the environmental, quality and economical performance in transport chains, given different governmental control policies. The transport chain actors are represented by decision-making agents in the model. Logistical factors for characterizing transport chains have been identified and described according to degree of influence. To illustrate the usage of the micro-level model, simulation experiments based on a real world case have been performed where different levels of governmental control policies are introduced. The simulation results so far have showed that the model seems to simulate the behaviour of the transport chain actors correctly in the studied scenarios. The simulation tool can then be used as a decision support for policy-makers and serve as a complement to existing tools based on macro-level models.

Acknowledgements

First of all I would like to thank my supervisor, Paul Davidsson, and my secondary supervisors, Jan Persson and Magnus Blinge, for sharing their knowledge and experience and helping me with this thesis. Johan Woxenius has given valuable comments on the thesis. I am also indebted to Markus Bergkvist for putting down a lot of his time for finalizing the simulator. I would further like to thank the research group ASSERT, as well as other colleagues and friends at BTH in Karlshamn and Ronneby, for a stimulating environment to work in. I would especially like to thank Johanna Törnquist for encouraging me to become a PhD student in Blekinge.

The municipality of Karlshamn has generously financed part of my work and has given me the opportunity of doing research in Karlshamn. VINNOVA has financed the project *Effects of governmental control policies on transportation chains: A micro-level study*. The Knowledge Foundation has financed the project *Integrated production and transportation planning within food industry*. The project partners in the two projects, FoodTankers, Karlshamns AB, Procordia and SIKA, have generously shared information.

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 work has mainly been conducted in the projects *Effects of governmental control policies on transportation chains: A micro-level study* and *Integrated production and transportation planning within food industry*, see http://www.ipd.bth.se/stem/ and http://www.ipd.bth.se/fatplan/ for further information.

The thesis is partially based on the following papers:

[I] Ramstedt, L., Davidsson, P., Persson, J.A., Using a Micro-Level Model for Governmental Policy-Making, *11th World Congress on Intelligent Transport Systems*, Nagoya, Japan, October, 2004.

[II] Bergkvist, M., Davidsson, P., Persson, J.A., Ramstedt, L., A Hybrid Micro-Simulator for Determining the Effects of Governmental Control Policies on Transport Chains, *Multi-Agent and Multi-Agent Based Simulation*, LNAI series Vol. 3415, Springer, 2005.

[III] Davidsson, P., Ramstedt, L., Törnquist, J., Inter-Organization Interoperability in Transport Chains Using Adapters Based on Open Source Freeware. Published in post-proceedings to *First international Conference on Interoperability of Enterprise Software applications* (*INTEROP-ESA'05*), Geneva, Switzerland, February, 2005.

[IV] Davidsson, P., Henesey, L., Ramstedt, L., Törnquist, J., Wernstedt, F., Agent-Based Approaches to Transport Logistics, Klügl, F., Bazzan, A., Ossowski, S. (eds.), *Applications of Agent Technology in Traffic and Transportation*, Whitestein Series in Software Agent Technologies, 2005. Extended version (An Analysis of Agent-Based Approaches to Transport Logistics) to appear in *Transportation Research Part C: Emerging Technologies*, Elsevier, 2005.

Chapter 5 is based on paper II, while the other papers appear to a lesser degree in different parts of the thesis.

Table of contents

1. Introduction

Governmental control policies, such as different types of taxes, fees and regulations, are often used as a means to decrease the negative environmental effects of transportation. Such environmental effects are for instance congestion on the transportation infrastructure, human health effects, noise, etc. However, it is difficult to predict the actual behaviour of transport chain actors in various situations and the effects of different governmental control policy implementations. We suggest to deal with this problem by the usage of computer simulation. In this chapter, the problem domain is described and the research questions are formulated as well as the methods used.

1.1 Background

Freight transportation has both positive and negative effects on the human society. An example of positive effects is that transportation enables goods to be transported over geographical distances which allow products to be consumed far from the production site. Transportation therefore contributes to the economical development of the society, and leads to increased welfare. At the same time, transportation has negative effects on the society. For instance, transportation causes emissions to the atmosphere (carbon dioxide, sulphur dioxide, etc.) which are claimed to cause climate changes such as global warming (Houghton et al., 2001), acidification, eutrophication and human health problems (Elvingson, 2001). Transportation also causes congestion, infrastructure wear, noise and accidents which incur costs for the society. According to the European Environment Agency (2004), the transportation sector is one of the largest contributors to several environmental problems. Transportation accounts for half of the oil consumption of the world, which directly leads to increased amounts of emission (Industry and Environment, 2000). Moreover, transportation, mainly road and air bound, causes 25% of the total carbon dioxide emissions (Industry and Environment, 2000). Measures have been taken to minimize the negative effects of transportation by technological improvements, such as more efficient engines. However, as transportation volumes, and especially road transportation, continue to increase, for instance in the EU (European Commission, 2004), the net negative effects of transportation have not been reduced (Blinge and Lumsden, 1996). To reduce the negative effects on the environment it is therefore necessary to take other kinds of measures apart from technical improvements.

Figure 1.1 illustrates the relationships between measures, transport demand and the context where the transports take place and effects. A given transport demand, generated from consumer demand, is added to the context, together with measures that are taken to achieve certain desired effects. The context is the available transport infrastructure, available businesses and their trading relations and resources, the environment, etc. The measures are for instance governmental control policies and technical improvements of transport resources. The context is influenced by the transport demand and measures, which result in certain effects, depending on the context. The effects in turn have a feedback influence on the transport demand and the measures. For instance, if the actual effects do not correspond to the desired effects, the measures may be revised. The feedback is illustrated with thinner arrows in the figure. In this thesis the focus is on the relationships illustrated by the thicker arrows, i.e., the feedback influence the effects can have on the transport demand and the measures are not mainly considered.

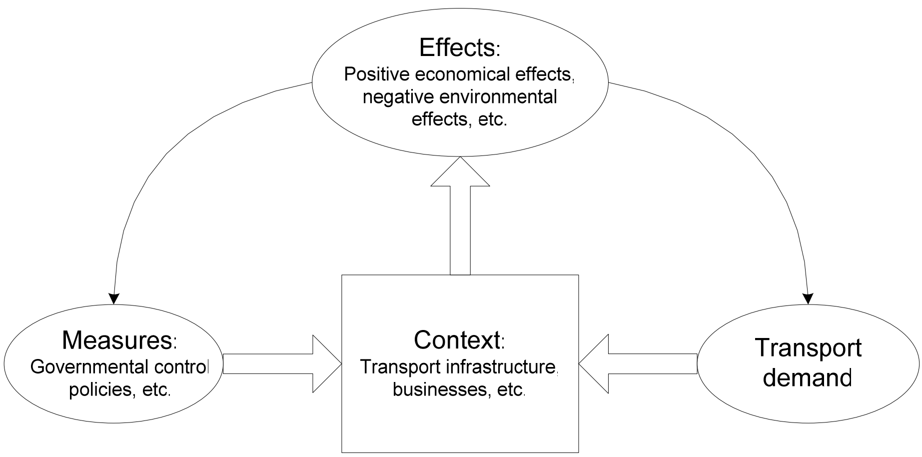

Figure 1.1. Illustration of the relationships between transport demand, measures, the context and effects.

Freight transportation can be viewed from three perspectives: the perspective of the individual transport chain actor, the whole transport chain and the society (Drewes Nielsen et al., 2003). Figure 1.2 shows a basic transport chain. First, transports are performed when there is a consumer demand, as expressed by the customer. The products a customer requires are transported to the customer, and are often stored at a terminal somewhere along the transport chain when necessary. The different transport chain actors all want to maximize their profit, for instance by reducing costs or increasing their income. Moreover, the transport chain actors have to synchronize their operations to be able to meet the consumer demand. If the coordination between the transport chain actors increases, it is possible to increase profit, reduce costs and improve customer satisfaction in the transport chain. Finally, the society, represented by the government, has interests in how transportation is conducted. The society wants to maximize the positive effects of transportation since it is connected to economical growth, while at the same time minimizing the negative effects of transportation which adversely influence the welfare in terms of human health effects, negative effects on the environment, etc. From the discussion above, we can see that there are conflicts of interest between the different actors, for instance between transport chain actors and the society.

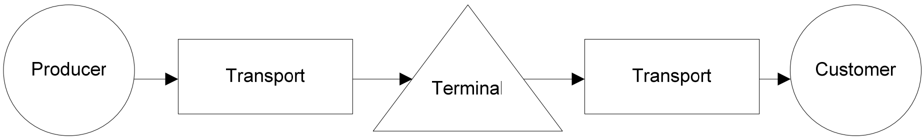

Figure 1.2. The physical flow of goods represented in a simple transport chain.

Logistics concerns the flow of goods and how the flow is planned, implemented and controlled in order to reach an efficient and effective solution which meets the customer requirements (CSCMP, 2005). In our interpretation we include planning and control of discrete transport units, such as trucks. There is therefore a potential to minimize the negative effects of transportation by using the concepts of logistics, i.e., by looking at transportation from a transport chain perspective.

The environmental impact of transportation depends on many factors, such as the energy source (e.g., oil, biomass), the energy carrier (e.g., diesel, ethanol, electricity), the transport mode, the vehicle type and characteristics of the engine (Swedish Society for Nature Conservation, 1997). Moreover, the way of driving, topography, weather, speed, traffic situation, etc., all influence the environmental impact. Further, some geographical areas are more sensitive to negative effects such as emissions and transport infrastructure barriers than other geographical areas. For instance, the negative effects of air emissions are greater in more populated areas. Moreover, transportation has different effects on the local, regional and global levels, as an example, carbon dioxide and other greenhouse gases are claimed to cause global warming which affects on a global level, while sulphur causes acidification in a more limited region (Elvingson, 2001). The environmental impact also differs if the emissions affect the air, water or soil. Fossil fuels such as oil and coal have considerable effects on the environment since these energy sources generate large amounts of carbon dioxide and sulphur.

Performance in transportation can include many aspects. The basic quality aspect companies consider is to meet the customer requirements, such as keeping time restrictions. Outside of the basic requirements, the focus is mainly on economical considerations. Sometimes not only the performance of individual companies is considered, as the performance of the whole transport chain is also crucial for the overall performance. A performance aspect which is important for the society is the environmental performance of transports, i.e., the environmental impact of transportation. Environmental performance is a measure of the environmental impact in terms of measurable parameters like, e.g., emissions. It is important to predict the environmental performance of transport chains to be able to take measures which minimize the negative effects of transportation. In order to facilitate the comparison between economical and environmental performance, environmental performance is sometimes expressed in monetary terms, i.e., environmental cost. However, when valuating the environmental performance in monetary terms, the different environmental impacts have to be valuated. This valuation can be done in several ways depending on which environmental impacts that are considered most important, i.e., valuations are not neutral and can be seen as political statements.

To guide transport chain actors in the direction of societal goals, governments use control policies such as taxes, fees and regulations. To reach the environmental goals of the society, governmental control policies should be designed so that transport chain actors are encouraged to take decisions that improve the environmental performance of the logistical operations, while still taking the economical situation of the transport chain actors into consideration.

Governmental control policies mainly concern traffic, i.e., the focus is not on the individual transport movements, but the amount of transportation. Since the control policies usually are designed to influence traffic it is difficult to study the actual effects on individual transport chains. Traditionally, macro-level models are used to analyse the effects on aggregated transport movements. We instead want to examine how control policies for influencing traffic influence the behaviour of individual transport chains in a micro-level model. However, the effects in individual transport chains are not possible to study with macro-level models. Therefore we believe that there is a need for micro-level models where detailed characteristics of transport chains, described by logistical factors, can be studied as well as the behaviour of the transport chain actors. We believe that a micro-level model can be used to bridge the gap between macro-level policy making and the behaviour in micro-level transport chains.

To be able to further study and verify the relationships between logistical factors and governmental control policies we believe that there is a need for a decision support that can take these relationships into consideration. Traditional macro-level models have been used to evaluate the effects of governmental control policies in transportation.

In micro-level simulation, specific behaviour of specific individuals as well as the interactions between the individuals are modelled. In contrast, in macro-level simulation the characteristics of an entire population are modelled. The characteristics are averaged together, and the model attempts to simulate changes in these averaged characteristics for the whole population.

There are several types of micro-level simulation, an example is Multi Agent Based Simulation, MABS. According to Parunak et al. (1998):

> "…agent-based modeling is most appropriate for domains characterized by a high degree of localization 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."

Hence, according to the above characteristics, transportation is a domain that is appropriate for agent-based modelling. Research has also successfully been conducted to apply agent technology to transport logistics, see Davidsson et al. (2004) for a review of applications.

There are examples of applications of MABS for policy making, e.g., Downing et al. (2001) have used it 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, couplings to macro-level models can be done.

1.2 Research questions

The main research question for this thesis is:

> *How can decision support systems based on agent-based simulation be used for analysing the consequences of governmental control policies concerning environmental, economical and quality performance of transport chains?*

To be able to answer the main research question the following corollary research questions have been formulated:

> RQ1. What type of conclusions can be drawn by means of MABS regarding how relevant governmental control policies influence the environmental, economical and quality performance of transport chains?
>
> RQ2. Which logistical factors are appropriate to include in a micro-level model?
>
> RQ3. How should a simulation model be designed to model the behaviour of transport chain actors, while including the effects of governmental control policies?
>
> RQ4. Which input in form of, for instance, scenarios is relevant in order to perform meaningful experiments of the effects of governmental control policies in transport chains?

We want to study the trade-offs between environmental, economical and quality issues, such as, when it is possible to improve the environmental performance in transport chains and what the effects will be in economical terms. The behaviour of the transport chain actors concerning their decisions on how to perform the logistical operations is therefore crucial. For environmental performance, we focus on energy usage and the amount of emissions to the atmosphere that the considered transports cause. Hence, we do not study negative environmental effects such as noise, congestion, barrier effects, infrastructure wear and accidents, as well as the environmental impact as a consequence of keeping products in storages.

The environmental performance can be influenced both internally in the transport chain, for instance, by better planning, or externally in terms of, for instance, governmental control policies. Both aspects are dealt with in the thesis, however, the focus is mainly on the external influence in terms of governmental control policies. Since the control policies change the prerequisites for transport chain actors, the incentives for the actors to improve the environmental performance can increase. We are interested in how the goals of the society, expressed in terms of governmental control policies, affect different transport chains. The society can for instance have a goal to minimize the negative environmental effects of transportation, and to achieve this goal taxes, fees and regulations are used. However, it is difficult to estimate the actual effects of those control policies in transport chains. There are different methods to study such effects, for instance to study historical data of control policy effects, to study cases of transport chains in depth or to perform large surveys. Macro-level simulation is also often used for this purpose, see, e.g., ASTRA consortium (2000), SAMPLAN (2001) and SCENES consortium (2000). However, we want to study if it is meaningful to model the societal perspective with micro-level simulation in order to capture the behaviour and decisions taken by individual transport chain actors concerning the logistical operations. We assume that the transport chain actors try to maximize profit. Here, the focus is mainly on cost reductions, since it is difficult to increase the income for the logistical operations. Also, since the road transport volumes stands for a considerable share of the negative environmental effects of transportation, the focus in this thesis is on land transportation. The other transport modes are also considered, but to a lesser degree.

1.3 Method

The work mainly makes use of three types of methods; literature study, the usage of a simulation model and a simple case study of an existing transport chain. First the problems were identified and possible relationships were described by the usage of literature study. Thereafter, some of those relationships were illustrated in simulation experiments. In order to connect the behaviour in micro-level transport chains with macro-level policy-making logistical factors have been identified. The logistical factors have then been applied to a case and used in the simulator.

On a higher level, the work can be viewed as a development of a method for how the effects of governmental control policies in transport chains can be studied with a simulation model. More detailed discussions of the methods used are found in the thesis. In the next sections, we discuss the methods that have been used.

1.3.1 Studying and analysing related research

Relevant logistical factors, governmental control policies and freight models have been studied and analysed in the literature. The material found in the literature have been structured and categorized to expose patterns. Furthermore, the relationships between logistical factors, governmental control policies and freight models have been examined by setting up possible relationships which were studied in the case study and simulation experiments.

A literature study of descriptions of factors that influence the performance of logistical operations has been done. The logistical factors have been classified and structured according to how easily and in what time frame the factors influence the performance of the transport chain. The relationships between transport chain actors and how they influence the identified logistical factors have then been described.

Since governmental control policies can influence the environmental performance of logistical solutions, relevant control policies for freight transportation have been identified from the literature. The control policies have then been grouped according to how they can influence the performance of transport chains. Possible relationships between control policies and logistical factors, i.e., which logistical factors the control policies influence, have been described.

There exist a number of freight models which evaluate the effects of governmental control policies. Therefore current freight models have been studied in the literature and we have examined if they are appropriate for analysing the relationships between governmental control policies and logistical factors, i.e., how governmental control policies influence logistical factors. The models have then been classified according to their characteristics. From the classification of the models we have concluded that none of the classified models take the explicit behaviour of the transport chain actors into consideration, which suggests the need for a different approach.

The usage of MABS in the context of transport chains have also been studied in the literature. The study showed that MABS has not been used for studying the effects of governmental control policies in transport chains. Also, there are several transport chain aspects in the applications which are lacking, for instance transport mode and vehicle choice.

