School of Business, Economics and Law
GÖTEBORG UNIVERSITY

For environmental and energy reasons, there is an increasing interest in intermodal road-rail transports among transport planners in governments and industry. However, their planning problem is complicated because cost efficiency and transport quality are also of great importance in all decisions on modal shifts. Therefore, there is an urgent need for relevant scientific tools that can help strategists to design efficient and effective systems for intermodal road-rail transports and to calculate their outcomes in market shares, costs, transport quality, environmental effects and energy consumption.

In his thesis, Jonas Flodén develops a flexible computer based calculation model for strategic analysis. The model takes its vantage point in the competitive situation between all-road transport and intermodal transport and computes the optimal split between these modes, given appropriate data inputs. The model can be used on an ordinary PC and it delivers results in terms of market shares, costs, transport quality, environmental effects and energy consumption for the intermodal system and the total market under analysis.

This strategic decision support model is especially designed to analyse the modal split between road transport and intermodal road-rail transport and it meets the requirements of being both practically useful and theoretically satisfactory. Building on research on intermodal transport decision models done within the Logistics and Transport Research Group at Göteborg University, Jonas Flodén, in his thesis, adds a significant step to this research.

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Jonas Flodén Modelling Intermodal Freight Transport

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- The Potential of Combined Transport in Sweden

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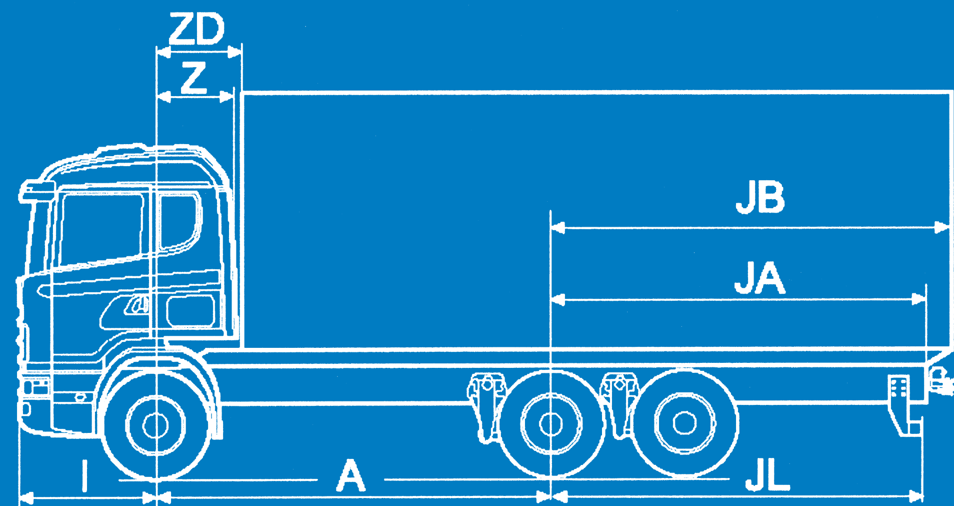

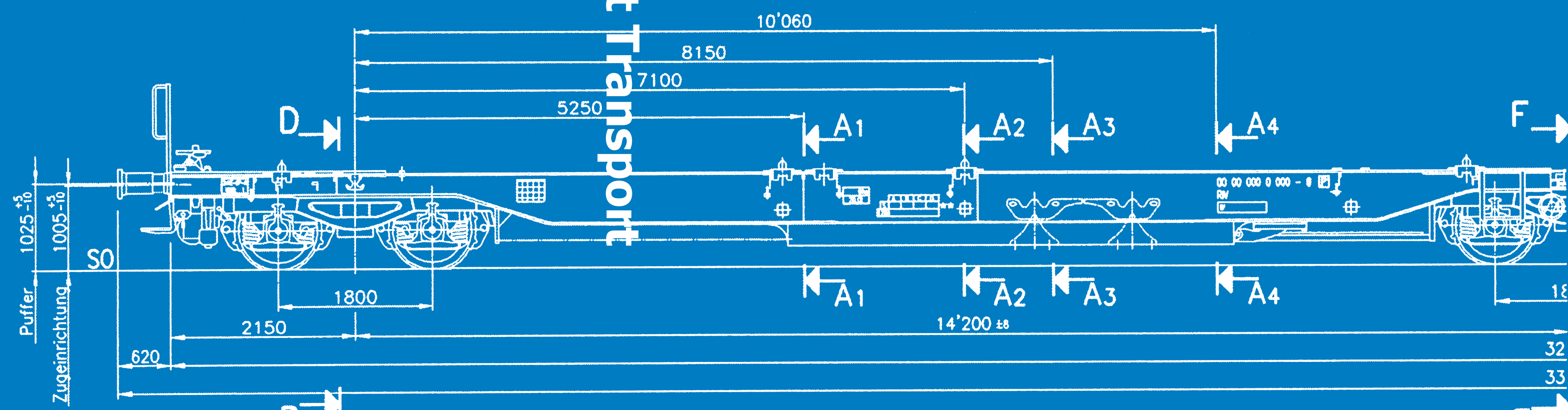

Modelling Intermodal Freight Transport

The Potential of Combined Transport in Sweden

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Abstract

Intermodal transport between road and rail, also known as combined transport, has received a large interest in recent years as part of a possible solution for a sustainable and efficient transport system. However, there has been a lack of tools to evaluate the potential in intermodal transport and of help in designing a competitive intermodal transport system.

The aim of this thesis was to develop a general, large-scale model for strategic modelling of intermodal transport between road and rail. The model is called The Heuristics Intermodal Transport Model, or the HIT-model. The model is a heuristic model and it takes its starting point in a competitive situation between traditional all-road transport and intermodal transport, where the theoretical potential of intermodal transport is determined by how well it performs in comparison with all-road transport. The model can also be used as a tool to calculate the costs and environmental effects of a given transport system.

A transport buyer is supposed to select the mode of transport offering the best combination of transport quality, cost, and environmental effects. Intermodal transport is also required to match, or outperform, the delivery times offered by all-road transport. Given a demand for transport, the model determines the most appropriate modal split, sets train time tables, type and number of trains, number of rail cars, type of load carriers, etc. and calculates business economic costs, social economic costs and the environmental effects of the transport system. The heuristics can further be controlled by a number of control parameters to adjust the behaviour and modal choice of the model. The model is flexible and can be used to test different suggested system layouts, conduct sensitivity analyses, and to test the effect of the intermodal transport system on specific factors, e.g. changed taxes, regulations or infrastructure investments. The model is useful for both large scale national transport systems and small individual transport systems. The model is programmed in C++ and the model size is only limited by available computer memory. Output from the model is the modal choice for each demand occurrence with departure time, arrival time, train departure used, position on train, type of lorry used, number of lorries used, business economic cost, social economic cost, environmental impact (CO_2, CO, SO_2, NO_x, PM, HC, energy consumption and a monetary estimation). If all-road transport is selected, the model also shows the reason why intermodal transport could not be selected (e.g. violated time constraint, economic constraint, etc.). The suggested train system is output with time tables, train lengths, business economic costs, social economic costs and environmental impact.

As a sub-aim, the potential of intermodal road-rail transport in Sweden was determined using the HIT-model. An input data set was developed, which included building a national demand database and calculating operational costs and cost structures for the transport system. Intermodal transport was found to have a large potential in Sweden. Business economic costs and social economic costs can be lowered and environmental effects can be mitigated by using more intermodal road-rail transport. It can also be seen that intermodal transport, almost always, is economically competitive, if the transport distance is long enough. Thus, the main challenge for intermodal transport is not cost, but achieving competitive pick-up and delivery times compared with all-road transport.

Keywords: Intermodal transport, Combined transport, Modelling, Freight transport, Sweden, Potential, Heuristics, Environment

Acknowledgments

This doctoral thesis would not have been possible without the help of several people. First, I would like to thank the following organisations for their generous funding: the Swedish Agency for Innovation Systems (Vinnova), the Swedish National Rail Administration (Banverket), the Swedish National Road Administration (Vägverket), and the Logistics and Transport Society (LTS). Without them, I would not have been able to eat or pay my rent for several years…

I am very grateful to my supervisor, Professor Arne Jensen, for giving me the opportunity to become a researcher and for helping and guiding me throughout the project. Without Arne's help and guidance I would not have been able to complete this thesis. Also, thank you Arne, for giving me the opportunity to focus on my research by securing the necessary funding! I would also like to thank my assistant supervisor, Dr Lars Brigelius, for useful inputs and fruitful discussions.

This thesis is a part of the thematic research program *Systems for Combined Transport Between Road and Rail*, containing several research projects for combined transport. Doctoral students Bernt Saxin and Catrin Lammgård, who also participated in the program, contributed insightful discussions and together we carried out a mail survey. The thematic research program was performed in cooperation with Chalmers University of Technology. The participants at Chalmers contributed useful insights and discussions from a more technical point of view. A special thank you goes to Dr Johan Woxenius.

Several opponents have also read and commented on this project during seminars at the School of Business, Economics, and Law at Göteborg University. Their time and effort are greatly appreciated.

Anne Ljungwall, B.A., copy-edited most of the chapters of this thesis. I am very grateful for her help.

I would also like to thank the forwarders Schenker, DHL and DSV for sharing transport flow data and the Swedish Institute for Transport and Communications Analysis (SIKA) for giving me access to the National Commodity Flow Survey (VFU).

My colleagues of the Logistics and Transport Research Group at the School of Business, Economics and Law at Göteborg University deserve a special thank you for all the fun we had during working hours and after work…

Last, but definitely not least, I would like to thank my family and friends for their support and encouragement during these years.

Göteborg, July 2007

Jonas

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APPENDICES

1 Introduction

In 2000, the thematic research program *Systems for Combined Transport Between Road and Rail*, was launched as a joint project between the Department of Business Administration at the School of Business, Economics and Law at Göteborg University and the Department of Transportation and Logistics at Chalmers University of Technology, Göteborg. The project was initiated by Professor Arne Jensen, Göteborg University, and doctor Johan Woxenius, Chalmers University of Technology. It aims at developing the intermodal goods transport research field and at contributing to the development of sustainable goods transport systems. At the department of Business administration, the project involves three doctoral students and one half-time senior researchers. The project is funded by the Swedish Agency for Innovation Systems (Vinnova), the Swedish National Rail Administration (Banverket), the Swedish National Road Administration (Vägverket), and the Logistics and Transport Society (LTS).

This thesis is a part of the research program and aims at building a model that can be used as decision support to determine the potential of intermodal freight transport and suggest a suitable transport system design.

1.1 Intermodal Freight Transport

The idea behind intermodal transport is to utilise the strengths of different transport modes in one integrated transport chain. The road network has the advantage of being able to access almost any location and also of being very flexible, while rail and sea networks have the ability to transport goods long distances at a low cost. A combination of the two networks could, thus, reduce the cost of transport. The structure of an intermodal transport system consists of three parts:

- A finely distributed distribution/collection system
- A roughly distributed long haul system
- Terminals

A distribution/collection system normally consists of a road system that transports the goods between the terminal and the sender/receiver. A long haul system is normally a rail or sea system that transports the goods between the terminals. The terminals, finally, link the two networks together by transferring the goods between them. To make the transfer between the modes more efficient, the goods are carried in standardised load carriers called Intermodal Transport Units (ITU), such as containers, swap-bodies or semi-trailers. See Figure 1.

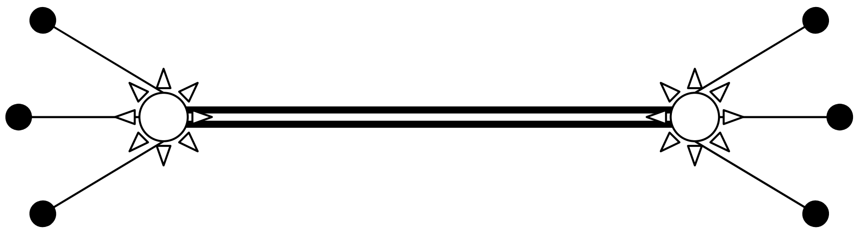

Figure 1 The intermodal transport system

The extra costs incurred and resources consumed by the terminal and the distribution/collection systems, compared to traditional all-road transport costs, must be outweighed by the cost and resource savings incurred in the long haul system. This means that a viable intermodal transport system should try to minimise the use of terminal and distribution/collection systems and maximise the use of the long haul system during the transport. Intermodal transport is, therefore, not a competitive alternative on short distances, since the advantage of using intermodal transport does not arise until the savings in the long-haul system outweigh the extra resources consumed in the terminal and distribution/collection systems. Of course, the exception is if there are some natural obstacles for road transport, such as across the Alps. Normally, a distance of about 500 km between the sender and receiver is considered to be the minimum distance for traditional intermodal transport between road and rail. However, as much research has shown, e.g. Jensen (1990), Woxenius (1998) and Bärthel and Woxenius (2004), this picture could change drastically with the use of alternative technologies and/or better planning and management. Another key issue in intermodal transport is that all the parts of the system must work together, both on a technical level and on a management and system design level. This interdependence makes great demands on the design of the intermodal transport system. The system needs to be well coordinated to fully utilise the benefits of intermodal transport.

Intermodal transport between road and rail, also known as combined transport, has a long history in the transport industry. When trains became common, the idea to combine them with the classical road transport was soon to be discovered. The first attempts at combined transport were made in England in the early nineteenth century, where stagecoaches were lifted onboard trains, but the main breakthrough was not made until the 1960s when the containerisation of the transoceanic shipping sparked a demand for land transport of sea containers (Woxenius, 1993, Woxenius, 1994). Today, combined transport terminals are spread all over Europe. In Sweden, there are currently 16 dedicated combined transport terminals (Banverket, 2005b), but the technical simplicity in lifting an ITU on or off a train makes limited combined transport a reality also at locations that do not have a dedicated terminal.

The goods transported in combined transport include almost all types of goods. Since the principle behind combined transport is to use detachable ITUs, it is safe to say that more or less anything that can be loaded on a normal lorry can be transported by combined transport. Only very special types of cargo that require special lorries and/or ITUs are excluded from combined transport for technical reasons.

1.2 Definitions

The idea to combine different modes of transport, such as road, rail, sea or air, may seem obvious. The combination comes naturally in many cases, for example when geographical obstacles need to be overcome. Seen in this broad perspective, where cargo utilising more than one mode of transport during the transport between sender and receiver is considered to be intermodal transport, almost all transport is intermodal. In the Swedish case, almost all European export and import would be considered intermodal due to the common use of truck and rail ferries between Sweden and Denmark, Germany and Poland. A study about the Swedish manufacturing industry in 1990 also shows that about one third of the outgoing shipments in tons was transported in transport chains consisting of two or more modes (Demker, et al., 1994). This broader definition of intermodal transport therefore has the drawback that so much transportation is considered to be intermodal where there is not always an explicit thought behind the combination of different modes of transport. Nevertheless, this broad definition has been commonly used. However, a more narrow definition of intermodal transport will be used here. Also, a distinction between the terms combined transport and intermodal transport will be made. A definition of the stricter concept of intermodal transport is given in a joint document by the European Commission, the European transport ministers and the United Nations Economic Commission for Europe (UN/ECE, 2001, p. 17) [1] which defines intermodal transport as:

> *The movement of goods in one and the same loading unit or vehicle which uses successively two or more modes of transport without handling the goods themselves in changing modes.*

In this more dedicated form of intermodal transport, the transport system is specifically designed to take advantage of the positive sides of each transport mode. To be regarded as intermodal transport in the stricter definition, the requirement of the goods having to be carried in a single ITU during the entire transport is added. The individual units of goods itself may not be individually reloaded between the different modes.

The term combined transport is yet a more strict definition of intermodal transport. (UN/ECE, 2001, p. 18):

> *Intermodal transport, where the major part of the European journey is by rail, inland waterways or sea and any initial and/or final leg carried out by road are as short as possible.*

thus, adding a restriction of road transport being the initial and/or final leg and minimising the use of road transport. In a European perspective, the focus on combined transport is on utilising combinations of road and rail transport or, in some areas of central Europe, a combination of road and inland waterways. In Sweden, the focus is almost exclusively on the road

[1] The complete terminology document can be downloaded from http://www.unece.org/trans/wp24/documents/term.pdf

and rail combination. However, this division between intermodal and combined transport is not strict and mixed uses of the names are common. Combined and/or intermodal transport may also be know under other names, such as multimodal or bimodal. To add to the confusion, yet other definitions are used in other EU documents and research reports. There may also be geographical differences. In North America, for example, the term combined transport is not used at all. A more comprehensive review of different terms and definitions can be found in Bontekoning, Macharis and Trip (2004) and Woxenius (1994). In this thesis, both “intermodal transport” and “combined transport” will be used. Intermodal transport will be used when referring to generic aspects that can apply to all intermodal freight transport.

The term ITU is also another source of confusion. In a strict definition, an ITU could be almost any packaging around the goods, such as a pallet, but normally, the term ITU is reserved for larger units. The UN/ECE definition of ITUs will be used here (UN/ECE, 2001, p. 45):

> *Containers, swap bodies and semi-trailers suitable for intermodal transport.*

Also, ITUs may be known under different names, such as load carriers, load(ing) units or unit loads.

1.3 A Description of the Transport Industry in Sweden

The overall transport industry structure in Sweden is based on the three large forwarders, Schenker, DHL and DSV and the railway company Green Cargo (the former freight division of the Swedish state railways, SJ). The structure in the transport industry has changed very rapidly in recent years. Until just a few years ago, the haulier owned company Bilspedition and the subsidiary of the Swedish state railways, ASG, dominated the road haulage sector and the Swedish State Railways (SJ) had a monopoly on rail transport. The services provided were mainly traditional transport. Added services, such as third party logistics, warehousing, merge-in-transit, etc. was still uncommon. However, the trend in the transport sector today is towards deregulation, consolidation through mergers and take-overs into a few large multinational corporations and alliances. The two large Swedish road transport companies have, in several steps, been bought by the international logistics companies

Deutsche Post[2] and Deutsche Bahn[3]. Deutsche Post owns ASG (since 1999) and operates under the name DHL. Deutsche Bahn owns Bilspedition (since 2002) and operates under the name Schenker. Both groups are established all over the world and offer land, air and sea transport and other logistics services, trying to become a complete provider for all logistical services. Traditional road haulage is, thus, only a part of their business. They are also expanding rapidly, mainly through acquisition of smaller logistics companies in different countries. The smaller DSV[4] is a part of the Danish DSV Group. Although operating in several countries globally, the group is much smaller than Deutsche Bahn and Deutsche Post.