1.3.2 Case study

The analysis and relationships described in the literature studies have been tested in a case study based on a simple transport chain to analyse if the relationships set up are possible to apply to a real world case. The case consists of a producer, Karlshamns AB, which produces speciality vegetable oils and fats, and the tanker transport provider FoodTankers. The information of the case study was mainly collected through open-ended face-to-face interviews with representatives from the companies, as well as through email contacts. The transport chain has been used in a simulation experiment where logistical factors and transport chain actors have described the case. The case study has been used to illustrate that the relationships described in the literature studies can be applied to a real transport chain. In case studies the problem of generalization is obvious since individual cases are studied. Our suggestion to deal with this is by applying the general descriptions of logistical factors and control policies to the case.

1.3.3 Simulation experiments

A micro-level simulation model based on agent-technology has been used to perform simulation experiments. Experiments with the case have been performed as part of the validation process of the simulator by studying the simulation results in relation to the behaviour of FoodTankers and Karlshamns AB. The relationships between logistical factors and governmental control policies as well as the interactions between the transport chain actors have been studied in the experiments. The effects of the governmental control policies have also been analysed in environmental, economical and quality terms.

In the micro-level simulation model the environmental performance of transport chains has been estimated. Different methods can be used to perform such estimations. The Swedish Network for Transport and the Environment (NTM, http://www.ntm.a.se/) works with trying to reach consensus between transport chain actors for how the environmental performance of transportation should be calculated, therefore this method was chosen. The method of NTM concerns emissions to air in Sweden, but the ambition is to reach consensus on a European scale in the future.

1.4 Contributions

The contribution of this thesis is mainly an exploration of how micro-level simulation can be used to analyse the effects of governmental control policies in transport chains and the development of a method for dealing with these issues. The corollary research questions have been used to support the main research question. The research questions have not been completely answered in this thesis.

We have outlined an agent-based simulation model where the behaviour of transport chain actors is modelled. Logistical factors have been defined and used as input to and output from the model. In the simulation experiments performed so far, where we have analysed the effects of a type of governmental control policy, we show that the model seems to perform well.

In order to address RQ1, concerning governmental policy analysis by means of MABS, a simple simulation experiment with one type of control policy has been performed in the agent-based micro-level simulator. We have analysed how the performance of a transport chain can be affected by governmental control policies. The environmental, economical and quality performance is for instance influenced by the transport mode choice, which has been analysed in the experiment for different levels of taxation. Hence, the behaviour of the transport chain actors can be analysed for different levels of taxes and fees, and breakpoints for logistical decisions can be found. The possible influence relevant governmental control policies has on logistical factors has been described to facilitate further analysis of the effects of governmental control policies.

Since we want to explore how governmental control policies influence the behaviour of transport chain actors, we suggest that the logistical factors that are appropriate to include in a micro-level model should illustrate the degree of influence, i.e., how easily and in what time frame the logistical factors can influence the performance of transport chains. RQ2, concerning appropriate logistical factors, has been further analysed in a simulation experiment where we have showed that the identified logistical factors seem to be appropriate to include in a micro-level model.

To answer RQ3, concerning the design of a simulation model, we have outlined an agent-based simulation model where the behaviour of transport chain actors is represented by decision-making agents. The micro-level model consists of two levels; one which models the physical transport movements, and one which models the decision-making and interaction of the transport chain actors. The transport chain actors are defined to be generic and can appear in different settings in different transport chains. Initial simulation experiments have been performed to study the effects of different levels of governmental control policies. The simulated decisions are short-term decisions. It is possible to indirectly account for long-term decisions, such as decisions concerning investments of vehicles, by the user of the simulator. Also, in a more advanced simulator direct simulation of long-term decisions can be enabled by increasing the decision domain.

There are several aspects of RQ4, concerning relevant input to simulation experiments. For instance, the scenarios should be related to real world cases and the scenarios should be generalizable. In order to use a scenario which is related to real world cases, a simulation experiment has been performed based on a simple real world case. Logistical factors describing the case have served as both input to and output from the simulation experiment. A governmental control policy which is under discussion to be implemented in Sweden has been studied in the simulation experiment.

There is a need for further work to fully be able to answer the identified research questions. To further validate the results there is a need for more simulation experiments with more governmental control policies and transport chains. We also want to study other aspects which influence the performance in transport chains, such as vehicle utilization. The effects of increased cooperation are interesting to study in a more advanced version of the simulator. There is a need to further study how the simulation experiments can be generalized, for instance, product groups which currently are used in macro-level simulations of governmental control policy effects can be included in the simulation experiments. Also, research on the behaviour of transport chain actors is needed, for instance by performing a survey, to study how the behaviour of transport chain actors can be generalized. The appropriateness of the logistical factors needs to be further validated in future simulation experiments. The future work which has been identified above can also be seen as a contribution.

1.5 Outline

The purpose of Chapter 2 is to identify actors in transport chains as well as logistical factors important to include in a micro-level model. We therefore address RQ2 in this chapter. The behaviour of transport chain actors is described taking the costs into account. Environmental, economical and quality performance aspects of transport chains are also described. Relationships between the identified roles of transport chain actors and logistical factors are outlined, and these relationships are further studied and used in the following chapters.

Relevant governmental control policies that affect freight transportation are described in Chapter 3. In order to address RQ1, possible relationships between governmental control policies and logistical factors are described. We conclude that these relationships need to be further analysed with the usage of models.

The purpose with Chapter 4 is to analyse if existing freight models can be used to evaluate the effects of governmental control policies in transport chains. Parts of RQ1, RQ2 and RQ3 are therefore addressed in this chapter. A framework is presented which has been used to evaluate existing freight models. We conclude that there is a lack of micro-level models designed for governmental policy analysis.

In Chapter 5 simulation experiments with an agent-based simulator are described. The simulation experiment aims at analysing if it is possible to estimate the effects of governmental control policies in transport chains, i.e., RQ3 is addressed. Moreover, in order to deal with RQ2, the logistical factors identified in Chapter 2 are used in the simulation experiment. The effects of governmental control policies included in the simulation experiments were analysed in order to deal with RQ1. Finally, to address RQ4, a simulation experiment of a case based on a simple transport chain is described. Chapter 6 concludes the work and outlines future work.

2. Transport chains – characteristics and influential factors

We want to study how computer simulations can be used for analysing the effects of governmental control policies in transport chains. Since we want to include the behaviour of transport chain actors into the simulation model, we need to define and describe the different roles of transport chain actors. In order to characterize transport chains we identify logistical factors. Moreover, the performance of transport chains is described in terms of environmental, economical and quality performance.

2.1 Transport chains

For consumption, products have to be transported from the production site to the customer. The flow of products takes place within a *transport chain*, see Figure 2.1 for an example of a simple transport chain. A transport chain can be the entire chain from the producer of raw material to the end customer, but it can also be a segment of the whole transport chain, e.g., from a production site to a customer that further processes the products. The transport chain can consist of several customers, production sites, storages, etc., i.e., a transport chain can be a network of interacting parts. There is sometimes a need to temporarily store the products directly after production if there is no immediate consumer demand. The products can also be stored in intermediate storages after shipping, as well as in storages at the customer.

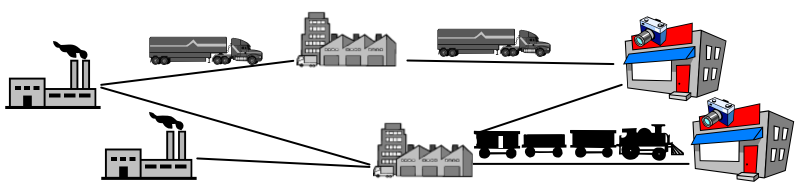

Figure 2.1. The physical flow of products represented in an example of a simple transport chain.

Transport chains consist of *transport chain actors* which represent different roles in the transport chain. The transport chain actors decide on how the logistical operations in the transport chain are going to be performed. The roles of the transport chain actors will be further discussed in Section 2.4.

The flow of products can also be expressed in the term supply chain, see for instance Stock and Lambert (2001) and Rushton et al. (2000). Since our focus is on transportation we find the term transport chain to be a more appropriate description. We consider also the roles of the producer and the customer, however, we see transportation as the main operation since we are interested in the environmental, economical and quality performance of transports.

2.2 Logistical factors

The performance of a transport chain depends on a number of factors which we here denote *logistical factors*. Logistical factors describe characteristics of transport chains. The performance of a transport chain can be measured in a number of ways, the aspects that are brought up here are environmental, economical and quality performance. The performance of transport chains is further discussed in Section 2.3.

There are several different ways of describing logistical factors and we discuss some of the descriptions with a certain focus on environmental aspects of transportation that have been suggested. First, to give an introduction on how logistical decisions can influence the volume and pattern of physical flow, the four levels of logistical decision-making described by McKinnon and Woodburn (1993) are brought up, followed by three different descriptions of logistical factors or indicators by Blinge and Lumsden (1996), Drewes Nielsen et al. (2003) and Richardson (2005). The descriptions are brought up here since they all have an environmental focus, i.e., how different settings of transport chains influence the environmental performance. The economical and quality performance is also discussed to different extents in the descriptions.

McKinnon and Woodburn have presented four levels of logistical decision-making that can have an impact on the volume and pattern of the physical flow (McKinnon and Woodburn, 1993):

1. *Logistical structure* – numbers, location and capacity of factories, warehouses and terminals
2. *Pattern of trading links* – relations between trading partners; sourcing, sub-contracting and distribution
3. *Scheduling of product flow* – scheduling of the actual transports to discrete transport operations

4. *Management of transport resources* – allocation of transport resources to transport tasks

Decisions on the two first levels – the logistical structure and the pattern of sourcing and distribution – have an impact on the number of ton kilometres in the goods flow generated by a logistical system of a company. Ton kilometre is the measure of transport work, i.e., one ton transported one kilometre. Decisions on the other levels – scheduling of product flow and management of transport resources – describes the volume of goods movement to vehicle kilometres. Vehicle kilometre is the measure of traffic work, i.e., one vehicle transported one kilometre. Next some examples are given of how decisions at the different logistical levels can affect the transport and traffic work, according to a survey by McKinnon (1998) where logistical trends, mainly in the UK, were observed.

A change in the *logistical structure* can influence the transport distance. For instance, centralization of the logistical structure to one or a few terminals can imply that the number of ton kilometres increase. This is not always the case since the effects depend on the logistical structure of the company.

When the *pattern of sourcing and distribution* is changed to a more geographically dispersed market, the number of ton kilometres increases. Moreover, outsourcing can increase the number of ton kilometres since an additional transport chain actor is added to the transport chain and there is often a need for transportation to the new actor.

According to McKinnon the *scheduling of product flows* indicates how the transports are planned. When the scheduling of a product flow changes, for instance, because of changed consumer demands with requirements on just-in-time transports, the size of the consignments sometimes decreases and the frequency sometimes increases. However, statistics show that load consolidation often increases, why it is difficult to say if the number of vehicle kilometres actually increases as a consequence of just-in-time strategies.

The *management of transport resources*, i.e., how goods are allocated to vehicles etc., influence the number of vehicle kilometres. For instance, if customers require large quantities of goods with low frequency, large, but perhaps fewer vehicles can be used. This would in turn result in less vehicle kilometres. The potential for improving vehicle resource usage by planning increases with larger the time window. Many measures can be taken to reduce the number of vehicle kilometres, e.g., vehicles that enable load consolidation of different types of products can be used.

Blinge and Lumsden (1996) have presented a model describing the environmental performance of freight transportation. In their model the environmental impact of the transport system is divided into internal and external environmental impact. The internally related environmental impact is connected to vehicle properties, the technical level of the vehicles and the available infrastructure. The internal factors are a prerequisite for using the transport system, i.e., there is a need for infrastructure and vehicles to transport goods. The externally related environmental impact deals with how the available resources are used. Externally related factors include load consolidation, backloading, route planning, ordering systems, packaging/handling, driver behaviour and information technology. According to Blinge and Lumsden (1996) attempts to reduce the environmental impact of transportation have so far primarily focused on internal impact. There has, e.g., been extensive work to reduce emissions to air from motor engines of vehicles, e.g., by improving motor efficiency and fuel efficiency. However, there is also a need to reduce the externally related environmental impact, i.e., to reduce the environmental impact by using the available resources better, given a particular customer demand (Blinge and Lumsden, 1996). This can, e.g., be done by increased use of load consolidation and return loading. The internally and externally related factors are connected to the customers and their requirements.

Drewes Nielsen et al. (2003) have developed a framework for describing the relationships between logistical organizations and transportation, see Figure 2.3. Changes at the four levels of *logistical decision-making* described by McKinnon and Woodburn (1993) are in their view revealed in *transport logistics indicators* such as distance, speed, frequency and time of delivery. These in turn have impact on transport and are described in terms of *transport indicators*, i.e., transport mode, transport content of a given transport (the ratio between average length of haul and the average payload, thus measured in kilometres per ton), transport distance and transport efficiency (i.e., the average payload which can be measured as the ratio between the ton kilometres and vehicle kilometres). The transport indicators have a direct impact on the environment and the society in terms of emissions, noise etc.

Figure 2.3. A simplified illustration of the framework by Drewes Nielsen et al. (2003).

Richardson (2005) has outlined a quite complex framework describing the most important factors affecting sustainability of transportation system. The correlation between the environment, market forces and infrastructure is brought up as well as the impact of governmental policy-making. The framework of Richardson is not mainly focused on transport chains, although, quite detailed parameters are brought up that concerns transport chains. The framework is mainly developed for road transportation; however, other transport modes can implicitly be applied in the framework. Aspects such as truck driver behaviour, weather conditions, congestion, incidents etc. are also brought up in the framework.

2.2.1 Degree of influence

The descriptions above have different perspectives and goals, why the descriptions differ. The above descriptions mainly focus on high level aspects of transport logistics, i.e., which logistical factors that have a negative impact on the environment, and the focus is not mainly on individual transport chain actors. Moreover, the descriptions are not designed with the aim to be used for the development of a decision support system. Since we want to describe characteristics of individual transport chain actors in a simulation model, there is a need for a more detailed description of logistical factors. We want to focus on the logistical planning aspects; therefore we choose not to include aspects such as driver behaviour and weather conditions as in the framework of Richardson. We also want to examine how easily and in what time frame the performance of transport chains can be influenced. Therefore we structure our description of logistical factors according to degree of influence, i.e., *given factors*, *indirect factors* and *direct factors*. The focus is on road transportation, however, the framework can also be applied on other transport modes.

The logistical factors can be used for describing typical transport chains and different logistical solutions. The description is inspired by the descriptions of McKinnon and Woodburn (1993), Blinge and Lumsden (1996), Drewes Nielsen et al. (2003) and Richardson (2005). Since we mainly focus on how decisions in different time frames influence the performance of transport chains, we prefer to make categories according to degree of influence. Moreover, we try to structure the factors to be applicable in a simulation model, i.e., the logistical factors will function as input to and output from the simulation model.

Figure 2.4 illustrates the relationship between actors, decision chain and descriptive indicators. Governments set the framework for how it is possible for transport chain actors to behave. The logistical operations are the actual operations that are performed as a consequence of the decision-making of the transport chain actors in order to satisfy the consumer demand. The decision chain is represented by descriptive indicators. The consumer demand is represented by given factors. The decision-making is represented by indirect and direct factors, and the performed logistical operations are described in performance indicators.

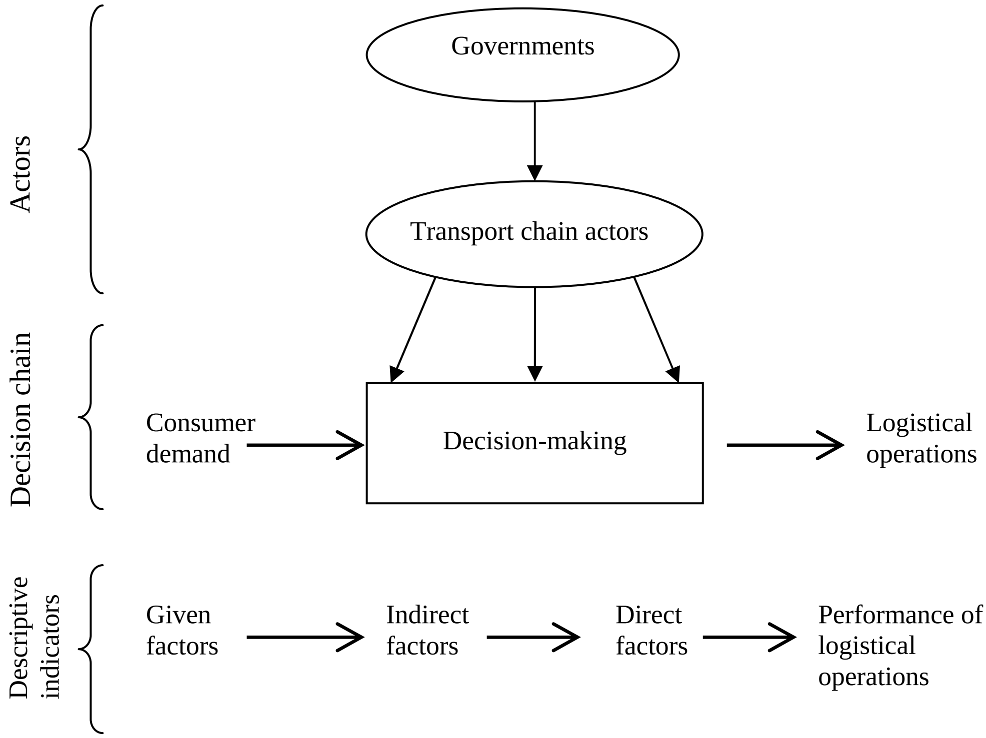

Figure 2.4. The decision-making in transport chains to reach a plan for how to conduct the logistical operations expressed in descriptive indicators. The decision-making is performed by transport chain actors and governments.