Combined transport in Sweden always includes at least two companies, one railway company and one road haulage company. There are no companies operating in both sectors today. On the rail side of combined transport in Sweden, most combined transport is carried out by CargoNet, jointly owned by NSB, the Norwegian state railways, (55%) and Green Cargo (45%). The company is a merger between the Swedish and the Norwegian combined transport operators. The Swedish part was previously known as Rail Combi. CargoNet in Sweden operates at 16 terminals, has about 1 100 railcars and handles about 400 000 ITUs per year (Rail Combi, 2001). The most common ITUs are swap bodies, trailers, and containers, of which CargoNet accepts a large number of different sizes. About 40% of the ITUs are trailers (Banverket, 2005a). CargoNet itself does not own any trucks or ITUs and has positioned itself as a subcontractor to the forwarders and hauliers (also included companies with own account transport). The company also has a policy of not marketing itself directly towards shippers and receivers (Rail Combi, 2001). Combined rail transport is also carried out by some small rail operators, but then mainly focusing on sea containers. In particular, the port of Göteborg has initiated several "rail shuttles" to and from the port. Between 2000 and 2006, the goods volume on the rail shuttles has doubled and is expected to continue to increase (Port of Göteborg, 2006).

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[2] The German Post
[3] The German Railways
[4] Previously known as Fraktarna and DFDS Transport in Sweden.

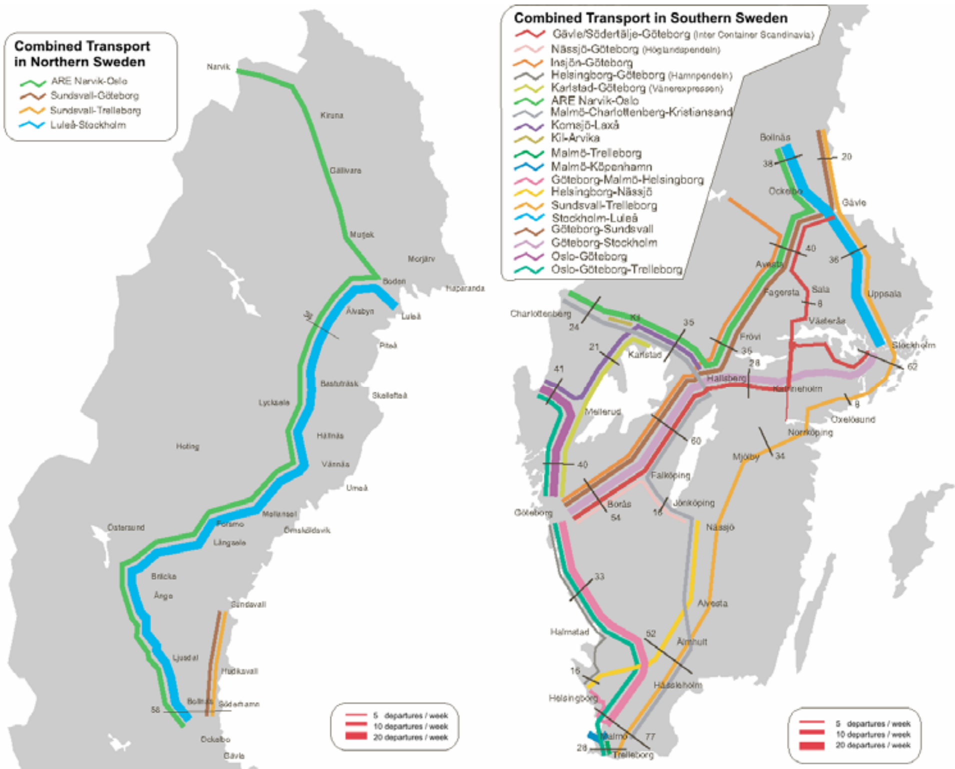

Figure 2 Map of combined transport services in Sweden. Adapted from Banverket (2005a, p. 20)[5]

On the road haulage side of combined transport, almost all large forwarders and hauliers sometimes use combined transport. The forwarders and hauliers sometimes use a permanently booked slot, e.g. a weekly transport of 10 trailers between two terminals, or a more random ad-hoc booking when needed. Almost always, they use CargoNet, but some limited combined transport is also run by some forwarders and shippers with rail sidings at their terminals. However, as they do not operate any trains, their wagons are added to the ordinary Green Cargo wagonload system like an ordinary rail car, but recently, some forwarders have started chartering block trains dedicated for combined transport. Today, the Swedish system for combined transport between road and rail transports about 3 200 million tonne-km annually. This represents about 3.5% of all transports in Sweden in tonne-km. The amount in ton is 6.2 million tonnes annually (SIKA, 2006a). Figures indicate that the amount of goods transported remained fairly steady

[5] The map has been translated from Swedish and cut down.

during the 1990s but have increased by almost 30 % from the late 1990s (Demker, 2000, SIKA, 2006a, Wajsman, 2005).

In the traditional rail freight sector, the freight market has been deregulated[6] since 1996. This means that anyone, who fulfils certain requirements, e.g. safety standards, can start a freight train service. However, in Sweden approximately 80% of the market is dominated by Green Cargo. Today, there are about 15 other companies running freight services. Almost all of these small railway companies work on a regional basis. A very special case is the iron ore traffic in Lapland run by the mining company LKAB's subsidiary MTAB that transports iron ore from the mines to a few ports in northern Sweden and Norway. Due to the heavy weight goods, this service alone accounts for about 19% of the Swedish rail transports in tonne-km. If not taking this very special traffic into account when comparing market shares, the remaining small railway companies has about 1% of the market (SIKA and SCB, 2000).

The traditional road hauliers in Sweden are in general rather small. Approximately 50% of the 12 000 hauliers in Sweden operates with only one lorry[7]. The trend is, however, towards larger firms with more lorries. The 400 largest firms (i.e. 3% of the hauliers) operate, for example, about 25% of the 37 000 lorries[8] in the haulage industry. Many of the independent road-hauliers operate on long-term contracts for the large forwarders. Competition in the Swedish road haulage industry is fierce. Among the smaller, independent, hauliers, profit margins as low as 1-2% are commonly mentioned. Apart from the haulage industry, there are also about 19 000 lorries[8] used for own-account transport for a company (Sveriges Åkeriföretag, 2001). Results from a survey conducted in this research project by Saxin, Lammgård and Flodén (see chapter 3.4.1) show that manufacturing and wholesale companies in Sweden use own-account transport for 43% of the transported weight[9]. 53% is sent by forwarders, 3% of the transported weight is transported by their customers and 1% in other ways.

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[6] For a description of the deregulation process and its effects, see Jensen and Stelling (2007) and Stelling (2007).

[7] A very interesting ethnological study into the Swedish "trucker" culture, i.e. lorry drivers, was made by Nehls (2003). The study showed the Swedish truckers to be very male dominated, freedom oriented, focusing on practical knowledge, proud of their profession and very committed to lorries and "trucking".

[8] Over 3.5 tons.

[9] 10% in vehicles owned by the own company and 33% in subcontracted vehicles.

1.3.1 Competition

As can be seen in Table 1, the different actors are active in different parts of the transport chain. The large forwarders are the only ones that control the entire chain. They have the possibility to operate their own transport all the way or to use any of the other companies as subcontractors, as they desire[10]. This transport decision may also be made at very short notice if needed. As they also dominate the transport buyer contact, the buyer associates them with the transport. Thus, they are the natural choice to contact for a transport buyer in need of a transport. Many transport buyers are unaware of any subcontractors being used. This gives the forwarders a very strong position in the market as the leaders of the chain[11].

Green Cargo has positioned itself towards a very specific part of the market. The numbers of customers with rail sidings are limited and a requirement of only accepting full rail cars further limits the number of potential customers. Most customers are large manufacturing industries or forwarders who consolidate shipments into rail cars at their terminals. However, some services are also maintained for customers with rail sidings in only one end of the transport chain, for example distribution from a large manufacturer to several customers, using trucks (traditional reloading or ITUs) for the distribution.

[10] Often, a fixed transport, e.g. an every day service between A and B, can be subcontracted to an independent haulier, who in turn has the possibility to choose to use combined transport for all or part of the service.

[11] It is not always easy to make a clear distinction between a road haulier and a forwarder. Many forwarders operate their own fleet of lorries and many road hauliers accept forwarder type assignments, i.e. more than just the transport. In the classical definition, the forwarder acts as a middleman between the shipper and the transporter (e.g. a road haulier) arranging services such as storage, consolidation, documents, customs declaration etc. and contracts the actual transport to a transporter in the forwarders own name. See also Lumsden (1998).

	End transport buyer contact	***Collection***	**Long-haul transport**	***Distribution***
Green Cargo	Only customers with rail siding in at least one end of the transport chain	*Own operations or subcontracted to independent rail/road companies*	Yes	*Own operations or subcontracted to independent rail/road companies*
CargoNet	No, subcontractor to road hauliers and forwarders	*No*	Trains operated by CargoNet or subcontractor with rail cars owned or leased by CargoNet	*No*
The forwarders	Yes	*Own or subcontracted trucks*	Own or subcontracted trucks, combined transport or traditional rail transport (rail part subcontracted)	*Own or subcontracted trucks*
Road hauliers	Sometimes. Often subcontractor to the forwarders	*Yes*	Own road transport or subcontracted to combined transport	*Yes*
Own account transport	A part of the transport buying company	-	Own or subcontracted trucks, combined transport or traditional rail transport	-

Table 1 The operators involvement in the transport chain

CargoNet's position as a subcontractor makes it vulnerable to sudden changes in behaviour of the large forwarders. Due to the dominant position of three large forwarders in the road haulage industry, CargoNet is very dependent on a few large customers. This dependence is also the rationale behind CargoNet's policy to work as a subcontractor, as they are eager not to jeopardise the relations to the forwarders by competing for the same customers. Research indicates that this strategy has limited the amount of transported goods, causing CargoNet not to utilise their scale advantages (Jensen, 1998). Historically, combined transport was used by many forwarders and road hauliers as an extra buffer to handle the peeks in transport demand, while the bulk of the transport is handled by their own fleets. However, CargoNet today feels that there is a change towards treating combined transport as a part of the ordinary transport operations (Rail Combi, 2001).

1.3.2 Possible Future Developments of the Market

It is very difficult to predict the future development of the transport market in Sweden, and this is outside the scope of this thesis. However, a short overview of potential directions of change is necessary for the understanding of the market.

The general trend in the transport industry is a large increase in transport demand, e.g. SIKA (2000). Generally speaking, the trend in the transport sector today is towards more valuable, smaller shipments being transported faster over longer distances with a higher demand for accurate timing in pick-up and delivery (Angel, et al., 2006, SIKA, 1999a, Sveriges transportindustriförbund, 1999, ÖCB, 2001). A greater demand for information services, e.g. Track-and Trace, is also expected. The general industrial production has changed towards higher valued and lighter products due to a higher degree of product refinement, e.g. electronics. Companies also try to limit their inventory costs by keeping smaller stocks and relying more on timely deliveries, e.g. in Just-In-Time, lean production and similar concepts. A more international society, for example the expansion of the EU, causes companies to expand their markets, both as sellers, purchasers and outsourcers. This also causes a need for more warehousing and distribution centres. Experts agree that this new transport demand will mainly be absorbed by an increase in road transport, e.g. SIKA (2000) and EU (2001). The environmental aspects of transports have decreased in importance for transport buyers in the last few years, however, it is possible that the environment might regain its importance in coming years. A high awareness of the environmental aspects, however still exists on the political level.

Actors

Potential changes in the Swedish transport market are closely related to the expansion of the large international transport companies. Both DHL and Schenker can easily expand into the rail freight sector, both on conventional trains and combined transport. There is also a recurrent rumour in Sweden that the rail company Green Cargo is for sale, and Deutsche Bahn is the most likely buyer. This would mean that Deutsche Bahn would own both Schenker and Green Cargo. The trend in the Swedish road haulage industry is towards fewer and larger hauliers (Sveriges Åkeriföretag, 2001). Since the Swedish rail sector is deregulated, there is also a possibility that the large European railway companies, e.g. Railion or SNCF, will expand into the Swedish market.

Repositioning among the current actors in the Swedish market is also possible. CargoNet might decide to start marketing themselves towards the end customers and expand into the road haulage sector. On the opposite side, road hauliers might decide to expand into combined transport rail haulage. There is also a concern in the road haulage industry that low cost hauliers from the new EU member states (mainly Poland and the Baltic states) shall establish themselves in Sweden.

System

Naturally, the physical side of the transport infrastructure might also change with new roads, terminals and railways. Also, the restrictions imposed on the transport actors might change, e.g. longer and heavier trucks and trains might be allowed, there might be changes in working hours, etc. The Swedish railway system is currently undergoing an upgrade to accommodate a bigger loading gauge and heavier railcars. In particular, taxes and infrastructure charges might be subject to large changes in the coming years. There is a great political concern for the negative environmental effects caused by transport. Most likely, we are about the see an increase in CO_2-taxes etc. and restrictions on non-renewable energy sources.

1.4 The Importance of Combined Transport

Combined and intermodal transport has, in recent years, attracted an increased interest from authorities and organisations. Although it is not a new invention, the international trend towards an increased transport demand in combination with more and more congested roads and environmental concerns has sparked an extensive interest in combined and intermodal transport. An OECD-study recently found that, of its 28 member countries, 26 have an explicit or implicit policy to promote intermodal freight transport (OECD, 2001).

Also, the European Union has a strong focus on intermodal transport[12]. The European Commission (EU, 2001, p. 14) has in the European transport policy stated that:

> *Intermodality is of fundamental importance for developing competitive alternatives to road transport. (…) Action must therefore be taken to ensure fuller integration of the modes offering considerable potential transport capacity as links in an efficiently managed transport chain joining up all the individual services.*

Also in Sweden, the interest is clear. The Swedish government states in its transport policy guidelines that (Swedish government, 2006, p. 291)[13]:

> *A strategic challenge for the transport policy is to contribute to a separation between transport growth and the negative effects of transport. Important steps in this to promote environmental friendly and safe transport solutions. Intermodal transport solutions, where railroad and shipping are fully utilised, should therefore be supported.*

The background to this growing interest lies in the trend towards increased transport that has been apparent in recent years. Transport has continued to increase for several years, with the majority of the growth being handled by road transport, see Figure 3 and Figure 4. This development is also expected to continue. In Sweden, the total long haul transport[14], in tonne- kilometre, is expected to grow by 21% (20 billion tonne-km) between 2001 and 2020. The majority of the increase will be handled by road transport, which is expected to increase by 30% (12 billion tonne-km) while rail transport is only expected to increase by 18% (3 billion tonne-km). As market shares are

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[12] See Janic and Reggiani (2001) for an overview of EU research and actions to promote intermodal transport.
[13] Translated from Swedish.
[14] Over 25 km.

concerned, road transport is expected to increase its share from 42% to 45%, while rail transport will remain unchanged at 19% (SIKA, 2005d).

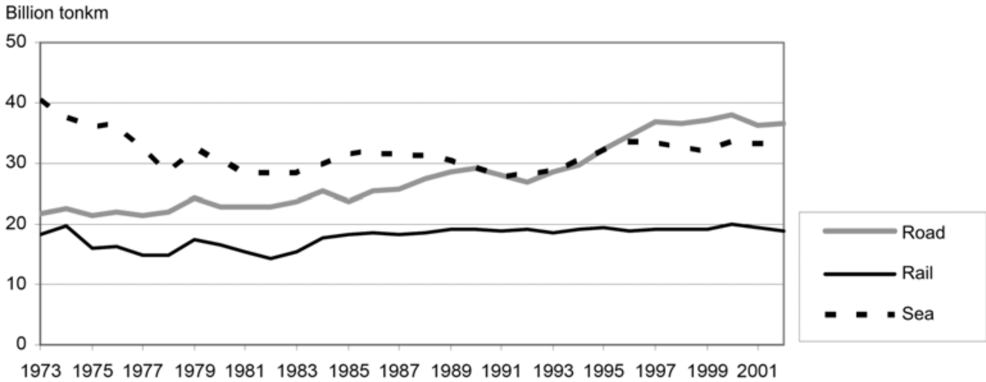

Figure 3 Goods transport evolution in Sweden 1973-2001 in billion tonne-km (SIKA, 2005e, p. 33)

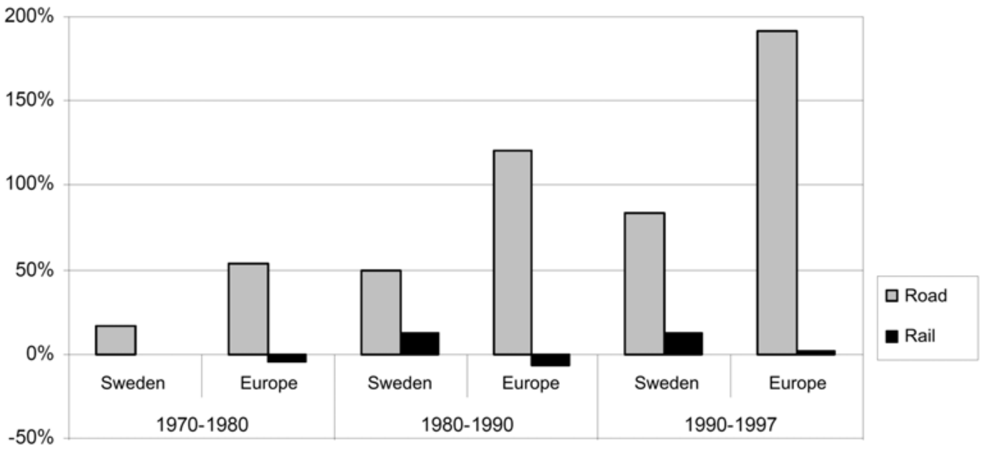

Figure 4 Expansion of goods transport in Sweden and western Europe in tonne-km 1970-1997 (SIKA, 2005e, p. 34)

This leads to some obvious problems. From society, there is a strong interest in reducing the increase in road transport, for example to reduce the wear on the road infrastructure caused by heavy traffic, the demand for new roads and the higher external costs caused by road transport compared to rail transport. The road network also runs the risk of being congested causing uncertain delivery times and increased pollution. As changing demands in today's industry, e.g. JIT and centralised warehouses, require more transport and reliable deliveries, the transport industry is looking at alternative ways to satisfy the customer demand. Many people, both politicians and people in the transport industry, consider combined transport to be a fruitful alternative. A clear example of this is that both the Swedish National Road Administration (Vägverket) and the Swedish National Rail Administration (Banverket), together with the official Swedish Agency for Innovation Systems (VINNOVA), have decided to fund this research programme and the support, e.g. in data collection, the research programme has received from the large forwarders.