First, *given factors* describe the consumer demand which is the reason for why the customer in the transport chain requires products. We see the consumer demand as an external demand (i.e., the demand of the end consumer). Since the consumer demand is not directly part of the transport chain, the given factors cannot be influenced by the transport chain actors in our simplified framework.

Next, *indirect factors* are the prerequisites that are needed to perform transport operations, e.g., the transport infrastructure. These factors are not directly coupled to the specific consumer demand, but they influence how it is possible to perform the logistical operations to meet the consumer demand. Indirect factors can be influenced in the long-term by strategical decision-making, however changes of these factors often demand substantial investments. Since the indirect factors do not directly influence the logistical operations, the effects of the indirect factors are difficult to predict. The given factors can have an influence on the indirect factors when strategical decisions are taken. For instance, if a new consumer demand of temperature sensitive products that require special handling when stored appears, investments might be necessary if the products need to be stored.

Finally, *direct factors* directly influence how the logistical operations will be performed. These factors are the ones that are influenced most directly in the short-term planning process, i.e., operational or tactical planning. Since the direct factors influence how the logistical operations will be performed, it is these factors that directly influence the performance of the logistical operations. The direct factors mainly influence the vehicle kilometres and the vehicle utilization. The indirect and given factors influence the direct factors, since they decide which logistical operations that are possible to perform.

Below logistical factors are listed according to the degree of influence:

Given factors

- Product demand
- Products characteristics
- Geographical location of the customer

Indirect factors

- Available transport infrastructure and its characteristics
- Available resources and its characteristics
    - Production resources
    - Storage facilities
    - Transport resources

Direct factors

- Logistical operation planning
    - Production planning
    - Inventory planning
    - Transport planning

- Transport choice
    - Transport mode
    - Vehicle type
    - Fuel type
- Vehicle utilization
    - Frequency of the transports
    - Load consolidation
    - Backloading

The indirect factors are similar to the internal factors described by Blinge and Lumsden (1996), except that production resources are not included in the internal factors. Also, the logistical structure and pattern of trading links described by McKinnon and Woodburn (1993) resemble the indirect factors. However, decisions concerning transport and production resources are not included in decision-levels by McKinnon and Woodburn. Further, the direct factors are similar to the external factors described by Blinge and Lumsden (1996), and the scheduling of product flow and management of transport resources described by McKinnon and Woodburn (1993). In the next section we look at the factors more closely.

Given factors

The given factors describe the consumer demand, i.e., product characteristics, quantity of the product, and geographical location of customers. We regard the consumer demand as fixed, i.e., the transport chain actors cannot influence the demand. Therefore we study which measures can be taken, given a certain amount of products which needs to be transported.

The *product demand* is the consumer demand expressed as a planned demand in terms of quantity (volume and weight) and time, taking inventory levels at the customer into account. The goal of the transport chain actors is to satisfy this demand.

Product characteristics include characteristics such as product value, density, handling requirements (e.g., temperature, packaging, and load consolidation possibilities), deterioration rate, production time, etc.

The geographical location of the customer is also important since it influences the transport distance as well as which logistical operators that possibly can perform the logistical operations. For some businesses the geographical distance between transport chain actors is not crucial, e.g., if the transport cost is low compared to the product value. The importance of the distance when logistical operators are chosen also depends on the quantity of the products as well as where other customers are located. If several customers are located close to each other, coordination of transports to several customers is possible.

Indirect factors

The indirect factors describe the infrastructure and resources that are needed to perform logistical operations. The *available transport infrastructure* sets the framework for where the logistical operations can be carried out. Available infrastructure include *network* infrastructure of different transport modes, i.e., rail, road and pipeline, as well as *terminals*, i.e., seaports**,** dry ports, airports and railway yards. Characteristics of the infrastructure are speed limits, capacity, geographical dispersion or location, etc. To influence the infrastructure there is a need for long-term infrastructure investments or regulations. Infrastructure investments can shorten the transport time, or make certain transport modes possible to choose on a certain link, and regulations can set speed limits. Hence, infrastructure investments can influence the competitiveness of certain transport modes.

The *available resources* set the framework for how the *transports* and *production* can be carried out and how it is possible to *store* the products. The resources are vehicle fleet, loading units, type of production resources, personnel, type of storages, the geographical location of the resources etc. Although investments in these resources are not as large as infrastructure investments, the investments can be large for the individual company. We see these investments as long-term. Characteristics are associated to the production resources, such as production capacity. Examples of characteristics connected to transport resources are transport mode, number of vehicles, vehicle types with characteristics such as possible fuel types, loading unit and capacity for each vehicle type. Characteristics associated to storage facilities are, e.g., storage capacity and storage equipment such as possibilities to handle cold or warm products.

Direct factors

The direct factors are influenced by the indirect and the given factors, which hence influence the planning process of the direct factors.

The *logistical operation planning* regards the planning of production, inventory and transport. The planning concerns the planning of the time window for certain product quantities to be handled. The different types of planning depend on each others, and often the production and inventory planning is done before the transport planning. The *production planning* depends on planned shipments, storing capabilities, inventory levels and how the production resources can be used. The production is planned in quantities on time periods. The *inventory planning* concerns how the inventory levels are planned and include aspects such as safety stock and order points. The inventory levels can be planned to vary a lot, or to be quite constant. The planned inventory levels depend on the planned production and the planned shipments. *Transport planning* concerns shipments which are planned to be performed and includes the time window for shipment as well as the quantity. The time window describes when it is planned that the products should have been transported to the customer site, according to the available transport resources and the customer requirement. The quantity describes how large the shipments are planned to be, according to available vehicles and the customer requirements (possibly expressed in maximum and minimum quantities). The shipments can be planned a long time before the actual shipment, or a short time before the actual shipment. The products to be shipped can be taken either directly from production or from storages.

The *transport choice* includes the choice of possible transport modes, vehicle types and fuel types. The *transport mode* choice is influenced by the available infrastructure, the location of the customer, product characteristics, customer requirements, etc. The *vehicle type* choice depends on available vehicles, product characteristics, chosen transport mode, etc. A certain vehicle type can be unavailable since it is planned for another transport task. A vehicle can be a certain truck type, a certain rail freight carrier type or a certain type of ship, etc. We also include unit load in the concept of vehicle. Sometimes it is possible to choose between different *fuel types*. The fuel types have different qualities and their environmental performance differs.

The *vehicle utilization* describes how well a vehicle is utilized. The vehicle utilization can be measured in a *vehicle load factor*, i.e., the amount of loaded goods divided by the maximum loading capacity of the vehicle. The vehicle load factor can be calculated in different ways, but is often determined by the quantity of goods to be transported, the maximum load capacity of the carrier and the transport distance, and is normally calculated from the weight and volume of the goods (Tarkowski et al., 1995). Here we group frequency, load consolidation and backloading since these factors influence how well a vehicle is utilized.

The *frequency of the transports* describes how often the products are transported to the customer. The frequency depends on the consumer demand, the available transport resources and in which time window the products are planned to be transported. If the time window is sufficiently large, a more flexible planning of the usage of available transport resources is enabled, for instance, by the usage of fewer vehicles in larger consignments. Hence, it is possible to increase the vehicle utilization, and possibly reduce the number of vehicle kilometres, if larger product quantities can be transported more rarely.

Load consolidation means that products to different customers are loaded in the same vehicle, which means that the transport route can include several stops. Since the customers may be located at different locations, the transport distance can be larger if loads are consolidated. However, compared to having one transport instead of two, this most often reduce the amount of vehicle kilometres. A prerequisite for using load consolidation is that the consolidated products can be loaded next to each other in the vehicle.

If there are transport opportunities in both directions, *backloading* can be used. With backloading the vehicle capacity can be used on the way back and products can be loaded and transported in the other direction. When backloading is used, the same problem as with load consolidation occur, i.e., the transport distance may become longer since the return route not necessarily has to be exactly the same. However, even if there are transport opportunities in both directions, backloading can be difficult to achieve. For instance, it may be difficult to coordinate the transports if the required time of deliveries differ or if the vehicle requirements differ between the orders because of product characteristics.

The direct factors, especially the transport choice and vehicle utilization, can be used to calculate the performance of the logistical operations. The logistical factors described here do not cover all aspects that have an influence on the performance. Factors such as driver behaviour, weather conditions, etc. also affect the performance of logistical operations. However, in this context we do not see those factors as relevant since we mainly are interested in logistical aspects of transport chains, i.e., the planning issues.

Beside the logistical factors described here, the logistical operations are going to be performed in a legislative and regulatory context which sets the frame for how it is possible to perform the operations. Moreover, the costs associated to the logistical factors influence the decisions of the transport chain actors.

2.3 Performance

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 be seen as quality performance. Moreover, performance of logistical solutions can also be measured in environmental performance. The environmental performance of logistical solutions is mainly of interest for the society; however, improving the environmental performance may also imply decreased costs for the transport chain actors.

Key performance indicators (KPI's) are widely used for describing the performance of logistical operators. As an example of KPI's, McKinnon et al. (2002) used five KPI's when analysing the effectiveness in the UK food supply chain, i.e., vehicle utilization, empty running, vehicle time utilization, deviations from schedule and fuel consumption. Those KPI's indicate how efficiently the available resources are utilized to reach the customer requirements in terms of the most influencing performance indicators.

Below we describe the performance of transport chains in terms of environmental, economical and quality performance.

2.3.1 Environmental performance

When considering the environmental performance of transport chains we mainly focus on the energy usage and emissions to the atmosphere from transportation. The Swedish Network for Transport and Environment (NTM) has developed methods to calculate the energy usage and emissions to the atmosphere from transports in Sweden (see http://www.ntm.a.se/). 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).

The fuel consumption of transport chains is closely coupled to the environmental performance and is influenced by for instance transport distance, vehicle utilization, speed and vehicle type. Also, the fuel consumption varies depending on where the transport takes place. For instance, driving a truck in Norway normally means that the fuel consumption is quite high since there is broken ground. Speed is a critical factor for the environmental performance since the fuel use rise with the speed. In the simulation model, we assume that the driver uses the maximum allowed speed, according to the speed limits, vehicle requirements, etc. Therefore speed is not explicitly included as a logistical factor, instead it is an associated characteristic of the available transport infrastructure. The fuel consumption is also influenced by the vehicle load factor; more fuel is required if the vehicle is fully loaded, but at the same time less fuel per product is consumed. Different fuel types have different environmental performance. For instance in Sweden, the fuel types are grouped into fuel classes according to the environmental performance. The environmental performance of a transport is also influenced by the transport mode, the vehicle type and the engine type.

To get an idea of how well the transport resources are used, given a certain amount of goods, the traffic work in relation to the transport work of a transport chain can be studied. The transport work does not by itself describe the environmental performance of the logistical operations 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 it is necessary to study the transport and traffic work in relation to each others.

According to McKinnon (2003), the environmental impact from freight transportation can be minimized in three ways when logistics is used:

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 transport modes with better environmental performance
3. reduction of the number of vehicle kilometres, i.e., increase the vehicle utilization

Reduction of the total number of ton kilometres can be achieved by, for instance, a reduction of volumes that are not necessary to transport, so called cross haulage (Steen and Åkerman, 1997). Cross haulage means that equivalent products, the only difference can for instance be the brand, are transported in opposite directions. Both flows are not necessary but can still be difficult to reduce since consumers often demand several products to choose between.

The number of ton kilometres can also be reduced by restructuring of the logistical structure, such as location of storages, factories (McKinnon, 1993). This in turn will for instance influence the transport distance. Changes of the logistical structure are long-term changes.

According to McKinnon (2003) and Backman (1997) a modal split from road transport to transport modes with a better environmental performance is not very realistic since only some goods volumes have the prerequisites to change mode. Transport modes have certain characteristics that are appropriate for certain types of products, e.g., road transport is a flexible alternative that is appropriate on shorter distances and for products that require high reliability. However, according to Böge (1995) the reliability of road transport is low on congested roads, which then make other modes more competitive. There is a wish within the EU to transfer volumes from road to rail and water transport in order to minimize the negative external effects of road transport (European Commission, 2001). To facilitate the transfer to rail transportation, incentives can be given in terms of governmental control policies and investments in transport infrastructure that increase the accessibility of transport modes with a better environmental performance.

Sometimes there is a correlation between cost-effective actions and environmental performance. For instance, rail transportation is cost-efficient on longer distances (see Section 2.3.2 for further discussions of the cost aspects of rail transportation) and it also has a low usage of energy compared to other modes since it can transport large goods volumes and also since electricity[1] can be used. For waterborne transportation the situation is similar. The speed of waterborne transportation is often low, and therefore requires less fuel which both implies that the environmental performance can be good and that the fuel costs are kept low.

Another example of when a logistical solution is both cost-effective and has good environmental performance is when the vehicle utilization is high. High vehicle utilization implies that the available transport resources are efficiently used so that the number of vehicle kilometres is as low as possible. As discussed in Section 2.2.1, the vehicle utilization can increase if load consolidation or backloading are used, or if the frequency of the transports is adapted to fit the consignments to the size of the available vehicles. Flexible customer requirements and cooperation between the transport chain actors can facilitate the planning of the transports.

[1] Electricity can be generated in different ways, for instance from wind and water power. In such cases electricity is considered a good environmental choice. However, electricity can also be generated in ways which are not as good from an environmental point of view, such as generation from fossil power.

Another issue which influences the environmental performance is that the transport price often is included in the total price for the products. In Östlund et al. (2003) it is claimed that if the transport price is included in the product price, the transport price is not economically transparent for the customer, why the customer has no incentives to try to reduce the transport price. As mentioned above, the transport price can for instance be lowered by high vehicle utilization or by the usage of transport modes with low costs. Measures to lower the transport price can lead to an improved environmental performance of the transport chain, however, Brehmer (1999) and Rodrigue et al. (2001) claim that this is not always the case. For instance, centralization which often leads to reduced costs sometimes increases the environmental impact.

Companies can be competitive if they choose to have a more “green” image (Welford, 1998). Some customers want the producers to be able to show that they work actively with reductions of the environmental impact (Welford, 1998). These might therefore choose producers or transport operators which take environmental aspects into consideration, for instance by performing logistical operations which have high environmental performance. Another issue is that the logistical operations with the best environmental performance do not always have the lowest overall costs. To encourage and facilitate logistical operations with a good environmental performance, governments can give incentives to transport chain actors with fiscal control policies. Also, stronger control policies such as regulations can be used to minimize the negative effects of transportation. Governmental control policies will be further discussed in the following chapter.

2.3.2 Economical performance

One important aspect to consider when planning the logistical operation is the cost aspect. The costs are connected to the logistical factors and therefore have a strong influence on the behaviour of the actors. The costs of the transport chain actors can be divided into fixed and variable costs (Button, 1993). The fixed costs are long-term costs that only change rarely, such as, capital costs for production and transport resources. In this context, fixed costs are for instance costs associated to owning a vehicle. The variable costs are connected to the usage of resources. The variable costs change more frequently, and can for instance be labour costs, fuel costs and maintenance costs (such as vehicle service and tyre costs). We regard taxes and charges, such as kilometre taxation and road pricing, as variable costs since they are variable costs with respect to the usage of resources for the transport chain actors. Correspondingly, there are also taxes and charges that can be seen as fixed, e.g., vehicle tax.

The transport chain actors are driven by the desire to increase profit, i.e., to reduce costs and to increase income (Drewes Nielsen et al., 2003). Therefore we assume that the transport chain actors make decisions based on profit maximization, i.e., that they aim at reducing costs.

2.3.3 Quality performance

When the performance of transport chains is discussed, quality aspects are always implicitly included in the concept. If the consumer demand is not satisfied, good environmental and economical performance are meaningless. Therefore, maintaining a sufficiently high quality performance is crucial. Different transport chain actors have different types of quality requirements in relation to the consumer demand, which consequently imply different prices.

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. Furthermore, the reliability of the time of delivery is often crucial for the customers to be able to plan the handling of the products or for further production planning. Deviation from schedule is also an important quality performance indicator. Some product types also require handling at certain temperatures and some are sensitive to shock.

2.3.4 Aspects of performance trade-offs

Good environmental, economical and quality performance does not always coincide. For instance, if there is a wish to have a very good quality performance, the costs for the transport chain actors are often higher than if the quality performance is worse. Different actors value the importance of performance differently. For instance, some societies value a high environmental performance as the most important, while some transport chain actors value a high quality performance as most important. Since the importance of the three performances discussed above is valued differently by different actors, a trade-off is needed to maintain a sufficiently good performance in all three performance aspects. To facilitate the trade-off between economical and environmental performance, the environmental performance can be expressed in monetary terms.

In Section 2.3.2 the costs the transport chain actors experience are described, i.e., the internal, or direct, costs. The external, or indirect, costs are the costs that are not directly coupled to the costs for the transport chain actors, but which appear as a consequence of the transports since the transports cause 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 this issue is often brought up and a common view is that the external costs of transport should be internalized, i.e., included in the price for transport (European Commission, 2001). Internalizing the external costs implies that the one that causes the negative external costs also has to pay for it. The external costs have to be valuated and an economical valuation is always a judgement. Therefore it is important to be critical to those valuations. Different persons value the environmental impact differently, for instance, 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). Since economical theory is widely used, especially in the industry, economical valuation of the environmental effects can be an appropriate tool for including the environmental perspective when environmental and economical effects of governmental control policies are analysed.