The increased road transport also raises environmental concerns. Although the development of cleaner and more efficient engines is progressing rapidly, the problem of carbon dioxide (CO_2) emissions from fossil fuels remains to be solved. In the Kyoto protocol on climate change, Sweden committed to reducing CO_2 emissions by 8% of the1990 level by 2010[15] (UN, 1997). For the transport sector, the goal is to stabilise the CO_2-emission at 1990 years level by the year 2010. Currently, that goal is not expected to be reached (SIKA, 2006b). Also EU, as a whole, has committed to reducing CO_2 emissions by 8% (Swedish government, 2001). Even if the entire reduction does not have to be made in the transport sector, such a drastic increase in road goods transport as predicted will be difficult to combine with reduced, or even maintained, CO_2 emissions[16]. The Swedish road transport sector, as a whole, has increased its CO_2 emissions with 9% between 1990 and 2004 (EEA, 2007). A study published by the IRU[17] shows that combined transport causes, on average, 20-50% less CO_2 emissions than all-road transport on 19 tested European routes (IFEU and SGKV, 2002). A comprehensive literature review made by Kreutzberger et al. (2003) also shows that intermodal freight transport is environmentally more favourable than conventional road transport.

Also in the transport industry, combined transport is viewed as an attractive alternative. Many forwarders in Sweden show an interest in using more combined transport, both for environmental and economic reasons. In the very competitive transport industry, the potential economical savings that

[15] Later revised to reducing the CO_2 emissions by 4% based on revisions of the Kyoto protocol (Swedish government, 2001).
[16] The transport sector accounts for about 35% of the Swedish CO_2 emissions of which 24% are caused by trucks and busses (SCB, 2000).
[17] International Road Transport Union

may come from utilising combined transport is also of highest interest. For the Swedish industry to remain competitive it is very important to have an efficient transport system with reliable transports at low cost. Also, Swedish consumers would benefit from more efficient transports as the transport costs, ultimately, must be paid by the end customer. Given a properly designed system, combined transport is generally considered to deliver at least as reliable transport as traditional road transport but at a lower cost, see e.g. Jensen (1990). In addition, it could also be a way to reduce congestion on the roads and the negative environmental effects of transport.

1.5 Lack of Information

As can be seen, combined transport is an important area for both businesses and society, and there is a great interest from a large number of actors into combined transport. However, combined transport has had problems meeting the high expectations. Forecasts made during the last decades have predicted much higher market shares than the actually outcome.

There is a lack of knowledge on the potential and design of combined transport systems, particularly at an overall strategic level. For example, politicians, government agencies (e.g. rail and road administrations), and regulating bodies need information on the possible potential of combined transport, in what areas and under what circumstances that combined transport has it's best potential and the environmental effects of the transport system. Forwarders, rail and road transport companies need information on if, and in that case how, they best should use and design combined transport systems and under what circumstances. Any combined transport system must be sure to have both a sustainable competitive advantage and a good market entry ability to be successful (Jensen, 2007). Researchers, working on combined transport, also face similar problems when trying to test new ideas and innovations. Questions that need to be answered include the effect of changed control instruments (e.g. taxes and regulations), new infrastructure investments, new terminals, new technology, changed lorry sizes and speed, changed transport demand, etc. These are just a few examples of important questions in the transport sector today that need to be answered to meet current and future demand for transport.

Today, these questions are very difficult to answer due to the complex nature and large size of national transport systems. There is a need for further studies about combined transport in general and, in particular, there is a need for tools to evaluate the potential in combined transport and for help in designing a competitive combined transport system.

1.6 Modelling

To answer these questions, it comes naturally to look towards the more quantitative tools. Some kind of calculation model of the transport system is necessary to allow for the system to be developed and tested and the potential evaluated. The use of a model gives the researcher the potential to control the design and behaviour of the system. Time can be compressed and several different scenarios can be tested in a short period of time. Well developed theories around modelling also allow for the model to include routines to help the researcher design the best transport system. A calculation model is, therefore, best used to answer these questions.

1.6.1 Previous Models

A large number of goods transport models have been made with different purposes. Generally speaking, most models focus on one subset of the intermodal chain. Several models exist for terminal localisation and design, physical network design, train scheduling and routing, empty haulage, etc. but very few models try to model the entire transport system. However, this review will only consider models intended for strategic analyses of intermodal transport systems. The models will be divided into optimisation, simulation and network models (see chapter 3.3), although the classification can sometimes be ambiguous. The review is based on searches in scientific article databases, library catalogues, EU projects and information from research colleagues. Further reviews of models can be found in Macharis and Bontekoning (2004), De Jong, Gunn and Walker (2004), Friesz (2000), Cordeau, Toth and Vigo (1998), Crainic (1998), Crainic and Laporte (1997) and Dejax and Crainic (1987). In particular, Macharis and Bontekoning (2004) have a very good review of models for intermodal transport systems.

Optimisation Models

One of the most interesting pure optimisation models is the TOFC-model by Nozick and Morlok (1997), which is a tactical model for planning the operations in combined transport company. The model tries to minimise the cost of transporting a known flow of ITUs via combined transport, while ensuring on-time deliveries and repositioning of empty rail-cars and trailers. The model is implemented in the standard optimisation software GAMS and was tested using 10-20 terminals.

An interesting heuristic model was made in the mid 1980s by Jensen (1990)[18]. The model is a competitive strategic model, which tries to determine the most efficient operating procedure of a combined transport system and its accompanying modal split. Since the market share of combined transport is relatively small, the heuristics finds it appropriate to let the model represent the change in costs caused by an increased market share of combined transport, i.e. a transfer of goods from door-to-door road transport to combined transport, when starting by transferring the goods with the largest cost savings. Focus in the heuristics is on the change of the total system cost incurred by the system. The Jensen model was implemented in the computer programming language Fortran and tested on a subset of the Swedish combined transport market in the early 1980s. The model will be explained in more detail in chapter 5.2.

Simulation Models

Most simulation models are addressing operational and tactical problems. In particular, terminal performance is a common area for intermodal simulation models. A simulation model, KombiSim, aiming at calculating the costs both for combined transport and for direct road transport for a given transport demand, was created in 1999 by the consultancy firm Mariterm AB (Sjöbris and Jivén, 1999) for the Swedish National Railway Administration. The transport system (routes, timetables, capacities, etc.) is considered given. A maximum of four trains, ten terminals, ten train routes and one type of ITU can be modelled simultaneously. The model is built in the simulation software PowerSim with input and output modules in Microsoft Excel and is commercially available.

Network Models

One of the best known network models was developed by Guélat, Florian and Crainic (1990) and Crainic, Florian and Leal (1990). The model is intended for strategic planning of freight flows and is also integrated into the commercial, interactive graphical STAN-software from Inro Consultants Inc.

[18] Also available in Swedish (Jensen, 1987).

The STAN software is used for national transport planning in several countries, among them Sweden. The model assigns transport flows to different modes and routes with an aim to minimise the total system cost. Each link and transfer is assigned an average cost function, not depending on the transfer flows, i.e. both the first and the tenth ITU on a link are assigned the same cost. Flows are handled on a very aggregate level. For example, the input flow in tons on a train route is converted a typical rail car for that commodity on each train route and not necessarily conserved when transferred to the next train route. Using this conversion, the number of trains on the link is calculated. Train timetables, etc. are, thus, not used. Time is only included as a part of the delay cost functions.

Another network model is the NODUS-system, developed by Jourquin and Beuthe (1996, 2001). It is a graphic software for analysing multimodal freight networks. The software aims at determining the choice of modes and routes that minimises total transport cost. Costs are considered proportional to the quantity transported and no capacity constraints exist. This means that the entire traffic flow of an origin-destination will be assigned the same mode and route. Costs are also considered to be linear functions of the distance transported. Time is only included as a monetary cost.

A particular case of network model that deserves mentioning is the commercial TransCAD GIS software from Caliper Corporation (Caliper, 2001). Although this is not a model itself in the traditional sense, it is an adaptation of GIS-software for transportation modelling. The system has its main focus on passenger traffic modelling, but it might also be used for freight modelling. Several different solution algorithms are included in the software, however, no explicit function for intermodal freight transport exists. The TransCAD software was used as a part in the TERMINET-model by Rutten (1995) to model short and medium intermodal transport with a focus on determining suitable terminal locations and their capacities in the Netherlands.

2 Research Aims

The review of previous models shows that there seems to be a lack of models with a strategic perspective for the management and design of combined transport systems. The existing models either have a very broad system perspective, e.g. STAN, or focus on a specific detail of the transport system. There is a lack of models that use a system wide approach, combined with a level of detail that can be used for analysis of the systems' operating policies. This puts much higher demands on the model, but the models by Nozick and Morlok and Jensen shows that this can be done. These models are very close to the current research, although implemented on a smaller scale. This lack of models is also found in the review by Macharis and Bontekoning (2004) who do not find any strategic or tactical models from the intermodal operators'[19] perspective. It is obvious that there is a need for model development in that field. Note, however, that the model by Jensen is not included in Macharis and Bontekoning's review.

The main aim of this research is to build a model that can be used as decision support to determine the potential of combined transport and suggest a suitable combined transport system design for the Swedish system for combined transport, or a subset of this system, on an overall strategic level. The tool should be able to determine the modal split between all-road transport and combined transport that minimises the resource consumption and, at the same time, determine the system design of the combined transport system. Delivery times should also be considered so that combined transport can match the delivery times by all-road transport.

[19] In the review defined as the user of intermodal infrastructure and services and responsible for the route selection for a shipment throughout the intermodal network.