There are several methods of 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., 2001), which estimates the external costs of infrastructure costs, supplier operating costs, transport user costs, accident costs, noise costs and air pollution costs; and
- ASEK (SIKA, 2000b), which estimates the external costs of accidents, emissions, carbon dioxide, and noise among other things, to be used for socio-economic calculations for both freight and personal transports.

Typically, when estimating the environmental external costs, the amount of the externality (i.e., the unaccounted negative 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 valuated 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.

To include quality performance in a monetary trade-off, for instance the time aspect of transport chains is possible to evaluate in monetary terms. As an example, SIKA (2000b) has made such estimations.

In the next section the roles and behaviour of transport chain actors are described, coupled to the performance aspects of the logistical factors.

2.4 Roles and behaviour of transport chain actors

There are several actors in a transport chain, which have different roles and different goals. These actors take decisions which influence the characteristics of the physical flow, for instance the actor responsible for the transport choice influences the transport mode used in the transport chain. Since we want to describe the roles in transport chains as generic as possible, we divide the different roles, or actors, in transport chains into *production planners*, *product buyers*, *transport buyers*, *transport planners*, *transport chain coordinators* and *customers*, see Figure 2.5. The identified roles belong to different organizations in different transport chains. In some transport chains, all decision-making roles can belong to one single organization, e.g., petroleum companies. In other transport chains, all decision-making roles belong to different organizations. There are also many other kind of mappings that are in-between these extremes. This is further illustrated by a real world case discussed in Chapter 5. The behaviour of the transport chain actors has an influence on the logistical operations in both the short- and long-term. In this section the focus is mainly on the short-term influence and behaviour since the current version of the micro-level simulator only include the behaviour of the actors which has an influence in the short-term.

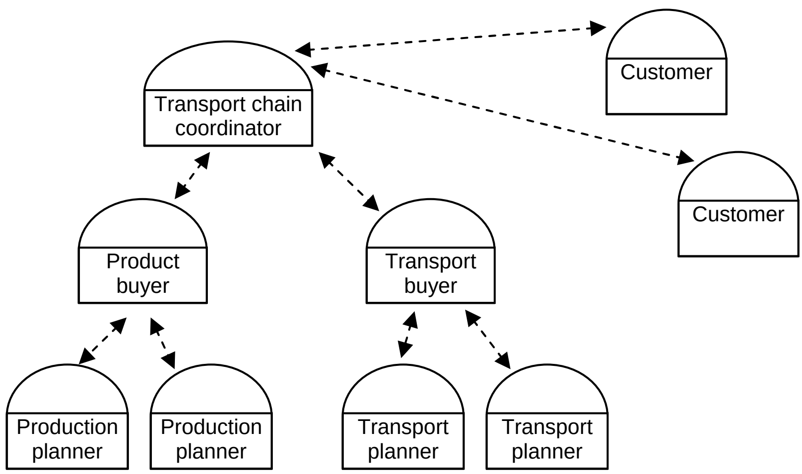

Figure 2.5. The roles of the transport chain actors.

Since we are interested in the *roles* of the actors in a transport chain, for instance a customer does not need to be an end-customer of the whole transport chain, but have the customer role in a part of the transport chain. In the following part of the whole transport chain, the customer can have the role of a production planner. The same is true for production planners.

The *customer* requires products when there is a consumer demand and often wants the products delivered at a certain time. Often this is expressed in terms of a time window with varying size. The time window is set depending on needs of the customer, i.e., based on the consumer demand. The importance of the delivery time reliability of transports depends on how the product is going to be used, as well as the type of product. Apart from the time aspect, it is important that the required products are delivered according to the agreement, for instance that the products have been handled according to the product requirements. For the customer, the quality aspect, i.e., receiving the products according to the agreement, is often more important than receiving the products to a very low price. The manner of transporting the products to the customer, such as, the choice of transport mode, is of minor importance.

The *transport chain coordinator* deals with the coordination of the requirements of the customer, the product buyer and the transport buyer. The transport chain coordinator tries to satisfy the customer requirements at the lowest cost by sending requests to the transport buyer and the product buyer. The location of the production site influences the decisions since the distance between the production planner and the customer influence the transport costs. Products can be bought from several product buyers, and the transport chain coordinator also decides when products are going to be taken from intermediate storages. Storage costs are associated with keeping products in storages, but higher inventory levels can facilitate better planning of the logistical operations. Moreover, since the transport chain coordinator has the overall responsibility for how the proposals from the transport and product buyers are coordinated, it also has an influence on the direct logistical factors.

The degree of cooperation between the different actors can vary. If the cooperation between the transport chain actors is high, the transport chain coordinator receives detailed information from the customer, the transport and product buyer. An example of cooperation between the transport chain actors is Vendor Managed Inventory (VMI), see, e.g., Stock and Lambert (2001). In VMI the inventory level at the customer site is known, which implies that the transport chain coordinator can demand products from the product buyer in terms of the planned demand instead of a fixed quantity. This type of cooperation can make the planning of transports and production more efficient since more information of the actual demand and supply is available.

The *product buyer* gets a request from the transport chain coordinator to give a proposal for a plan for how a certain amount of products can be produced and what the costs are for this production plan. From this requirement, the product buyer chooses from which production planner the products should be bought. The product buyer bases the decision on the price the production planner can offer while still fulfilling the product requirement. Since the product buyer influences the product planning it has an influence on the transport and inventory planning since these are connected.

The *production planner* gets a request from the product buyer to present a production plan. The production planner then plans the usage of production resources and capacities as effective as possible taking inventory levels and production costs into account. If the product buyer accepts the price offered by the production planner, the planned production is carried out by the producer. When planning production, the production planner wants to maximize profit, which implies that it often wants to decrease the time products are stored since the capital then is tied up. There is also a cost for storing the products, and these costs can be even higher if there is a need for special handling. However, the production planner also wants to have a high utilization of its production resources while avoiding extra costs (such as labour costs) due to production peaks and costs for preparing the production resources to be used for different product types. Therefore better planning can be facilitated by having products in storages. Moreover, if the customer requests products in advance, it is easier for the production planner to plan the production efficiently. Often part of the customer requirement is known in advance, while a part is not known until a short time before it should be delivered.

The *transport buyer* gets a request from the transport chain coordinator to give a proposal for how a transport can be carried out. The transport buyer chooses to buy transports from the transport planner which provides the lowest costs while still providing the customer requirements. Product requirements have to be taken into account where certain transport choices are preferable, e.g., the choice of transport mode. For instance, requirements on transports without much shock may imply that rail transport is not an alternative. 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. Since the transport buyer decides from which transport planner the transports should be bought, it also influences the vehicle utilization.

Since the transport buyer selects from which transport planner the transport should be bought, the transport buyer influences the transport mode choice.

Several aspects influence the decision of transport mode. An important aspect is the costs of the transport mode, but quality requirements like reliability and fast transports often have an important influence on the transport mode choice (Cullinane, 2000; SULOGTRA, 2000). There is often a trade-off between those aspects, and the trade-off depends on the type of transport chain, product characteristics, etc. Different types of products have different demands on how the transport is carried out. For instance, sturdy raw materials such as steel and wood often do not have high demands on time reliability, while finished products often have high demands on fast transports.

The most common transport modes are road, rail, waterborne, air and pipeline (Stock and Lambert, 2001). Sometimes it is appropriate to use intermodal transports, 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). An intermodal transport can, for instance, start with a truck transport from the producer, continue with waterborne transport and end with a truck transport to the customer.

Rail transport has relatively low variable costs, as an example, one extra rail freight carrier causes little extra cost, and the energy use is quite low, especially for electrically powered trains. However, at the same time the fixed costs are quite high (e.g., transport resources) and therefore a common statement is that rail transport needs longer distances to benefit from the low variable costs (the break-point for when rail transportation becomes competitive can vary between 200 and 1000 km according to some researches (Fröidh et al., 2000; Bonnafous and Raux, 2003). Further, it is possible to load large amounts of goods on a rail freight carrier, which means that the cost per product unit is relatively low on longer distances. Labour costs per product unit are also relatively low since the personnel needed to transport large volumes is fairly low. However, the delivery time reliability of rail transport is often claimed to be too poor (Rodrigue et al., 2001) and another drawback is that rail transport is not very flexible due to the dependence of rail track.

The characteristics of waterborne transport are quite similar to rail transport. The variable costs are quite low due to low fuel consumption, especially at low speeds, but the fixed costs are relatively high. Like rail transport, waterborne transport can transport large quantities of goods, however, waterborne transport is less geographically spread than rail transport.

Road transport have quite low fixed costs, such as capital costs of vehicles, but instead the variable costs are high due to high fuel consumption, driver costs, maintenance costs (such as tyre and wear costs), etc. Therefore often road transport is appropriate on shorter distances. Road transport 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 transport (Böge, 1995).

Air transport shares some of the characteristics of road transport. Air transport is often a quite expensive way of transporting goods, especially due to high variable costs, such as fuel costs. Also fixed costs are very high. For high value goods air transport can be an attractive choice since the transport is fast and the time the capital is tied-up in transportation is short.

Pipeline is only possible for certain liquid products where there exist pipeline infrastructure, therefore the discussions of pipeline will be rather short. Since pipelines are only possible to use for certain products, the fixed costs can be seen as rather high in relation to how much the infrastructure can be used. The variable costs of pipeline are very low.

The *transport planner* gets a request from the transport buyer to provide a transport plan for a certain transport task. The transport planner plans the transport in terms of type of vehicle, vehicle size, special features of the vehicles, etc. The transport planner has to take the availability of appropriate vehicles and loading units into account, i.e., vehicles and loading units that fit the amount and type of products. The decision is taken based on the costs associated to the transport choices, such as fuel costs, maintenance costs as well as labour costs. The transport planner wants to use the personnel resources as efficient as possible. The transport planner often wants the requests to be as flexible as possible to be able to plan transports in an efficient way. Large time-windows for delivery and stock-keeping often help the transport planner to find more efficient plans. Also, often the transport alternative with the lowest cost is chosen if there are no other demands from the customer, such as environmental or high quality demands. To have a more economically efficient vehicle fleet, the transport planner may want to invest in transport resources, e.g., new vehicles that are more fuel efficient.

The transport planner wants high vehicle utilization in order to use available transport resources as much as possible. If a shipment from one customer is not enough to fill up a vehicle, load consolidation might be possible to use. If possible, backloading is a good way to reduce costs for the transport planner since the empty return transport otherwise only implies a cost without any incomes. Furthermore, a low frequency of the transports often implies lower transport costs since less vehicle kilometres are driven.

In Table 2.1, we indicate which direct logistical factors the transport chain actors can influence according to our definition of transport chain actors and their roles. Only direct logistical factors, which can be influenced in the short-term, are included since they are possible for the transport chain actors to influence in the current version of our micro-level simulator presented in Chapter 5. In the current version of the simulator the indirect factors influence the behaviour of the transport chain actors, but it is possible that the transport chain actors can influence the indirect factors (for instance by investments of resources) in a later version of the simulator. To describe the influence transport chain actors has on the indirect logistical factors, there is probably a need to include more transport chain actors into the framework.

In the table both strong and weak influence is indicated. Strong influence indicates which transport chain actors that have most or strongest influence of the logistical factor. Weak influence indicates which transport chain actors that have an indirect or weak influence on the logistical factor. The relationships in the table need to be further verified.

Transport chain actors / Direct logistical factors	Customer	Transport planner	Transport buyer	Production planner	Product buyer	Transp. chain coord.
Production planning						
Inventory planning						
Transport planning						
Transport mode						
Vehicle type						
Fuel type						
Frequency of transports						
Load consolidation						
Backloading						

Table 2.1. The influence of transport chain actors on logistical factors is indicated. The transport chain actors that can influence the logistical factors are indicated. Strong influence is indicated with black, while weak influence is indicated with grey.

Outside the influence the transport chain actors have on the logistical factors, governments can influence logistical factors. In Chapter 3 governmental control policies and their influence on logistical factors are studied.

3. Governmental control policies

Transportation of goods 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. Governmental control policies, such as taxes, fees and regulations, are a means to encourage, guide, control or force the members of the society towards governmental goals. Control policies can exist at different levels, for instance at a national, global or regional level.

Well-implemented policies should signal what is the best alternative. According to, for instance Engström et al. (2001) and Delucchi (2003), efficient control policies should be directly coupled to the activity that they are supposed to influence. In the context of transport policies, the actual impact of the transport should therefore decide the level of taxes and fees. When the aim of the policy is to reduce negative environmental effects, for instance the transport mode and vehicle type with less environmental impact should be encouraged. To encourage behaviour that minimizes congestion, the control policies should depend on the transport infrastructure which is used, the time of the day the transport is performed, etc. Whitelegg (1993) claims that the best alternative according to the government should be the most profitable (e.g., in monetary terms) for the transport chain actors, as well as the alternative with best environmental performance.

It is difficult to achieve such precise control policies and the actual effects of control policies are difficult to predict (Rodrigue et al., 2001). Therefore models are used to predict the effects of implementations of governmental control policies. We want to further study the effects of governmental control policies in a micro-level simulator, taking the behaviour of the transport chain actors into account. For instance, we want to analyse what the effects will be if control policies are directly coupled to the activity the governments want to influence.

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 et al., 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 governmental control 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 control policies that are regulative, and distributive norms correspond to fiscal control policies. There are also some differences between human societies and artificial societies. For instance, agents are programmed to follow certain norms, while you cannot be sure that humans follow norms (Boella et al., 2005). Obviously there are several connections between norms and governmental control policies. Therefore agent technology seems appropriate when the consequences of governmental control policies are modelled since the concepts of norms can be used in order to capture the behaviour of members of the society.

As mentioned in Section 2.3.4, there is a wish, for instance within the EU, to include the external costs of transportation into fees and taxes. 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 internalized into fees and taxes. Today, however, the external costs are not fully internalized (European Commission, 2001; ECMT, 1998), which is particularly apparent for road transport, and especially heavy transport (Hesselborn and Swahn, 1998). Although the largest share of transport control policies regards road transport, it is claimed that there is a need to develop existing control policies to fully include the external costs of road transport (Hesselborn and Swahn, 1998). To internalize 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. Variable control policies, which for instance depend on the number of vehicle kilometres, are appropriate when applying the marginal costs principle since they depend on the amount of transport.

There are also some disadvantages if the external costs would be fully internalized. For instance, if the taxes and fees for transportation in a country would increase, the market is opened up for international transport operators where the operators with the lowest transport costs have an advantage (Hesselborn and Swahn, 1998). Transport operators which provide lower transport costs do not necessarily provide logistical operations with a good environmental performance. Therefore, when deciding upon governmental control policies the economic perspective of the actors in the transport chain has to be taken into account so that behaviour which causes a good environmental performance of the transport chain actually is encouraged by the control policies.

The purpose of this chapter is to describe relevant governmental control policies which may have an impact on the behaviour of the transport chain actors. Furthermore, the relationships between those control policies and the logistical factors will be examined.

3.1 Description of relevant governmental control policies

There are several types of governmental control policies which governments use depending on how they want to influence the behaviour of transport chain actors. The major types of governmental control policies are regulatory control policies and fiscal control policies. *Regulatory* control policies are laws and regulations, such as regulations of speed and vehicle sizes. The regulatory control policies are set up to concretize goals specified by the government, and the actors are forced to act in a certain way. *Fiscal* control 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 subventions since governments choose to support certain investments and the users of the infrastructure not directly pay for the investments. Value added tax (VAT) is also a tax, but since the tax is taken out on all actors in the transport chain we do not study it further here. Traditionally, taxes are used as income to the state, but they can also be used as incentives toward certain governmental goals. Characteristic for fiscal control policies is that they give incentives to the actors to act in support of goals specified by the government. The actors are free to decide how they want to act, but there is a monetary advantage to act in accordance of the governmental goals. Furthermore, information and education can also be seen as control policies. They are important, especially to reach an understanding in the society of the purpose of the control policies when the policies are implemented (Wandén, 1997). However, these control policies are outside the scope of this study.

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

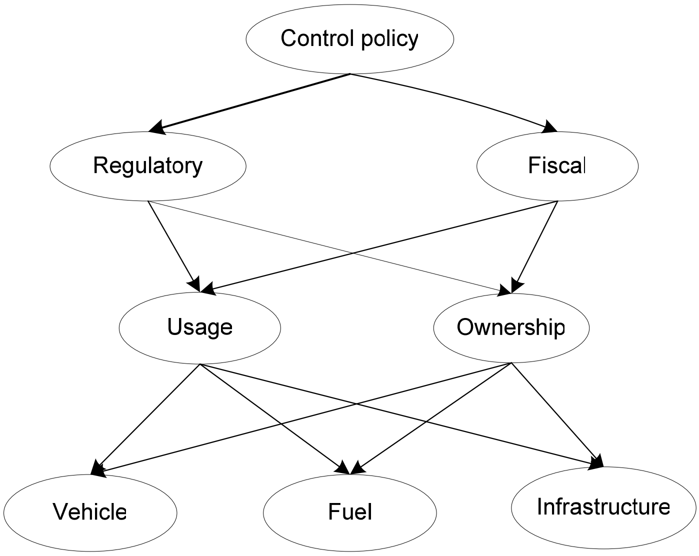

Figure 3.1. Overview of how Table 3.1 and Table 3.2 are organized. Control policies are divided into policies which are regulatory (Table 3.1) and policies which are fiscal (Table 3.2). The regulatory and fiscal control policies can concern the usage or ownership of different types of resources, i.e. vehicle, fuel and infrastructure.

In this chapter we study the effects of governmental control policies in transport chains. Therefore, in Table 3.1 and Table 3.2 we list different kinds of control policies which are fiscal and regulatory in the context of freight transportation. The focus is mainly on control policies within the EU, however, the control policy types also exist in other countries. The governmental control policies are divided into two tables: *regulatory control policies* and *fiscal control policies*. The control policies are further divided into *usage* or *ownership* of resources. In each table the control policies are grouped according to *type* of governmental control policy, i.e., if the control policy concerns vehicles, fuel or infrastructure. See Figure 3.1 for an illustration of the division of control policies. The control policies are further described under *control policy* and *goal*. We describe the goals of control policies as limitation of infrastructure wear (infra), reduction of environmental impact (environ), reduction of congestion (congest), increase of safety (safety), limitation of noise (noise) and increase or maintenance of accessibility (access). The goals are based on the external costs defined by the European Commission (2001), and accessibility is added to these effects. If the control 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 control policy is implemented, therefore the cost basis mainly serves as giving examples of possible cost bases. The *mode* that the control policy concern is also described in the tables, and when necessary *comments* are given for further description of the control policy. Table 3.2 is partly based on tables in Engström et al. (2001) where fiscal transport policies in Sweden are described.

Most control policies concern traffic since the governmental goals mainly concerns the amount of transportation, not the individual transport movements in particular. There exist control policies that concern transport, such as transport subsidies for companies to be located in sparsely-populated areas; however, we do not bring up transport subsidies here since they are quite specific control policies.

Some fiscal control policies, for instance infrastructure investments, can also be influenced by private actors. Since we only are interested in governmental control policies, we only consider the part the control policy that is governmental.

The purpose with Table 3.1 and Table 3.2 is not to completely cover all different types of existing governmental control policies, but to give an overview of what different kinds of control policies that exist today, and exemplify how they can be implemented. There exist some surveys of existing governmental control policies in Europe in the context of freight transportation, see, e.g., ECMT (2000) and EPA (2000).

Type	**Usage/ ownership**	**Control policy**	**Goal**	**Mode**	**Comments**
Vehicles	Ownership	Design requirements of vehicles	Infra.wear, safety, environmental	All	Coupled to emission and noise requirements since new vehicles have to fulfill these requirements.
Vehicles	Ownership	Emission and noise requirements	Environmental, noise	Road, air, sea	
Infra.	Usage	Speed limits	Safety, noise, environmental	Road, rail	Speed limits can depend on the size of the vehicle.
Infra.	Usage	Restrictions or bans of transports	Environmental, congestion, noise	Road, air, rail	In certain areas there are restrictions of transport volumes, certain vehicle types etc.
Fuel	Ownership	Fuel requirements	Environmental	All	

Table 3.1. Regulatory control policies

Type	Usage/ owner	Control policy	Goal	Basis	Mode	Comments
Vehicle	Owner	Vehicle tax	infra, environ	Weight, fuel type, emission class	Road	Differentiated in, e.g., in Sweden and Germany.
Vehicle	Owner	Sale tax for vehicles	environ	Emission class	Road	Sometimes differentiated, e.g., Sweden.
Vehicle	Owner	Scrapp-age fee and premium	environ	Same fee for all trucks.	Road	
Infra.	Usage	Vignette	infra, environ	Emission class, no. of axles	Road	A (often) yearly road fee to use the vignette road network, e.g., the Eurovignette.
Infra.	Usage	Congest. fees	congest, infra	Time of day	Road	Used in London and Oslo etc.
Infra.	Usage	Tolls	infra	Vehicle size, special transport	Road, rail	Tolls for the usage of certain motorways, tunnels or bridges.
Infra.	Usage	Km taxation	infra, environ, congest	Emission class, driven km, time of day, location	Road	Exist today in, e.g., Germany, Austria and Switzerland.
Infra.	Usage	Track fee	infra, safety, environ	Energy source, per net tonkm	Rail	Sometimes differentiated, e.g., in Sweden.
Infra.	Usage	Port and route fees	infra, environ, safety	Gross tonnage, goods, emissions, safety, ship properties	Sea	Oil tankers can get a discount if the ship has double hull or double bottom, e.g., in the port of Stockholm.
Infra.	Usage	Landing fee	infra, noise, environ	Noise, emissions	Air	Sometimes differentiated, e.g., in Sweden.
Fuel	Usage	Fuel tax	environ	Fuel properties, fuel type	Road	In some countries fuels that have a high environmental performance do not pay fuel tax, e.g., in Sweden.
Infra.	Owner	Mainten. of infra.	access		All	
Infra.	Owner	Infra. invest	access		All	

Table 3.2. Fiscal control policies

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). We use the notation fixed tax or fee as the tax or fee for owning a vehicle and have it prepared to be used. The variable tax or fee is seen as the tax or fee for using the resource and depends on how it is used.

Since an effective control policy should be closely coupled to the actual environmental impact, as well as where the impact takes place, it is desirable to have a control policy which affects the length and location of the transport (Engström et al., 2001). Thus, for instance 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 utilization, and also support a modal shift. If the cost for transporting goods on the road is too high, other transport modes such as rail transport might be considered. Kilometre taxation has for instance been introduced in Switzerland 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.

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 it is more profitable to use diesel vehicles if the vehicle is used a lot.

Infrastructure investments concern transport network infrastructure (rails, roads, pipelines) and terminals. Governments can use infrastructure investments to encourage certain transport alternatives, such as rail transportation, by improving rail infrastructure so that the quality performance of rail is improved. The most common purpose of infrastructure investments is to maintain a sufficiently good transport infrastructure that enables transportation. When governments 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 performed. Infrastructure investments is claimed by for instance Jonsson and Johansson (2003) to contribute to increased road transport volumes which in turn causes increased negative environmental effects.

Restrictions and bans of transports can imply that certain types of trucks are banned from larger cities, for instance in some larger cities in Sweden. It can also imply that air transports are forbidden over certain areas during nights.

Design requirements can for instance be size regulations of vehicles, load restrictions, etc. Heavy road transportation results for instance in considerable road wear and environmental impact. However, larger trucks may imply that the number of vehicle kilometres can be reduced since more goods can be loaded on the trucks (McKinnon, 1998). As an example, in Sweden a total weight of 60 tons per truck is allowed, while in Norway and Denmark the restriction is 50 tons, and in the rest of Europe 40 tons. Therefore, if a 60 tons truck is fully loaded in Sweden, the truck cannot drive fully loaded in for instance Norway.

There are few control policies that concern pipeline. This could be explained by the fact that pipelines have little negative environmental effects as a consequence of the usage of the pipelines.

The effects of governmental control policies vary. Current implementations of control 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 governmental control policies should be implemented to be efficient. Some claim that control policies that encourage a shift to techniques with a better environmental performance is most probable to have an effect (Hesselborn and Swahn, 1998). Others claim that control policies that encourage a modal split, for instance kilometre taxation, would have an influence in the direction of the control policy goal (Johansson et al., 2003).

3.2 Influence of governmental control policies on logistical factors

As discussed in Section 2.3.1, the environmental performance of transportation can be influenced mainly in three ways when logistics is used: reduction of total number of ton kilometres, modal split and improvement of the vehicle utilization. Of these we are mainly interested in how the vehicle utilization can be improved and how a modal split can be achieved since they can be influenced in a shorter time frame. The logistical factors that directly influence the environmental performance are the direct factors. Governmental control policies can influence the behaviour of transport chain actors and the logistical factors which in turn affect the performance of transport chains. We want to examine which control policies that have a potential to influence the logistical factors. In this section we describe the relations between the indirect and direct logistical factors described in Section 2.2.2 and the control policy types listed in Table 3.1 and Table 3.2. We still assume that the transport chain actors behave rational and that the decisions are based on a desire to minimize costs. All governmental control policies influence all logistical factors in some sense. Here we describe the most important relationships.

3.2.1 Indirect factors

Governmental control policies can influence the indirect factors in several ways. Infrastructure investments, that the government chooses to support, influence the available transport infrastructure. Moreover, regulations of the usage of infrastructure determine how it is possible to use the available infrastructure, such as which speeds that are allowed and where there are traffic restrictions or bans. The geographical location of production plants is very difficult to influence since the capital costs are large. However, if it is very profitable to be located at a certain location, for instance since there is transport infrastructure that the producer needs and the infrastructure has very good quality, the producer may consider locating the production plant at a certain geographical location. It is also possible that the storage facilities can be influenced by infrastructure investments in the same manner. The available transport resources are influenced by regulations on vehicles, such as concerning design requirements. If the vehicle tax on trucks is differentiated, for instance based on the environmental performance of the vehicles, the most profitable vehicles may be chosen when investments of trucks are going to be made. If the fuel tax becomes a considerable part of the cost for the transport chain actors, it is possible that the transport operator take this into account when investments of new vehicles are done. Taxes or fees for the usage of infrastructure are also sometimes differentiated depending on vehicle properties. Therefore, if the differences are significant, the transport operator might choose the most profitable vehicles when vehicle investments are needed.

3.2.2 Direct factors

The direct factors are mainly influenced by taxes and fees, i.e., by incentives. To decrease the number of vehicle kilometres, variable taxes and fees can be used to give incentives to enable a better utilization of available transport resources. The planning of the logistical operations is difficult to influence with control policies. If there is cooperation between the transport chain actors the incentive is more probable to have any effect since the control policies are not directly connected to the logistical operations planning. Incentives in form of fuel taxes and variable taxes or fees for the usage of infrastructure can be implemented so that it is more profitable to plan the production so that a better utilization of available production and transport resources are enabled. The production planning can for instance be planned to match the available transport resources. Production schemes and demand often vary during the week which implies that the transport demand differs during the week. Variable taxes and fees can also give incentives to inventory and transport planning that enables a more efficient usage of available resources. For instance, transport planning that enable high vehicle utilization can be encouraged. Like for logistical operations planning, incentives in form of fuel taxes and variable taxes or fees for the usage of infrastructure can be given so that transport modes and vehicle types with less environmental impact are given an economical advantage.

The choice of transport mode is also influenced by regulations of the usage of infrastructure since they determine how it is possible to use the available infrastructure. As an example, speed restrictions influence the transport time on certain links. This in turn influence which transport modes that are appropriate to choose for a certain transport task as well as the transport planning. Moreover, the choice of transport mode is influenced by infrastructure investments that determine which infrastructure that is possible to use in certain geographical areas. The choice of the vehicle type is also influenced by regulations of the usage of infrastructure, for instance if a certain type of vehicle is banned from a certain city. The choice of the fuel type is mainly influenced by the fuel tax. If the tax is differentiated for different types of fuels, incentives are given to the best choice according to the government, such as the fuel with lowest amount of carbon dioxide.

Regulation of vehicles can influence the possibilities to use load consolidation. As an example, larger vehicles enable larger quantities to be loaded in a vehicle, i.e., it can be easier to match consignments to several customers to the vehicle.

Logistical factors \ Governmental control policies		Regulation of vehicle	Regulation of infrastr.	Regulation of fuel	Tax/fee of vehicles	Fuel tax	Tax/fee of infrastr.	Subvention of infrastr.
Indirect	Available infrastructure networks							
	Available terminals							
	Available production resources							
	Available transport resources							
	Available storage facilities							
Direct	Production planning							
	Inventory planning							
	Transport planning							
	Transport mode							
	Vehicle type							
	Fuel type							
	Frequency of transports							
	Load consolidation							
	Backloading							

Table 3.3. Overview of which logistical factors the governmental control policies possibly can influence. Filled black cells indicate strong influence and filled grey cells indicate weak influence.

The influence governmental control policies can have on logistical factors as described above is illustrated in Table 3.3. If the influence governmental control policies have on logistical factors is known, the effects of governmental control policies are easier to predict. The purpose of the table is to serve as input to simulation experiments, i.e., the relationships described in the table is interesting to further study in order to determine if the possible relationships are correct. Since regulations force the transport chain actors to act in a certain direction, the effects of regulations are easier to predict than the effects of fiscal control policies. Governmental control policies influence the logistical factors in varying degrees, therefore we divide the influence in strong and weak influence. Strong influence is regulations that directly influence a logistical factor, as well as strong and direct incentives from fiscal control policies. Weak influence is regulations that indirectly influence a logistical factor, as well as fiscal incentives that are possible or weak.

3.3 Discussion

From the discussion above and Table 3.3, the control policies that seem to have possible influence on many logistical factors are variable control policies, i.e., mainly fuel tax and variable taxes and fees on the usage of infrastructure. Control policies for road transportation are mainly of interest since the volumes continue to increase and the negative environmental effects are considerable. However, these possible relationships need to be further studied and verified. Therefore we believe that there is a need for the usage of quantitative models to further analyse the relationships between the governmental control policies and the logistical factors. The governmental control policies that we find interesting to further study are listed here:

- *Kilometre taxation* is a variable tax that can be closely related 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. It is interesting to study for which levels of the tax it is possible that there will be a modal split from road to rail transport. The price sensitivity of transportation could then be studied.

- *Road tolls* or *congestion fees* are also variable fees that have a potential to influence the amount of transportation. 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 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. In Brand et al. (2002), however, it is showed with the STEEDS model that a higher fuel tax appears to be effective to slow down the carbon dioxide emissions from transportation. We want to study this further in quantitative models as well as the price elasticity for different businesses.

- The effects of *differentiated* vehicle taxes, fuel taxes, etc., are interesting to study since differentiated taxes and fees have potential to give incentives in the direction of the governmental goals concerning, e.g., vehicle choice.

- Different *design requirements on vehicles* influence the possibility to utilize 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.
- Today there is a *tax exemption of aviation and shipping fuel* since the air and waterborne transport is highly international. It is be interesting to study what the effects would be if this exemption was taken away.

Traditionally the effects of governmental control policies are studied in macro-level models. The data that are used in such models are averaged data, and the behaviour of individual transport chain actors is not captured. We believe that macro-level models are not sufficient to capture the actual effects of control policies. In the next chapter we examine existing models considering governmental control policies and how they simulate the effects of control policies.

4. Existing freight models

In this chapter we present a review of existing freight models that potentially can be used for studying the effects of governmental control policies. The purpose of the review is to examine weather it is possible to study the influence governmental control policies have on the logistical factors identified in Section 2.2.1 in existing freight models. Moreover, we want to study the characteristics of the models. The aim of the review is not to fully cover all existing freight models since there already exist freight model reviews, see for instance Department for Transport (2002) and Friesz (2000). Instead we intend to give some examples of categories of models, why several models are left out since they resemble the included models. Moreover, models that include logistical aspects are reviewed since we believe it is important to capture more detailed aspects of transportation. We choose to only include models that have been implemented. Categories of models that are included are *national* models, models developed in *EU-projects*, *commercial* models and *other* interesting models. Many countries, e.g., within the EU, have their own national model. Such national models are exemplified with the Swedish SAMGODS model and the Dutch SMILE model. Models that have been developed within EU-projects are exemplified with SLAM (which is a module in the SCENES model) and STEEDS. Commercial models that include a governmental perspective are exemplified with Cube Cargo. Other models that are interesting to review since they include logistical aspects are PACE-FORWARD, GoodTrip and TLUMIP.

The models mentioned above are classified according to a framework presented below. The majority of the models that are classified are rather course grained. There exist models that include more transport chain specific characteristics, see, e.g., Terzi and Cavalieri (2004) for a review of supply chain modelling. However, the purpose of such models is not to include governmental policy analyses and they are therefore not further described here. The aim of such models is to improve the performance of individual transport chain actors, and there is no ambition to improve the overall performance of the whole transport system, which is the case when the purpose of the model is to perform governmental policy analysis.

4.1 Framework for describing freight models

To examine whether the models capture the effects governmental control policies have on the logistical factors, the reviewed models are described according to a framework. The logistical factors are included in the framework together with other important characteristics that are important for analysing how well the models are suited for analysing the effects of governmental control policies. The following characteristics are included in the framework: geographical scale, transport mode, purpose, level, maturity and input and output. *Geographical scale* and *transport mode* are brought up since they give a context in which the model functions. Therefore the discussion of these two characteristics is rather brief. The *purpose* of the model, such as to use the model for governmental policy analysis, is crucial since it influences the model design. The *level* of the model (macro or micro) is crucial in this context since it describes whether the focus is on the behaviour of the population or the individuals. The *maturity* of the model is interesting to examine since this shows how far the work has proceeded. Finally, *input and output* of models are important since parameters that are included in the model, as well as whether these parameters function as input or output, describe important model characteristics. We focus on the input and output from the part of the model that models the transport movements. Below the framework is described.

Geographical scale

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

Transport mode

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

Purpose

All reviewed models aim at performing forecasts in various settings. Some models have a societal perspective which implies that the societal aspects, such as sustainability and economic growth, are of interest to study. These models concern the evaluation of the effects of different governmental control policies. The models can function as decision support for governments when evaluating possible implementations of control policies. The model can be aimed at performing analysis of what the consequences would be for different scenarios where governmental control policies are included. The model can also be directly aimed for governmental policy-making where control policies that are probable to be implemented are evaluated. We call such purposes *governmental policy analysis*.