System design refers to operating and infrastructure variables such as train time tables, train length, lorry types, terminal capacities, collection and distribution areas, etc. Potential refers to the reduced resource consumption, if any, from using combined transport compared to traditional all-road transport. Resource consumption should be measured as business economic cost and social cost. When determining the potential, it should be possible to choose if business economic or societal costs should be used. The environmental effects of the transport system should also be calculated.

A sub-aim is to test the developed decision support tool on the current Swedish transport system and determine the system design and potential of combined transport. The purpose of the sub-aim is also to demonstrate the developed model.

Although the model is being built to model the Swedish transport system, a second sub-aim is to make the model flexible and user friendly to be able to, if possible, use it to examine other related areas, e.g. other countries, future transport scenarios, different transport system sizes, general intermodal transport, etc. The main focus is, however, on the current Swedish transport system.

The main contribution of this research is the development of the model. The model can be used for further studies on combined transport systems, both within the current thematic research project and in other research projects and in political decision processes and business analyses. A second contribution is to determine the potential for combined transport in the current Swedish transport system. A general contribution is also to expand the knowledge of combined transport and to provide decision support information, primarily from a strategic perspective, on how to build a competitive combined transport system, which is of greatest interest to national policy makers, politicians and the large transport companies.

2.1 Intended Model Characteristics and Model Use

The model is intended to be a user friendly model that can run on an ordinary desktop PC. An input data set, for which the potential of combined transport is to be determined is created and input to the model. The data set is the input data to the model and will consist of all prerequisites for the transport system, e.g. transport demand, costs, emissions, infrastructure, equipment etc. The model user will choose if the model should try to create a suitable transport system design by minimising business economic costs or social costs. Note that the output from the model should not be regarded as a given answer to how to design the combined transport system. The model should be used in conjunction with other data sources to allow the decision maker to reach the best solution. Sometimes, changes in the scenario can be required to reach the combined transport system's full potential, e.g. by "building" a new terminal in the data set. An analytical analysis of the output data will be used to finally decide the suitable system design. After the model run, the results will be analysed analytically and it will be decide which, if any, parts of the suggested transport system that should be adjusted to reach a better solution and if any adjustments to the input data set should be made. After the adjustments, the model will be re-run with the adjusted input data. This will be repeated until the model user is satisfied with the results. It is also appropriate to carry out a sensitivity analysis of the suggested system, i.e. to see how sensitive the model is to changes or deviations in the input data set. This can be accomplished by adjusting the data set and re-running the model.

It is important to conceptually separate the actual model from the input data sets used in the model. The model is a general tool that is input with a data set. Different data sets can be used in the model. The model represents the modelling technology used, or simply put, the "calculations". See chapter 7. The data set is the input data calculated, e.g. a representation of the current Swedish transport system. See chapter 9 for an example of an input data set. By combining the general model with different data sets and control parameters, it becomes possible to conduct a large number of analyses[20]. The output shows the performance of the system in the form of costs, delivery times etc., and also the characteristics of the system in the form of modal split, train lengths etc. From the output from each data set run in the model, analysis can be made to determine the market area for a terminal, need for additional combined transport terminals or superfluous terminals, geographical areas where combined transport has a strong potential, capacity bottlenecks etc. It is also possible to test different scenarios and parameters setting such as effects of changed taxes, effects of allowing larger lorries, increasing train speeds, allowing longer trains, congestion (i.e. reduced speed), standardising of the type of ITUs used, market entry of foreign low-cost road hauliers, new infrastructure investments, changes in infrastructure fees, changed cost structure (fuel prices, salaries, etc.), changed time

[20] Note that the intention is not to conduct all these analyses in this thesis.

requirements (e.g. later deliveries allowed by combined transport), effects of different cost estimations (e.g. the valuation of environmental effects), etc. See Figure 5. The model can thus be used as a very versatile tool in analysing intermodal transport systems.

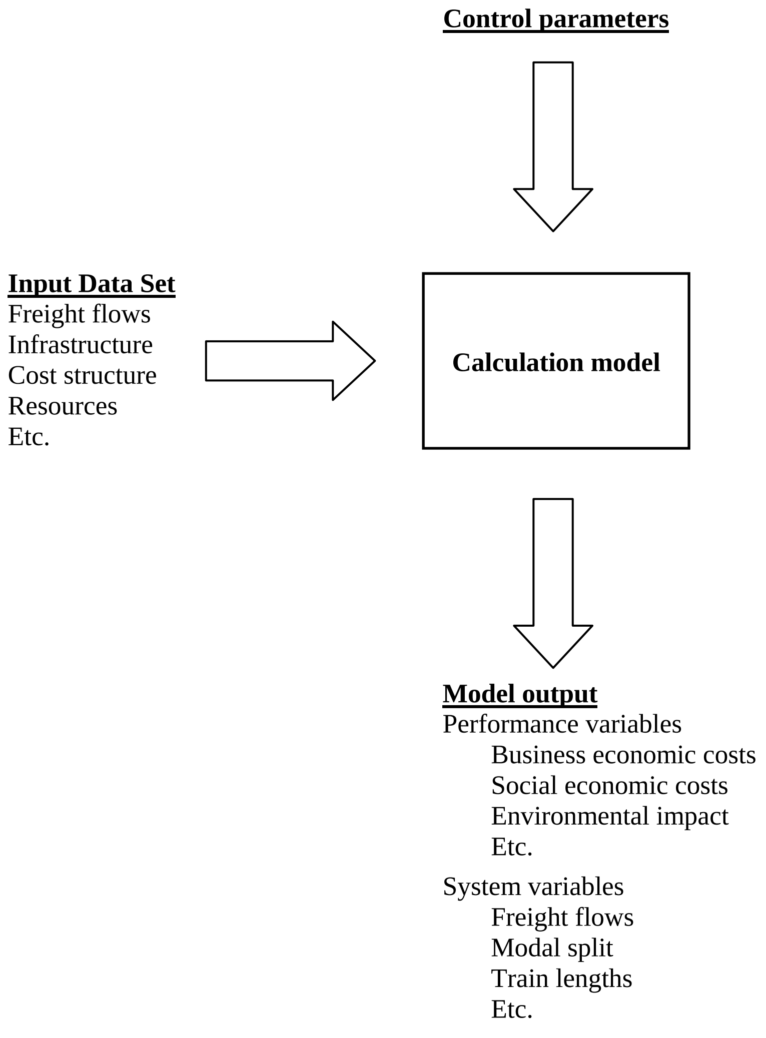

Figure 5 Model overview

2.2 Overall Delimitations

The intention of the tool is to find the potential of the combined transport system and the main design principles, and not to predict its development. Focus is thus on the performance of the physical transport system and not on the behaviour of individual actors. The model is intended to be used as a decision support model, which, as the name implies, is intended to support decisions in a strategic setting and not to explicitly make the decisions.

The aspect of actually implementing the suggested transport system and determining how much of the potential that actually will be reached is a very interesting research area. However, it is not within the scope of this research. It is of particular importance to note that it is the potential of combined transport that is sought after here, and that this potential will differ from what can practically be achieved in a real world transport system in a free market. Included in the thematic research project, of which this research is a part (see chapter 1), are several projects with a focus on system implementation and marketing. At the School of Business, Economics and Law at Göteborg University, Bernt Saxin is working on transport quality and implementation issues of combined transport and Catrin Lammgård has recently finished her doctoral thesis (Lammgård, 2007) on the use of environmental arguments in marketing of combined transport and the modal choice for combined transport[21].

Further, the intention is that the results of the project could be used as decision support for the development of the combined transport system in Sweden. The level of detail sought after in the results is therefore on a level-of-detail suitable for long term decision making, i.e. strategy development, considering the uncertainty involved in data collection and predictions of the future. Note, however, that the research and modelling will consider data on a more detailed level as a necessary step during the research process, but that the output should not be analysed at that level of detail. For instance, the output from the model might imply the need for a train departure at exactly 4 p.m., but the result should only be interpreted as the need for a train departure sometime in the afternoon. As in all modelling, it is important to underline that even if a model might output detailed figures, this does not necessarily imply that the figures are valid to the last decimal. All results

[21] She found that environmental arguments are most efficient against large manufacturing companies, but also efficient against medium manufacturing companies and large wholesale companies. See Lammgård (2007).

must be interpreted while considering the assumptions made in the modelling and the quality of the input data. The detailed data output should only be used as an intermediary step in the analysis.

It is also assumed that there are only two modes of transport available: Road transport only (the traditional trucking system) or combined transport between road and rail. Transport by other modes such as direct rail, sea and air will not be included. Road transport and combined transport share common characteristics that make them fairly interchangeable. Since the physical restrictions of the goods are determined by the lorry, one can, in general, assume that anything that can be transported by an ordinary lorry can also be transported by combined transport. For the end customers (shippers/receivers) the goods will be picked up and delivered by a lorry in both systems and, therefore, no adaptation or change in behaviour on their part is required. Throughput time can, also, in a properly designed system, be matched by both systems. Direct rail and sea are two modes that require special infrastructure at the sending and receiving ends (ports and rail sidings), thus limiting the number of possible transports. They are also modes that have a low unit cost for transport compared with road- and combined transport. It is, therefore, not likely that there would be any significant change of transport volumes from sea/rail to road/combined transport. The focus will be on the system for combined transport between road and rail. Since the focus is on combined transport, only the parts of the traditional road transport system that are relevant in a comparison with the combined transport system will be taken into account. The road transport system is considered to be given, following the well known transport times, system designs and costs of the existing system.

This thesis will not try to develop any new technical or mechanical solutions for combined transport, such as rail car designs or transhipment techniques.