Some models focus on transport chain issues. The main interest of transport chain actors is to maximize profit, i.e., increase income and reduce expenses (e.g., the transport cost). These models concern the evaluation of different strategies that can be implemented by transport chain actors. The strategies can for instance concern warehouse location or investments in new transport equipment, and the influence on transport cost, environmental load, etc. can be analysed with the model. Both transport chain actors and policy-makers can have an interest in analysing such strategies with a model. We call such purposes *transport chain strategy analysis*.

Level

In the simulation literature, simulation models can be divided into macro-level models (e.g., equation-based models) and micro-level models (e.g., agent-based models). Micro-level models include detailed information of individual transports and are therefore fine-grained. In micro-level models specific behaviours of specific individuals as well as the interactions between the individuals are modelled.

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. 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. 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 generalized more easily than in micro-level models. The data can also be disaggregated, i.e., divided into smaller parts.

Maturity

Models can have varying degree of maturity, see for instance Parunak (2000) for a classification of the maturity of models. We choose to describe the maturity of the models as laboratory experiment or deployed system. *Laboratory experiment* is the level which indicates that the model has been tested in a simulation environment. The most mature models are *deployed*, i.e., the model has been implemented and used for analyses of the real world. If the model has been involved in real world contexts, we call it deployed.

Input and output

In the classification of the models it is indicated which parameters that are input versus output. The logistical factors described in Section 2.2.1 are included in the framework to be able to draw conclusions from the appearance of the logistical factors in the models. Some of the logistical factors are included in another form than in Section 2.2.1 to facilitate the description of model characteristics. *Geographical location of the customer* appears in *transport flow between actors*. *Product characteristics* are further elaborated in *product group characteristics* where more parameters are added. *Available transport infrastructure* is included in *transport mode* described above. Besides the logistical factors, more parameters are added to better describe the models.

The input and output are described in the following way:

- Governmental control policies
    - Fiscal, e.g., vehicle taxes, road fees
    - Regulatory, e.g., load regulations of vehicles, emission standards
    - Infrastructure investments, e.g., new transport infrastructure and improvements
- Product demand
    - Aggregated, i.e., averaged data between for instance zones
    - Individual, i.e., demand from individual consumers
- Product group characteristics
    - Logistical aspects, e.g., value density, packing density, perishability, delivery time, shipment size, demand frequency
    - Possible transport modes and vehicle types, e.g., based on shipment size, perishability
- Transport flow
    - Between geographical zones
    - Between transport chain actors
- Available resources
    - Production resources
    - Storage facilities

    - Transport resources
- Logistical operation planning, which concerns the operational or tactical planning of the time window for certain product quantities to be handled
    - Production planning
    - Inventory planning
    - Transport planning
- Transport choice
    - Transport mode, i.e., the assignment of transport movements to transport modes
    - Vehicle type, i.e., the assignment of transport movements to vehicle types
    - Fuel type, which is needed to calculate environmental performance
- Vehicle utilization
    - Vehicle load factor
    - Frequency of the transports
    - Load consolidation
    - Backloading
- Effects
    - Revenues to the government.
    - Transport work, measured in ton kilometre
    - Traffic work, measured in vehicle kilometre
    - Emissions, e.g., carbon dioxide, nitrogen oxide, particles, carbon monoxide, sulfur dioxide
    - Environmental impact of emissions, e.g., in terms of global warming
    - Reliability of time of delivery and product quality
    - Costs
        - External costs, e.g., emission cost, congestion cost

- Internal costs, e.g., capital cost, fuel cost, labour cost, maintenance cost, time cost

4.2 Discussion of existing models

Table 4.1 and Table 4.2 show the classification of relevant freight 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.

		SAMGODS	SMILE v.1	SLAM	STEEDS	Cube Cargo	GoodTrip	PACE-FORWARD	TLUMIP
Geograph. scale	International			x	x	x			
	National	x	x	x	x	x		x	
	Regional					x			x
	Urban					x	x		
Transport mode	Road	x	x	x	x	x	x	x	x
	Rail	x	x	x	x	x		x	
	Waterborne	x	x	x	x	x		x	
	Air	x	x	x	x				
	Pipeline		x	x			x	x	
	Multimodal	x	x	x	x	x	x	x	
Purpose	Governm. policy analysis	x	x	x	x	x	x	x	x
	Trp. chain policy analysis		x	x		x	x	x	x
Level	Macro	x	x	x	x	x	x	x	x
	Micro								
Maturity	Laboratory experiments			x	x	x	x	x	x
	Deployed system	x	x						

Table 4.1 Characteristics of the reviewed models. An x indicates that the property is included in the model.

Input/Output		SAMGODS	SMILE v.1	SLAM	STEEDS	Cube Cargo	GoodTrip	PACE-FOR.	TLUMIP
Gov. ctrl. policy	fiscal	i	i	i	i	i		i	i
	regulatory	i	i	i	i			i	
	infra. investments	i	i	i	i	i	i	i	i
Product demand	aggregated	i	i	i	i	i	i	i	i
	individual								
Product gr. char.	logistical aspects		i	i			i		
	modes and vehicles	i	i	i		i	i		i
	production pattern								
Transport flow	between zones	o	o	o	o	o	o	o	
	between actors								o
Avail. resources	production		i	i		i	i		i
	storage facilities		o	o		i	i	i	i
	transport				i	i			i
Log. op. planning	production								
	inventory								
	transport								o
Transport choice	transport mode	o	o	o	o	o	o	o	o
	vehicle type	o		o	o	o	o	o	o
	fuel type	i		i	i	i	i	i	
Vehicle utiliz.	vehicle load factor			i	i	i	i	i	i
	frequency of trp		i	i		i	i		
	load consolidation					i?		i	o
	backloading		i			o			o
Effects	governm. revenues	o	o	o				o	
	transport work	o	o	o	i	o		o	o
	traffic work	o	o		o	o	o	o	o
	emissions	o	o	o	o	o	o	o	
	environ. impact				o				
	reliability		o				o	o	
	internal costs	o	o	o	o	o	o	o	o
	external costs	o	o						

Table 4.2 The input and output in the reviewed models. Input is indicated with i, and output is indicated with o.

Different conclusions can be drawn from Table 4.1 and Table 4.2. For instance, none of the classified models is a pure micro-level model. Hence, none of the models use a pure micro-level perspective of transportation for studying the effects of governmental control policies. TLUMIP include some micro-level characteristics, for instance, the transport movements are assigned to vehicle routes between individual transport chain actors. The data that is used in TLUMIP is originally aggregated, therefore it is not a pure micro-level model. SMILE, GoodTrip, SLAM, Cube Cargo, PACE-FORWARD and TLUMIP include some detailed aspects of transportation, such as different ways of designing the transport chain and planning the usage of storage facilities, for instance by centralization. Still these aspects are simulated based on aggregated data, such as the goods flow of a whole country, so the decisions made by the individual transport chain actors cannot be simulated. In SMILE, GoodTrip and SLAM the product types are grouped into product groups with similar logistical characteristics to make the simulations more realistic and detailed. Some of the other models also include product group characteristics, but these groups are only based on possible transport modes, and are therefore not as detailed.

SMILE, GoodTrip, PACE-FORWARD, Cube Cargo, SLAM and TLUMIP have an explicit purpose to be able to perform transport chain strategy analysis. Therefore these models also include more details than more traditional macro-level models.

In some models are production resources included in the models. In these models are production chains included, i.e., product types are connected to the geographical location of the product plant, and possible connections between product plants are included. In none of these models is the actual production planning included.

Only one of the reviewed models includes logistical operation planning. TLUMIP includes transport planning, i.e., the planned shipment time is connected to a certain quantity of goods. TLUMIP is also the model that includes most micro-level characteristics.

Model characteristics can be defined from the parameters used for input and output in the models. This is especially interesting for parameters that in some models are input parameters, and in others are output parameters. An example of such a parameter is vehicle utilization. For instance, in the models that include frequency of transports and vehicle load factor, are these parameters input parameters. Load consolidation and backloading both appear as input and output in the models. If parameters concerning vehicle utilization appear as input, it implies that it is not possible to study the effects of governmental control policies on these parameters. Such effects are possible to study in micro-level models since these parameters typically serve as output.

Available storage facilities are input parameters in some of the models and output parameters in some of the models. In SMILE and SLAM is the location of storage facilities calculated in the model based on the attractiveness of locations of storage facilities. In the other models that include storage facilities, is the location of storage facilities given.

The transport mode assignment for all models is classified as output. The mode assignment[2] typically depends on the amount of transport and the cost parameters (i.e., both internal and external costs) 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 minimization 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 some models, such as SAMGODS and SMILE, is the governmental revenue calculated. This indicates that the purpose of the models mainly is to perform transport analyses for the government, for instance how control policies can achieve governmental goals and what the effects will be for the governmental economy. These models also have a more explicit purpose to function as a decision support for governmental policy-making. SAMGODS and SMILE have been involved in real world evaluations of policies that are probable to be implemented, and the final policy-making has also been influenced by the simulation results. The other models have been used for performing laboratory experiments for the evaluation of the effects of governmental control policies.

TLUMIP does not include the environmental effects of governmental control policies, but the ambition is to include environmental effects of transportation in TLUMIP in the future. In some of the other models, such as SLAM and Cube Cargo, is the calculation of emissions not explicitly done in the actual freight model, but since calculation tools are closely coupled to the model it is indicated in Table 4.2 that emission calculations can be done in these models.

[2] In SAMGODS the mode and route assignment are performed at the same time.

4.3 Conclusions

As discussed above, all reviewed models are macro-level models. Consequently, issues that concern individuals in the models cannot be captured. The planning of logistical operations and several vehicle utilization parameters are therefore not captured in the macro-level models. Therefore we conclude that it is not possible to study the influence governmental control policies have on all identified logistical factors.

The reviewed macro-level models concern traffic and the main purpose is to include governmental control policies. Since individual entities are not possible to model in macro-level models, it is obvious that the behaviour of the individual transport chain actors is not modelled. Micro-level models that models transport chains concern individual transport movements since individual entities are modelled. Micro-level models mostly used for studying transport characteristics that are of interest for individual transport chain actors. However, we argue that it also is possible to include a societal perspective in micro-level models. Since the behaviour of the individual transport chain actors can be modelled, their behaviour can be studied when different implementations of governmental control policies are introduced. Then the behaviour of the transport chain actors, as well as its effects, can be captured more accurately than in macro-level models.

The attempts to use a micro-level approach are promising. According to the Department for Transport (2002), TLUMIP (which assigns the transport flow to individual vehicle tours) performs better than the more traditional and less detailed models. However, micro-level models demand detailed input data which often is problematic to gather. The simulation results therefore depend on the reliability of the provided data.

In the next chapter we outline a micro-level model that currently is being developed. In this model the logistical operation planning and the vehicle utilization are simulated and appear as output. The decision-making is distributed to different parts of the model that represents different roles in transport chains, i.e., the roles of the individual transport chain actors. Since the behaviour of the different transport chain actors is modelled we believe that a micro-level model better can study the actual impact of governmental control policies on transport chains.

5. A micro-level model

We want to investigate the appropriateness of micro-level models for analysing the effects of governmental control policies in transport chains. The behaviour of the transport chain actors has a strong influence on how the transports are performed, therefore it is important to capture this behaviour when predicting the actual effects. In this chapter we describe a micro-level model and how the model can be used for analysing the influence of governmental control policies on the behaviour of transport chain actors. To illustrate how the micro-level model can be used, an initial simulation experiment is described, and the problems so far are discussed.

5.1 Related work

When transport chains are simulated different techniques are used. Traditional simulation techniques are, for instance, object oriented techniques and discrete event simulation, see for instance Terzi and Cavalieri (2004) for a survey of the usage of traditional micro-level simulation techniques for analysing supply chains.

The simulation technique that we have chosen for the micro-level model is multi-agent based simulation (MABS). According to Parunak et al. (1998), "…agent-based modeling is most appropriate for domains characterized by a high degree of localization and distribution and dominated by discrete decision.". One reason for this is that agent-based simulation is a simulation technique that captures the behaviour of individuals. According to the above characteristics, transport chains seem appropriate to simulate with MABS. Research has successfully been conducted to apply agent technology to transport logistics, see Davidsson et al. (2005) for a review.

As opposed to other simulation techniques, MABS is especially appropriate to use if it is important to capture the interactions between individuals, such as cooperation, negotiation, etc. In transport chains there are lots of interactions between the transport chain actors which for instance influence how the logistical operations are performed. Therefore it is important to capture these interactions when transport chains are simulated. Cooperation between transport chain actors is important since it can improve the utilization of available resources and infrastructure. MABS has been used for simulating supply chains, see Swaminathan et al. (1998) and Strader et al. (1998) for examples of approaches. In these approaches, analyses of supply chains and supply chain strategies have been performed. The transport chain actors are represented by agents and the focus is on how performance indicators change, given certain supply chain strategies. The performance indicators that are studied are cost and quality for the transport chain actors. Performance indicators that are of interest for governments, such as environmental performance and governmental income from taxes and fees, are not included in these models. In Swaminathan et al. (1998) discrete event simulation is combined with agent technology. In Strader et al. (1998) the Swarm multi-agent simulation platform is used. In neither of the approaches is choice of vehicle or transport mode considered, as well as other fleet management issues. Then the vehicle utilization cannot be captured in the models. Instead the focus is on coordination issues between the different parts, or agents, in the supply chain. In Swaminathan et al. (1998) the control (concerning inventory, material flow, information, etc.) in the model is managed by contractual agreements.

MABS has successfully 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.

In the research field of agent technology, norms have been widely used to control agent societies (Boella et al., 2005). Norms in the context of agent societies have very similar functions as governmental control 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.

In Abouaïssa et al. (2002) an agent-based model is described which aims at evaluating the quality and safety effects of different regulation strategies in transport chains. The regulation strategies concern regulation of the behaviour of the actors to make them consider the traffic situation, such as traffic jams. At the moment the model is only a conceptual proposal. The regulation strategies do not correspond to control policies set by the government. However, since the aim of the regulation policies is to regulate the behaviour of the transport chain actors in order to increase the overall performance of the whole transport system, the principle of the regulation strategies is similar to governmental control policies. The described transport chain actors are the distributor and the driver. The distributor agent performs actions such as transport planning and transport choice, for instance, the distributor chooses which driver that are going to perform the transport. The driver agents perform actions such as load, unload, handling of the products etc. The customer agent is also identified but not further described. The focus of the agents therefore seems to concern the interactions between the distributor and the drivers, i.e., within the distributor organization. Hence, the complex interactions between other transport chain actors are not modelled so far. Production and storage are not included in the model and the environmental performance is not studied.

From above it can be seen that MABS has been used in the context of transport chains. However, the work that has been done so far lacks certain aspects which we find important to be able to capture the effects of governmental control policies. In Swaminathan et al. (1998) and Strader et al. (1998) it is not possible to capture the transport mode or vehicle choice in transport chains, and fleet management issues are not considered. Further, governmental control policies are not considered. In Abouaïssa et al. (2002), the effects of regulation policies are studied, which have some similarities with governmental control policies. However, the interactions between relevant transport chain actors are not captured, and storage and production are not modelled.

5.2 Description of simulator

The purpose of the micro-level model is to serve as a simulation-based decision support for governmental policy-makers where the policy-maker can evaluate the effects of different control policies. Since the decisions taken by the transport chain actors have a strong influence on the performance of transport chains, we argue that it is important that the simulation model can take the decisions of the transport chain actors into account. At this stage we focus on short-term decisions, i.e., decisions taken by the transport chain actors concerning the direct factors. The direct factors are influenced by available transport infrastructure and resources (i.e., the indirect factors), as well as the consumer demand (i.e., the given factors). The input to the simulator is therefore the given factors and the indirect factors, and a number of parameters describing different settings of governmental control policies. The output is the direct factors, as well as different performance measures of the transport chain. The performance measures are for instance transport work, traffic work, internal costs, emissions, governmental revenues and reliability of the performed logistical operations. See Figure 5.1 for an illustration of the input and output.

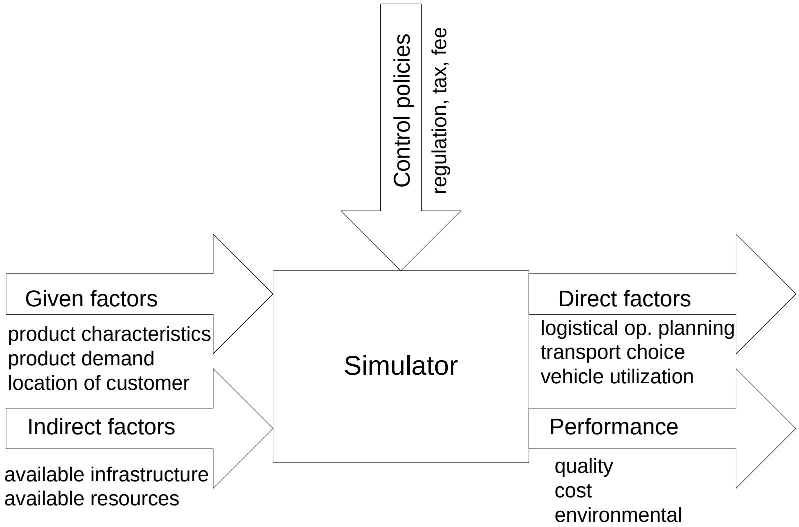

Figure 5.1. Input and output from the simulator.

The approach that has been chosen for the micro-level model is a hybrid approach. One layer simulates the physical movements by using a more traditional object-oriented micro-level approach, and one layer simulates the decisions made by the transport chain actors by using an agent-based approach, see Figure 5.2.

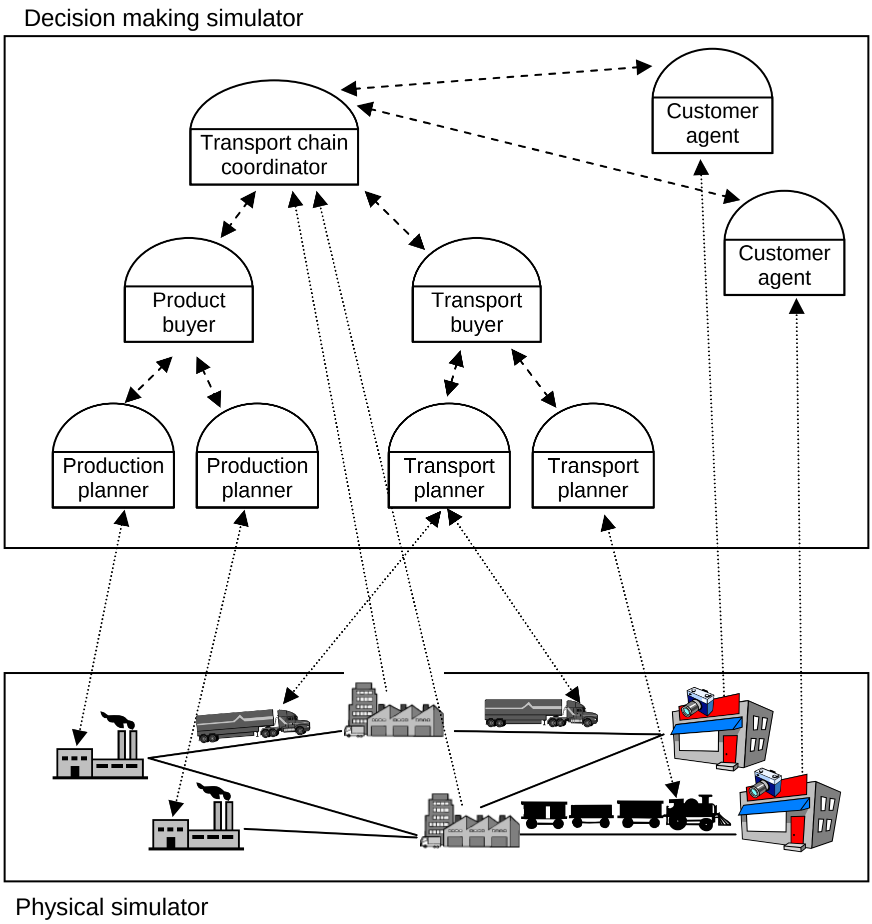

Figure 5.2. The two layers of the simulator.

5.2.1 Decision-making simulator

A number of agents, or roles, have been identified which correspond to the behaviour of the transport chain actors described in Section 2.4, i.e., customer agent, production planner, product buyer, transport buyer, transport planner and transport chain coordinator. See Table 5.1 for a description of the roles.

Decision maker	Decisions and actions	Based on	Goal
Customer agent	Makes requests of products with respect to quantities, time of delivery (or time window), and quality level.	Anticipated consumer demand and inventory levels at customer.	Mediate customer requirements in the most accurate way that is possible.
Transport chain coordinator	Decides how much should be bought from producers and how much should be taken from storages. Makes requests to product and transport buyers.	Requests from the customer agents, intermediate inventory levels, and transport and production opportunities.	Satisfy the customer requirements at the lowest possible cost.
Product buyer	Decides from which producer the products should be bought. Makes request of production to production planners.	Requests from transport chain coordinator. Bids from producers (production planners), including prices, deadlines, quality of product etc.	Satisfy the product requirements at the lowest cost possible (given the constraints).
Production planner	What is the best bid that the producer can provide? Gives production orders to the producer.	Production capacity, storage levels (at the production site).	Minimize production costs.
Transport buyer	From which transport operator should the transport be bought? Makes request of transports to transport planners.	Requests from transport chain coordinator. Bids from transport operators (transport planners), including prices, quality of transport, etc.	Satisfy the transport requirements at the lowest price possible (given the constraints).
Transport planner	What is the best bid that the transport operator can provide? Assigns tasks to transport carriers (fleet management).	Status (availability, position, etc,) of the transport carriers controlled by the operator.	Minimize transport costs.

Table 5.1 The modelled roles of a transport chain.

The agents can appear in different settings in different transport chains and there can be several agents of the same agent type. Below, some examples of how the agents are represented in different organizations are given.

- The customer agent might be a retailer or a producer, with the goal to buy a certain quantity of products to the lowest possible price, delivered at a certain time. However, this agent might accept to receive the products earlier than required, but to a reduced price, and hence store the product until needed. The most important aspect for the customer is that the consumer demand is satisfied, i.e., that the products are available when they are needed, for instance in production.

- The transport chain coordinator might act within a larger company. It can also be a third or fourth party logistics operator. The transport chain coordinator has an important responsibility for how the logistical operations are performed.
- The product buyer is often connected to the organization which hosts the transport chain coordinator. However, the product buyer can also be independent, for instance in case when the transport chain coordinator is a third party logistics operator.
- The production planner belongs in most cases to the producing company since it has to have knowledge of available production resources.
- The transport buyer might belong to different types of organizations, for instance, the transport buyer might belong to the same organization as the customer, the transport chain coordinator or the production planner.
- The transport planner typically belongs to the organization owning and controlling the transport resources. It can be an organization which only focuses on transport operations, or it can be an organization which also performs other logistical operations.

As an example of how the transport chain actors can appear in a transport chain, we present a real world case. Karlshamns AB is a producer, which produces speciality vegetable oils and fats. The producer is located in Karlshamn in southern Sweden and has customers that are spread over the world. The roles that are represented by Karlshamns AB are the transport chain coordinator, the product buyer, the production planner and the transport buyer. Karlshamns AB 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 storages. The transport operator FoodTankers is a tanker transport provider which transports a large amount of Karlshamns AB’s products by truck. The role of the transport planner is represented by FoodTankers which therefore has to consider the availability of appropriate vehicles in the planning of the transports, allocation of consumer demand to vehicles, etc. Finally the customer agent is represented by the customers of Karlshamns AB.

5.2.2 Physical simulator

The physical simulator is based on the description of the production and distribution network suggested by Davidsson and Wernstedt (2004). It simulates the physical level of the production and distribution of commodities, whereas the decisions for what to produce, where to store the commodities, fleet management, etc. are simulated by the decision making simulator.

There are four basic types of entities in the simulator that makes up the production and distribution: nodes, links, vehicles and commodities. A *node* is a producer, an internal distribution node, or a customer, and has the following attributes:

- production capacity for each commodity,
- production level (dynamic, i.e., the value may change during the simulation),
- storage capacity (volume) for each commodity type,
- inventory level (dynamic),
- load time for each vehicle type, and
- unload time for each vehicle type.

A *link* connects a pair of nodes in the distribution network and acts as a distribution channel for the vehicles. A link has the following attributes:

- connected pair of nodes,
- transport mode,
- length, and
- average distribution speed.

A *vehicle* is an entity that performs a transport along a link and has the following attributes:

- vehicle type (each type is associated with a particular transport mode),
- volume capacity for each commodity type,
- location (dynamic),
- load (dynamic),
- maximum speed,

- delay probability distribution,
- transport cost, and
- environmental performance.

A *commodity* is produced at nodes and transported via links by vehicles and has the following attributes:

- commodity type (based on storage requirements),
- production cost,
- production time,
- mass,
- volume, and
- quality (dynamic, based on age).

The activities in the physical simulator can be controlled during run-time through a number of commands. There are commands available to start a production batch, load and unload commodities from a vehicle, initiate a transport or consume commodities. Commands that are sent to the simulator are placed locally at the target entity in a first-in-first-out queue.

The available commands, their constraints and expected outcomes are:

Manufacture(n, c, s) Adds a new command to the command queue of node *n* to start a new production batch of commodity *c* of size *s*. The command is executed if the node has the required production capacity. The time until the batch is completed is determined by the production time. When the batch is completed the new commodities are placed in storage at *n*.

Load(v, c, s, n) Adds a new command to the command queue of vehicle *v* to load the quantity *s* of commodity *c* from the storage of node *n*. The command is executed if the vehicle is located at node *n*. It then requests the commodities from the node which returns the commodities (if available) and the time it takes to load them.

Unload(v, c, s, n) Adds a new command to the command queue of vehicle *v* to unload the quantity *s* of commodity *c* to the storage of node *n*. Works similar to the Load command with the difference that a request to unload is sent to the node.

Dispatch(v, e) Adds a new command to the command queue of vehicle *v* to initiate a transport using link *e*. The command can only be executed if the vehicle is at either of the nodes connected by *e*, and is not un/loading.

Consume(n, c, s) Adds a new command to the command queue of the node n to consume quantity s of commodity c from the storage of node n.

In addition, it is possible to read the attributes of all entities.

5.3 Using the simulator

An initial simulation experiment has been performed to illustrate how the micro-level simulator can be used for studying the effects of governmental control policies on transport chains. The initial simulation experiment is based on a real world case of a simple transport chain.

5.3.1 Experiment design

In order to illustrate the usage of the simulator we have chosen to perform a simulation experiment based of a simple case study described in Section 5.2.1. The case that we have chosen to study is interesting since we believe it has the characteristics that can be found in many transport chains, for instance, the products are perishables and have been processed in varying degrees. The case is simplified in the simulation experiment. The producer produces fluids with a density of 1000 kg/m^3. The customer is located in Fredrikstad in southern Norway and no intermediate distribution nodes exist. Two transport operators are available, one is the truck transport operator and the other is a train operator.

	Link A	**Link B**
Nodes	Karlshamn,Fredrikstad	Karlshamn,Fredrikstad
Mode	Road	Rail
Length (km)	540	600
Average speed (km/h)	72	14

Table 5.2. The links of the transport chain. The length for the road alternative is assumed based on the case, and the average speed is assumed based on the length and the transport time in the case. The length for the rail alternative is assumed based on the road length, and the average speed is assumed based on the length and transport times obtained from Green Cargo.

In the experiment we focus on the decisions made by the transport buyer, and to some extent the decisions made by the transport planner, assuming that sufficient amount of products and vehicles are available to meet the consumer demand. As outlined in Table 2.1, the decisions made by the transport buyer concern which transport operator the transport should be bought from and influences the choice of transport mode. The decisions made by the transport planner concern the choice of vehicle type. Details of the two links that connects the two nodes and the three different vehicle types used in the scenario are given in Table 5.2 and Table 5.3 respectively.

	Truck	**Rail_27**	**Rail_50**
Mode	Road	Rail	Rail
Volume capacity (m^3)	30	27	50
Max speed (km/h)	90	90	90
Probability of delay	0	0	0
Cost (€)	[665, 680]	1005	1764
Env. perf.: CO_2 (g/km)	[754, 891]	143	265

Table 5.3. The attributes of the vehicle types. The cost and environmental performance for trucks depends on the load [empty, full]. The values for rail are based on proportions of the size of the average freight train set in Sweden which is 535 tons (according to the Swedish Network for Transport and Environment, see http://www.ntm.a.se/). The volume capacities are obtained from the transport operators.

The environmental performance of transportation can be influenced in several ways. To improve the environmental performance, the number of vehicle kilometres can for instance be influenced by governmental control policies (Engström et al., 2001). Heavy road transportation stands for a large share of the negative effects on the environment, e.g., in the EU and there is a wish to reduce this negative impact. We want to study how kilometre taxation on road transportation may influence the behaviour of transport chain actors, and consequently the environmental performance of transport chains. Kilometre taxation is a current topic since several countries are considering to implement such a taxation, for instance in the EU. Kilometre taxation has potential to influence the environmental performance via increased vehicle utilization as well as via a modal shift to transport modes with a better environmental and economical performance. In the experiment we focus on the potential of the control policy to improve the environmental performance via the choice of transport mode and choice of vehicle type. The environmental performance is exemplified with the amount of carbon dioxide from the transports. In Table 3.3 it is indicated that a tax or a fee on the infrastructure has a strong influence on the transport mode choice as well as the vehicle type choice. We want to study if the simulation results indicate the same influence.

Assumptions and characteristics of the studied scenario are given below:

- A time horizon of 52 weeks is considered.
- Two customer orders are generated per week. The delivery time and the quantity of the order are randomly generated. The quantities are generated to match an ideal size of a truck, which is 30 tons with a probability of 0.5 or of a rail freight carrier of either 27 or 50 tons, with a probability of 0.25, respectively.
- In the scenario, the effects (costs and environmental performance) of returning the truck or the rail freight carrier to the producer have been ignored. This has been ignored in the initial experiment since the effects are highly dependent on the possibility to take on other loads on the return trip which is not modelled explicitly.
- It is assumed that the rail freight carrier is transported using diesel engines for 30% of the distance and electrical engines for 70% of the distance, since only parts of the railway network are electrified.
- It is assumed that products can be loaded directly into and directly from the different vehicles types at both the customer and the producer.
- We study the effects of different values of kilometre taxation on heavy trucks. Kilometre taxation can be implemented in various settings, e.g., only on certain roads. In this simple experiment the only road that is available has a kilometre taxation. Moreover, only one truck type is available, why differentiation is not considered.
- We assume that the transport chain actors minimize costs.
- The reasonableness of the cost assumptions as well as the environmental performance has been validated by the partners in the project *Effects of governmental control policies on transportation chains: A micro-level study*, although the costs are not exact costs that exist in the transport chain. Also, template values for transport costs have been obtained from Sveriges Åkeriföretag.
- The emissions from the different transport chains are calculated using the method by the Swedish Network for Transport and the Environment (http://www.ntm.a.se/). This method is used since it, at least in Sweden, has reached consensus among transport chain actors and researchers. The method is for the moment only valid in Sweden, however, we assume Swedish conditions for the part of the transport chain that takes place in Norway. When fuel consumption, vehicle type, fuel type, engine type, transport distance and vehicle load factor

is known, the environmental performance can be calculated. The energy usage from the production of fuel is also considered, however, environmental impacts which occur when vehicles are constructed are not included. For the train alternatives we have used template values for the fuel consumption and energy usage of the average weight of a freight train set. Since not all the environmental performance of the train set is a result of the rail freight carrier, we use the proportion of the rail freight carrier to determine the environmental performance of the rail freight carrier. The vehicle load factor is therefore not used for the calculations since the available data not is very detailed. For the truck alternative we have more detailed data of the actual fuel consumption of the truck type. The fuel consumption depends on the vehicle load factor related to the weight of the vehicle. The same fuel type (MK1) is used for both the train and truck alternatives since it is the most commonly used fuel type in Sweden.

5.3.2 Analysis of experiment result

In Figure 5.3 and Figure 5.4, the costs and environmental performance have been plotted for different levels of kilometre taxation. We study the effect on the total cost for the customer (including the paid taxes), tax income, and emitted carbon dioxide. As expected, the total cost is increasing for increasing kilometre taxation. The tax income is not zero for zero kilometre taxation, since a fuel tax is associated with the diesel of €0.55/litre which applies both for trucks and diesel trains. Also, as expected, the emitted carbon dioxide decreases for increasing kilometre taxation.

In Figure 5.5, the transition from using only trucks to using only trains is illustrated. Using only trucks is competitive up to a kilometre taxation of €0.38; and in order to make only trains competitive a kilometre taxation of €2.0 is required. These breakpoints will naturally shift if the cost for moving vehicles back to the producer is fully considered. Moreover, it can be concluded that the rail freight carrier of 50 tons is chosen more often than the carrier of 27 tons when the kilometre taxation is €2.0 or larger. This can be explained by the fact that the costs are lower per ton for the 50 ton carrier, provided that the shipment is sufficiently large.

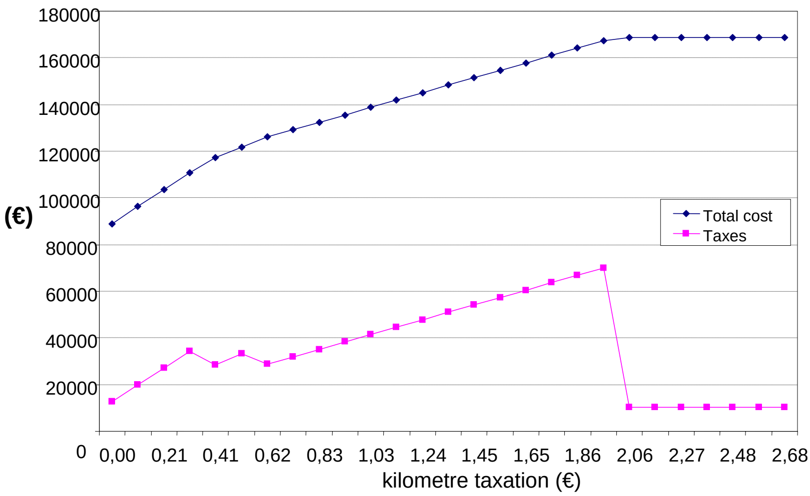

Figure 5.3. Total costs and taxes for different values of kilometre taxation.