3 Modelling methodology

A model is a tool to handle problems. A model is created in response to a problem and is closely connected to the problem it is created to solve (Hägg and Wiedersheim-Paul, 1994). It is a representation of reality and as such it is not an exact representation of reality but a simplification. When creating these simplifications it is important to find the core of the reality being modelled, thus, not to include superfluous parts or to exclude important parts of the reality, with respect to the problem being studied. Unfortunately, in contrast to the natural sciences, the social sciences like logistics, hold no fixed, independent, representation of reality. The problem, and system studied, can, thus, be viewed differently by different actors. Therefore, there is no universally true way to model a problem. Each problem can have several possible models. The connections can be illustrated in Figure 6.

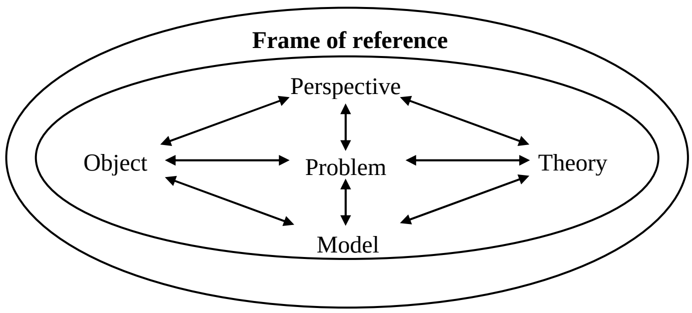

Figure 6 Frame of reference in modelling
(Hägg and Wiedersheim-Paul, 1994, p. 12)

The object represents what is being modelled, the perspective is the researcher's view of the problem and theory is the theoretical framework, or paradigm, of the object studied. A model can also be viewed as normative case study representing a subset of reality on which reality can be examined (Jensen, 2007).

Most traditional methods for model development, e.g. Ackoff (1972), Ackoff, et al. (1962), Banks, et al. (2001), Carter and Williamson (1996), Hägg and Wiedersheim-Paul (1994) and Savén (1988), view model development as a linear process, although everyone agrees that the process, in reality, is not a linear one (Hägg and Wiedersheim-Paul, 1994, Pidd, 1999). Today, however, a common view of the modelling process is that of a learning process where the modeller can go back and learn from his mistakes. The focus of all methodologies is to first understanding the system being modelled and its boundaries, problems and characteristics. From this, suitable system demarcations and delimitations are determined, considering the purpose of the modelling.

In particular, a large amount of work has been done on the development of computer software systems and decision support models/systems. There are no general definition of a decision support system (DSS), but a classical definition is given by Keen and Morton (1978):

> *Decision support systems couple the intellectual resources of individuals with the capabilities of the computer to improve the quality of decisions. It is a computer-based support system for management decision makers who deal with semistructured-problems.*

These systems can vary greatly in size, design and focus. However, they are all intended to support various management decisions. It is important to note that the purpose of a DSS is, as its name indicates, to support decisions and not to make them. The final decision must be up to the manager, although the DSS will facilitate for the manager to make a well founded decision. Due to the lack of a single definition and the wide scope of DSS, the term DSS might be a source of confusion. A number of different classifications have been suggested (see Turban and Aronson (2001) for an overview). Most DSSs are, however, focused on operational or tactical decision-making. The current strategic decision support model being developed in this project is, as previously mentioned, intended for strategic decision support and can, therefore, be regarded as a specific type of DSS.

Several methodologies for developing decision support systems exist, see e.g. Keen and Morton (1978) and Turban and Aronson (2001). The methodologies are designed to be used by external consultants for a company or organisation and, therefore, have a rather hands-on focus with step-by-step design and checklists, etc. However, the common focus of all methodologies is to understand the system being modelled and its boundaries, problems and characteristics, as in the traditional modelling methodologies. Most DSS-methodologies are also heavily influenced by the systems thinking theory, since almost all computer software development today are made according to the closely related object-oriented methodology[22], which has its foundation in the soft systems methodology (Rose, 2002). The use of systems thinking in model development can, today, be considered a standard method for the development of computer-based models. Systems thinking will, therefore, be used to develop the framework for the computer model.

Although the focus in the current model is on the physical flows, it also models a competitive situation between traditional road transport and combined transport. As stated previously, the model is not intended to model the actual competition in the market, since the focus is on the potential in the market. However, it is important to be aware of the market structure of the system to properly model its potential. A more market oriented theory will, therefore, also be used to supplement the systems thinking in understanding the market structure of the system. The obvious choice is to look at the different channel theories, due to the combined transport industries channel structure. Particularly, marketing channels theory is suitable to understand the market structure.

Systems thinking and marketing channels will, therefore, be used together to explore the current system and the general transport market in Sweden. From this, the system demarcations for the modelling will be selected. Special consideration will be given to the fact that the model is a long-term strategic model and, therefore, should be flexible to potential changes in the transport market.

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[22] The extensive object-oriented methodology is based on the principle that the system is divided into objects, each carrying certain attributes and abilities/functions and information about the status of the object. These objects are then linked together in relationships to form the greater system. See e.g. Booch (1994), Coad and Yourdon (1991), Mathiassen, et al. (1998), Rumbaugh (1991) and Brown (1997). The object-oriented principles have also been extended into a pure modeling language for modeling of logistics systems (Arnäs, 2001, Arnäs, 2003, Arnäs, 2007, Flodén, 2002a, Ohnell, 2004).

3.1 Systems Thinking

The fundamental of systems thinking is the system (Checkland, 1999, p. 13):

> *the existence at certain levels of complexity of properties which are emergent at that level, and which cannot be reduced in explanation to lower levels, is an illustration of an alternative paradigm – that of 'systems'. The systems paradigm is concerned with wholes and their properties.*

Arbnor and Bjerke (1994, pp. 166-167) state that the ambition of systems thinking is

- To classify (the system)
- To describe
- To determine the connections
- To predict
- To guide

As can be seen from the aims of this thesis, these ambitions fit very well with the aims of the model being developed. Systems thinking also implies that there are no universally true models, but that all models are dependent on the modeller (Arbnor and Bjerke, 1994).

Systems thinking is also closely related to operations research (Pidd, 1979, Woolley and Pidd, 1981), distribution channel theory and management research, which together constitute the fundamentals of logistics (Jahre and Persson, 2005).

Several versions of systems theory have been suggested. A methodology often used in logistics and transport research is the soft systems methodology by Checkland (e.g. Woxenius (1994), Waidringer (2001) and Holweg (2001)). This is also supported by Bechtel and Jayaram (1997) who, in a literature review, consider soft system methodology to be a promising new area for analysing the processes in a supply chain. As mentioned above, the methodology, or variations of it, is also commonly used in computer software development. It originates in the systems engineering methodology (Jenkins, 1976), which, by some authors, is considered to be the same as the classical operations research, but with a greater focus on the future prospects of the system (Flood and Carson, 1993). The methodology takes a more open view on the system than traditional systems theory and, also, it includes the individual in the system and not only the technical system, which is particularly important in systems where the goals are unclear and varying between the actors. For a more detailed description, see Checkland (1999) or Checkland (1988). Rose (1997) also gives an elaborate account of soft systems methodology's position in the theory of science, particularly social science. The methodology is based on seven steps, see Figure 7, of which the first four steps are relevant for the understanding of the combined transport system.

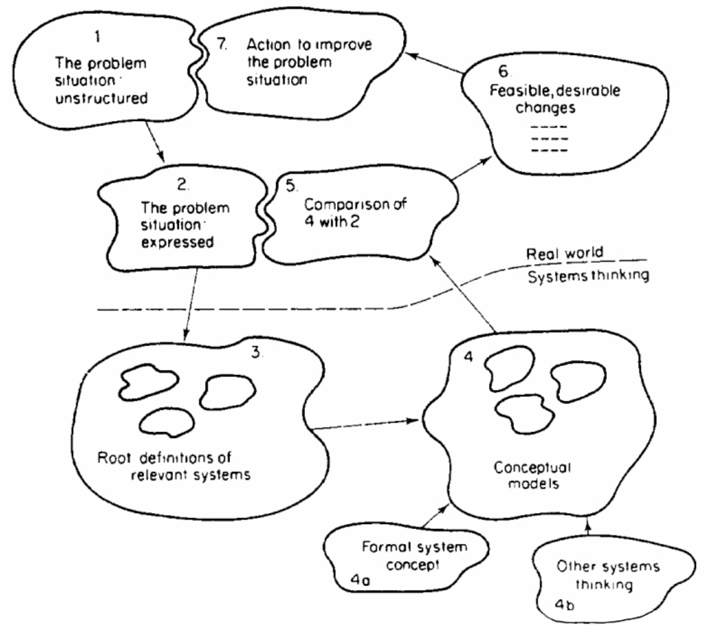

Figure 7 The seven steps of the soft system methodology (Checkland, 1999, p.163)

The first two steps are concerned with creating the richest possible picture of the situation being studied. This is then followed by defining the root definition of the system studied from which a conceptual model of the system is developed. The conceptual model is "an account of the activities which the system must do in order to be the system named in the definition"

(Checkland, 1999, p. 169) illustrated on paper[23]. In the following steps, the conceptual model is validated and action is taken to determine appropriate changes to the system to solve the problem or to design the software system. It is particularly in these last steps that the soft systems methodologies used for software development deviate from the original methodology with a greater focus on computer programming techniques.