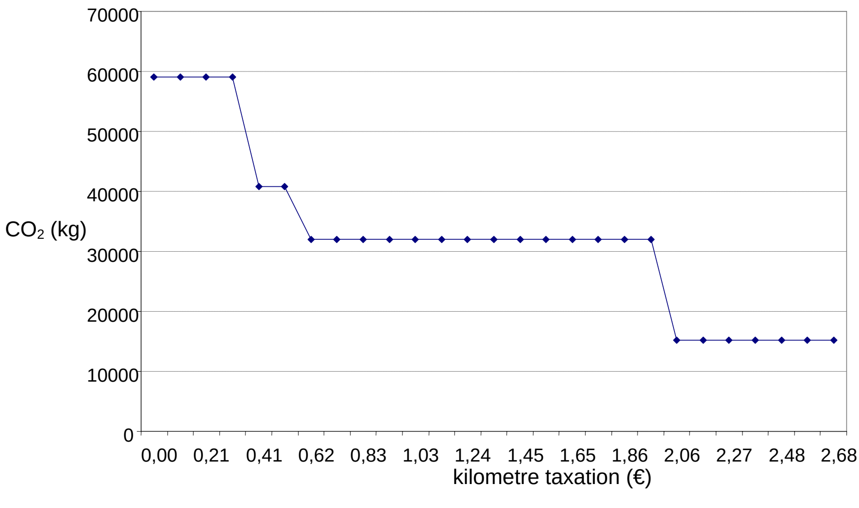

Figure 5.4. Carbon dioxide (CO_2) emissions for different values of kilometre taxation.

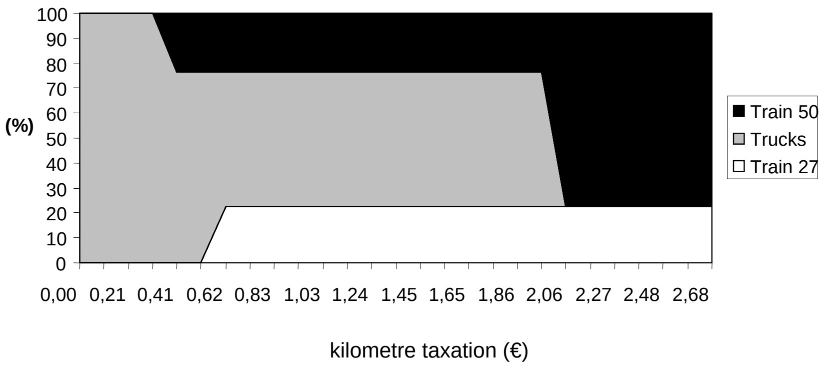

Figure 5.5. Percentage of the three vehicle types for different kilometre taxations.

The environmental performance parameters for the truck alternative are based on real world performance data, while the train data is based on template data. The total weight of the freight train set is not known, therefore it is not possible to perform detailed calculations of the environmental performance of only one rail freight carrier. Since truck transportation has a larger contribution of the environmental performance in terms of carbon dioxide, it is reasonable that the environmental performance is more detailed for the truck alternative.

In the simulation experiment the probability of delay is set to zero. Usually, train transport is more sensitive to delays than truck, why this performance measure is probable to be better for truck than for train transport.

In Table 3.3 it is indicated that infrastructure taxes influence the choice of transport mode and vehicle type. This influence corresponds to the simulation results we got. However, since the performed simulation experiment is simplified, there is a need for more complex simulation experiments, where more details are included, to be able to find more accurate relationships. For instance, the possibility to coordinate different consumer demands influences the decisions of transport mode and vehicle type made by the transport chain actors.

5.3.3 Discussion

The simulation experiment is based on a real world case. Some of the characteristics of the case are included in the simulation experiment. For instance, the geographical location of the transport chain actors correspond to the actual location of the real world actors, the shipment size is similar to real world shipments of this customer, the truck type is similar to the real world truck type, and the generated customer demand is similar to the actual transport frequencies. The kilometre taxation studied in the simulation experiment is possible to be reintroduced in Sweden as well as introduced in other EU countries. The simulation experiment could be extended to include different implementations of the tax. For instance, the effects of an implementation of the tax on all roads compared to an implementation on only some of the roads is interesting to study. The effects of a differentiation of the tax on different vehicle types are also interesting to examine. See, for instance SIKA (2000a) and SIKA (2003) for studies of different possible implementations of kilometre taxation in Sweden, or McKinnon and McClelland (2004) for a study of a possible implementation in the UK.

Since the initial simulation experiment is based on a simplified transport chain it is not possible to simulate the behaviour of all identified transport chain actors and the interactions between the agents. Moreover, in the initial simulation experiments we assume that there are always sufficient amounts of products and transport resources. This implies that not all types of decisions taken by the product and transport planners are taken into account. For instance, fleet management issues, such as load consolidation, frequency of the transports and backloading, are not considered so far. Complex transport planning of the coordination of different consumer demands is therefore not regarded. Intermediate storages are also not considered so far.

The environmental performance of transportation can be allocated in different ways. It can be allocated per vehicle kilometre, per ton kilometre, per customer, per kilogram of the product, per euro of the product etc. Depending on how the environmental performance of transportation is allocated, the results differ. Allocation is not studied in this thesis, but more information can for instance be found in Bäckström (1999).

To be able to generalize the results, additional simulation experiments are needed. The results so far are only valid for simplified scenarios. To generalize the results the product groups used in macro-level models could be used. Ideally, detailed data for the different product groups are available. However, since this is not the case there is a need to distinguish this data, for instance cost parameters that can be connected to different product types or transport chain types. We believe that the identified logistical factors can be used to distinguish typical transport chains.

The simulator is intended to be a tool for governmental policy-makers to evaluate the effects of different levels of governmental control policies. The simulator can be used for studying what the possible effects are when different types of governmental control policies are implemented. To better understand how control policies function, the correlation between different types of control policies can be studied. For instance, the correlation between control policies that influence variable costs and control policies that influence fixed costs can be studied. Another issue that can be studied with the simulator is the effects of the internalization of external costs. By using the simulator, the internalization of external costs for different transport volumes can be studied. It is of interest to examine how the estimated external costs vary with different control policies and their effect on different transport chains for a given amount of transport. Moreover, the simulator can be used to study what the effects will be when transport chain actors have to adapt to new policy requirements.

We believe that the micro-level model can complement macro-level models that currently are being used. For instance, we believe that the transport mode assignment in macro-level models, such as the Swedish SAMGODS model, can be improved by micro-level models. More exact breakpoints for when the transport chain actors choose certain transport modes can for instance be determined by the micro-level model for the product groups used in macro-level models. SIKA is currently planning to develop the Swedish SAMGODS model to include more detailed aspect (RAND Europe, 2004). The proposed approach combines an aggregated approach with a disaggregated approach, see Figure 5.6. This approach is similar to the TLUMIP model described in Chapter 4. In the proposed model, the P/C (production – consumption) flow is disaggregated to allocate the product flow to individual companies. Then the logistical decisions taken by the individual companies are modelled and products are allocated to shipments. Finally the flows are aggregated back to OD (origin – destination) flows and the mode and route assignment is performed. We believe that our model could be developed in order to be a part of this proposed model and then act as the module that models the logistical decisions. RAND Europe proposes several ways to model the logistical decisions. Our model is more detailed than the proposed methods, for instance we include fleet management issues in our model, which is not included in the proposals by RAND Europe. In order to evaluate which approach that is most appropriate to use for the modelling of the logistical decisions in the proposed model, the different approaches for modelling the logistical decisions could be compared. According to Downing et al. (2001), MABS can represent different grains, therefore couplings can probably be done between our micro-level model and macro-level models.

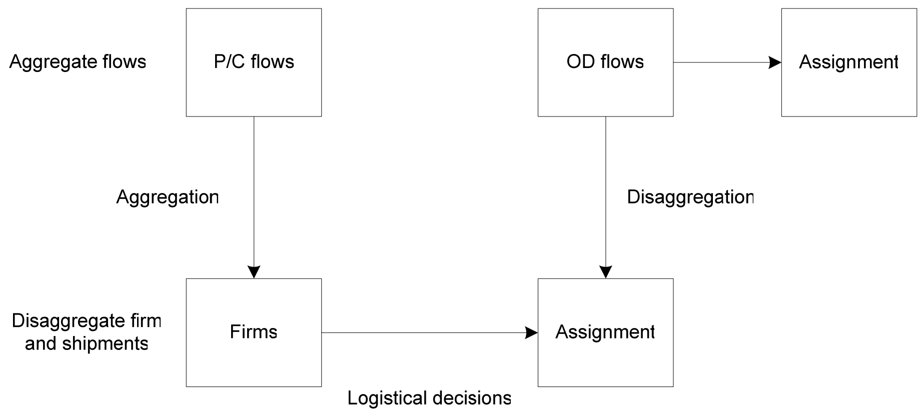

Figure 5.6. Structure of the proposed model for the Swedish national model (RAND Europe, 2004).

The micro-level simulator is currently being developed, therefore some of the issues discussed above are not possible to include with the current version of the simulator. For instance, the behaviour of the transport and product planner is not fully considered. When more advanced behaviour of the transport planner can be included in the simulator, fleet management issues can be considered. This is important in order to examine how the available resources can be used as efficient as possible.

The initial experiments indicate that MABS is suitable for the purpose of studying the effects of governmental control policies in transport chains. The behaviour and interaction of individuals are important to capture since this influence how the logistical operations etc. are performed. This is also possible to capture with MABS. Since norms already are commonly used in agent technology for influencing the behaviour and interactions of the agents, it seems promising to apply the concepts of norms as governmental control policies. So far, the simulation results show that the model simulate the behaviour of the transport chain actors correctly in the studied scenario.

6. Conclusions and future work

A micro-level model based on agent-technology has been developed which captures the environmental, quality and economical performance in transport chains, given different levels of governmental control policies. The transport chain actors are represented by decision-making agents in the model. The agents represent different roles in transport chains, why different mappings can be done between organizations and the agents. The interactions between the agents are modelled. In order to describe characteristic transport chains, logistical factors are identified. The logistical factors serve as input and output in the model and are described according to how easily and in what time frame they can be influenced. The output from the model is the consequences of the decisions taken by the agents, as well as the input.

To illustrate the usage of the micro-level model, a simple simulation experiment based on a real world case has been performed where different levels of kilometre taxation on trucks are introduced. The kilometre taxation is under discussion to be introduced in Sweden and other countries, why the taxation is relevant to study. In the simulation experiment the focus was on some of the short-term decisions made by the transport buyer and the transport planner, i.e., concerning the transport mode choice and the vehicle type choice. The effects of these decisions have been studied. The simulation results so far have showed that the model seems to simulate the behaviour of the transport chain actors correctly in the studied scenarios.

A review of models that consider the effects of governmental control policies on transportation has been performed. The review shows that macro-level models are mainly used for this purpose. However, since the macro-level models concern traffic, the behaviour of the individual transport chain actors can hardly be captured in such models since the decision making actors are not modelled explicitly. Consequently, the effects caused by the decisions taken by the individual transport chain actors are not fully captured in these models.

Before implementing governmental control policies, it is crucial to predict the effects in order to make probable that it is a good measure and that the policy goal is reached. The micro-level model can be used as decision support for governmental policy-makers and serve as a complement to existing tools based on macro-level models. For instance more exact breakpoints for when the transport chain actors choose certain transport modes can be found, as well as other breakpoints concerning the logistical operations. We believe that the micro-level model has the potential to bridge the gap between governmental policy-making and the behaviour of transport chain actors. MABS seems to be an appropriate simulation technique to use since the behaviour of individuals is simulated and global norms can be included. Micro-level behaviour and macro-level goals can therefore be connected. The usage of MABS in the context of transport chains has been studied in the literature. The work that has been done so far lacks certain aspects which we find important to be able to capture the effects of governmental control policies. For instance transport mode and vehicle choice have not been considered, as well as the effects of governmental control policies. However, we have showed that it is possible to include such decisions in an agent-based model.

Logistical factors can be described in several ways. Our description mainly focuses on the logistical planning, in both short- and long-term, and is described to suit simulation models. In the initial simulation experiments the given and indirect logistical factors serve as input, while the direct factors serve as output. In future simulation experiments can the effects of indirect factors, concerning the long-term decisions such as investment of vehicles, be taken into account, either indirectly by the user of the simulator, or directly in a more advanced version of the simulator by extending the decision domain. In the latter case will the indirect factors be simulated and function as output, and there will probably be a need to introduce new transport chain actors, represented by agent. Since the focus is on logistical planning, some factors that could be considered important, such as driver behaviour, are not included in the description. Some of the logistical factors have been used in the initial simulation experiment, and so far the logistical factors seem appropriate for the usage in micro-level models. In future work it is possible that the logistical factors will be revised to better match the description of simulated transport chains. Also, the interrelationships between the logistical factors need to be further analysed.

There is a need to further validate the simulator. Some validation has been performed by cooperating with transport chain actors that are represented in the studied case. For instance, the reasonableness of the assumptions made for the simulation experiment has been validated by the transport chain actors as well as the other partners in the project *Effects of governmental control policies on transportation chains: A micro-level study*. We have also had discussions about the micro-level model with representatives from the Swedish Institute For Transport and Communications Analysis (SIKA). There is a need to further study the behaviour of real world transport chain actors to increase the degree of realism in the micro-level model, for instance by performing a survey. The criteria that are crucial for different types of transport chain actors and transport chains are also important to identify, as well as what the decision-making is based upon. This is important to identify to be able to generalize the simulation results and validate the simulator. We believe that the logistical factors can be used to describe typical transport chains, and therefore be used for the generalization of the results. Possibly the product groups that are used in current macro-level models can be used when performing simulation experiments with the micro-level model. Then it would probably be possible to compare the simulation results of the micro-level model with the results of the same simulation experiments that have been performed with macro-level models which in turn can facilitate the generalization and validation of the results. We believe that our model could complement current macro-level models, such as the Swedish SAMGODS model, for instance by improving the marginal cost curves used for the transport mode assignment. SAMGODS is also planned to be developed, and it is possible that the micro-level model could be a part of the model suggested by RAND Europe (2004). In the proposal by RAND Europe a combined aggregate and disaggregate approach is suggested, and the micro-level model could then possibly function as the disaggregated part where the logistical decisions are taken.

There is also a need for further simulation experiments where more types of governmental control policies and different types of transport chains are studied in order to validate the micro-level model. There are different types of governmental control policies that are interesting to study in the simulator. For instance, in future simulation experiments we want to study the combinations of governmental control policies and what the effects are when the control policies interact. An example of a governmental control policy that is interesting to study since it has a potential to improve the environmental performance is the impact of a change of the maximum allowed truck weight. See Section 5.3 for more examples of governmental control policies which are interesting to study. To further validate the simulator, real world implementations of governmental control policies can be studied and these implementations can then be simulated in the micro-level model. The simulated effects can then be compared to the real world effects.

In the performed simulation experiment, customer orders are randomly generated in order to include uncertainty for the transport chain actors. In future simulation experiments we want to include uncertainty during transportation of the products. Uncertainty can then correspond to congestion, bad weather conditions, accidents, etc. and can then be simulated by random disturbance. If uncertainty is included, the degree of realism is increased.

Moreover, there are certain relationships and statements that we would like to verify or falsify in future experiments. For instance, it is interesting to study how sensitive transport operators are to increased fuel taxes. Several researches, for instance McKinnon (1995) and Engström et al. (2001), state that the transport price is not very price elastic. In Brand et al. (2002), however, it is showed with the macro-level model STEEDS that a higher fuel tax appears to be effective to slow down the carbon dioxide emissions from transportation. This is interesting to further study in our model. The price elasticity is also interesting to examine for different businesses. Another issue that is interesting to study is that it is claimed by some researchers (Hesselborn and Swahn, 1998) that an increased fuel tax in Sweden will be a disadvantage for Swedish transport operators and give an advantage to foreign transport operators.

The simulator is currently being developed, why more sophisticated simulation experiments can be done when more functionality has been included. An example of a characteristic that is planned to be implemented is to enable intermodal transportation with common unit loads. Now the simulator includes the possibility to use multimodal transports, but not the usage of common unit loads. Moreover, the possibility to include fleet management issues are planned to be implemented. For instance, we want to examine how more flexible time windows for delivery influence the possibility to use load consolidation, backloading, changed transport frequencies, etc. and what the consequences of this will be. Simulation experiments with customers located close to each other could then be interesting to perform in order to examine fleet management possibilities and how the available transport resources can be used more efficiently. Different degrees of cooperation between the transport chain actors could then be examined. For instance it is possible that if more information is exchanged between the transport chain actors, like when VMI is applied, the performance of the whole transport chain can improve.

Since fleet management issues are planned to be implemented in the simulator, it is possible that transport chain actors can be future users of later versions of the simulator. Different transport chain strategies can then be examined with the simulator.

The environmental performance of transport chains can be expressed in several ways. In the current version of the simulator the environmental performance is described in terms of emissions. The calculation method that is used is the method of NTM (The Swedish Network for Transport and the Environment). Work is in progress at NTM to also include calculation methods for international transportation, why the calculations will be more reliable in the future when international transport chains are simulated. The environmental performance can also be described as external costs. It is possible that external costs for emissions etc. are included in future versions of the simulator. External costs facilitate the comparison between the different types of performance, such as comparison between the internal cost for transport chain actors and the external costs for the society. Simulation experiment with different methods for calculating the external costs, such as ExternE, UNITE and ASEK, can be performed to compare the effects of the different valuations.

Since norms often are used in multi-agent systems we believe that the concepts of norms can be used to model governmental control policies. It would be interesting to implement different types of norms in the simulator.

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