Soft system methodology is particularly intended for modelling “soft” human systems with soft ill-structured problems of the real world, where it can be difficult to set the exact objectives. The computer model being developed in this research is a mix between traditional operations research models, e.g. optimisation of a physical logistics system, and the soft human activities of the modal choice. To build a detailed model of all individual actors in the transport system is, for obvious reasons, impossible. However, to completely disregard the fact that the modal choice is a human activity is to oversimplify the model. The first four steps of the soft systems methodology will, therefore, be used to understand the system with the intention to determine a more physical conceptual model that can be implemented in a computer system and still be able to answer the research question. The conceptual model will, therefore, have a physical focus, and later it will be followed by more traditional computer modelling technologies.

3.2 Marketing Channels

A number of different channel concepts, such as logistics channels, distribution channels, marketing channels and supply chains, are used in logistics. There is no uniform definition of the concepts and they share a lot of common ideas and the concepts are commonly mixed and confused. However, the logistics and transport channels focus more on the physical transport, while distribution and marketing channels include the full concept of creating time, place and possession utility (including the physical transport). See Figure 8 for an example. In combined transport research a similar division into a logistical channel and a transaction channel was used by Jensen (1990). Yet a more integrated concept is that of supply chain management, which integrates key business processes throughout the chain.

[23] Note that the conceptual model in soft systems thinking is not a computer model, but a drawing on paper of the different activities and the way they are connected. Figure 7 could, for example, be considered a conceptual model of the soft systems methodology.

The focus in this research will be on the marketing channel concept with the aid of the logistics channel concept to understand the physical flows. The supply chain management concept is a too management oriented concept to be appropriate for the current modelling and the logistics channel concepts is to narrow. The concepts will be used when creating the conceptual model in chapter 4.

The combined transport system will, therefore, be studied both from a physical logistics channel perspective and from a marketing channels perspective. Marketing channels are a well known framework for understanding the process of how a product or service is made available for consumption. Due to the combined transport industries' obvious channel structure, a channel perspective is a suitable framework to increase the understanding of the industry. The framework includes an integrated view of the entire process of making the product available for consumption, e.g. channel management, financing, marketing, etc. However, considering the aim of the current model, the wide marketing channels concept will be narrowed down and focus laid on the actual structure of the channel today. The focus will mainly be on the sub-flows for production (i.e. the transport service) and marketing and the channel management, specifically power.

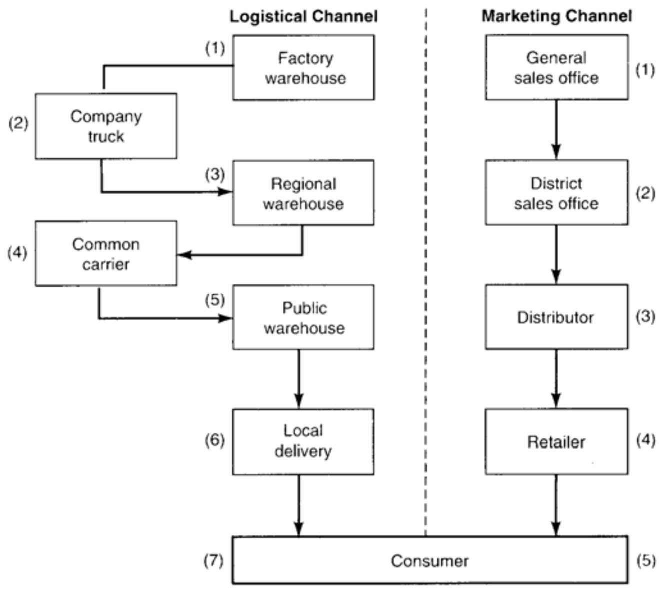

Figure 8 Logistics and marketing channels (Bowersox, et al., 1986, p. 91)

Marketing channels can be defined as (Stern and El-Ansary, 1992, p. 1):

> *sets of interdependent organizations involved in the process of making a product or service available for use or consumption*

Marketing channels include not only how the product is brought to the market, but also the creation of a competitive advantage for the channel and stimulation of demand through cooperation and marketing. The channel consists of a number of intermediaries between producer and consumer that facilitate the exchange of products. The reasons for an actor to want to be a part of a marketing channel are, among others, the functional performance (e.g. need for transport), reduce complexity (e.g. routinization of exchange) and specialisation (e.g. acquiring/exploiting skills) (Bowersox and Cooper, 1992). Stern and El-Ansary (1992, p. 4) list four steps to explain the use of channel intermediaries:

1. Intermediaries arise in the process of exchange because they can improve the efficiency of the process
2. Channel intermediaries arise to adjust the discrepancy of assortments through the performance of the sorting process
3. Marketing agencies hang together in channel arrangements to provide for the optimisation of transactions
4. Channels facilitate the searching process

The structure of individual marketing channels might differ greatly. The channels might be of different length, have different channel leaders, different levels of cooperation, different rules guiding the channel, etc. Bowersox and Cooper (1992) make a division of different channels depending on the level of dependency in the relationships. See Figure 9.

The structure ranges from simple single purchase-channels to whole channels owned by a single company. The channel types are divided into transactions and relational vertical marketing. Transactional channels are more open channels without any deeper integration. Relational vertical channels have a greater level of integration and formalisation on a more long-term focus.

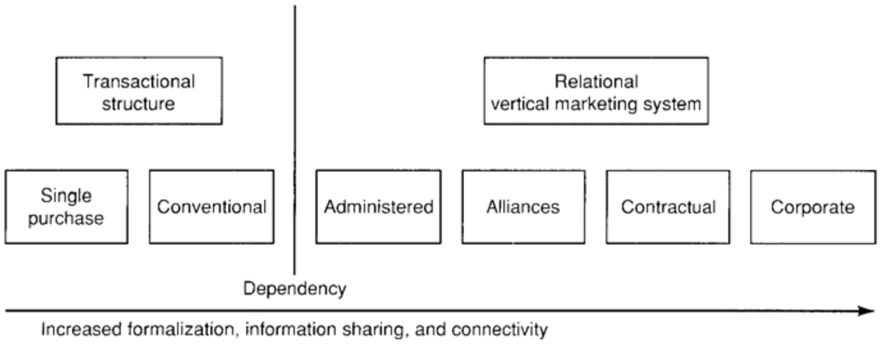

Figure 9 Classification of channel relationships (Bowersox and Cooper, 1992, p. 102)

Each marketing channel consists of a number of flows. A flow is a set of functions performed in sequence by the channel members (Stern and El-Ansary, 1992). See Figure 10. A marketing channel can, thus, also be viewed as a number of sub-channels for different flows and functions.

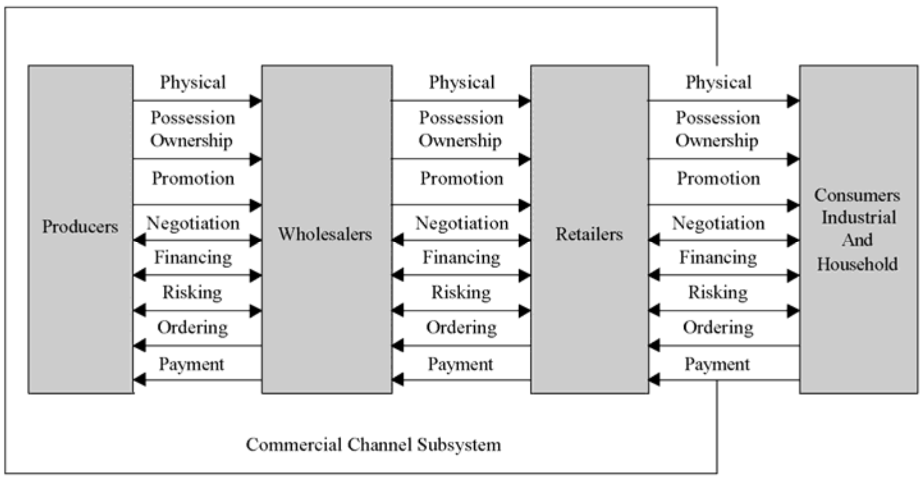

Figure 10 Flows in channels (Stern and El-Ansary, 1992, p. 12)

The actors participating in the channel fall into two categories: primary participants and specialized participants (Bowersox and Cooper, 1992). Primary participants are the main actors in the channel. They are "business that acknowledge their dependence upon one another in a channel arrangement and assume risk during their value-adding distribution process" (Bowersox and Cooper, 1992, p. 28), e.g. manufacturers, wholesalers and retailers. Specialized participants are facilitators to the primary participants. These participants have previously been regarded as passive supporters (often called supporting members, see e.g. Lambert, Cooper and Pagh (1998)), but have increasingly taken on a greater responsibility and risk sharing and are also capable of channel leadership. Specialized participants fall into two categories: Functional specialists and support specialists. Functional specialists provide specialist involvement in the "hands-on" channel activities, e.g. transport and warehousing. Support specialists provide support services, e.g. financing and insurance.

Each channel normally has a channel leader, which is the channel member with the greatest power to control and direct the channel. The channel leader uses his power to coordinate the channel and to prevent independent channel members to operate only according to their own self-interest. Power is, thus, commonly defined as the ability of one channel member to make another channel member do what he otherwise would not do (see e.g. Stern and El-Ansary (1992), El-Ansary and Stern (1972) Bowersox and Closs (1996), Jensen (1993) and Wilkinson (1973)). The origins of power are multiple, but commonly mentioned factors are the level of dependence between members (El-Ansary and Stern, 1972, Wilkinson, 1973), ability to reward and punish (Stern and El-Ansary, 1992), expertise (Stern and El-Ansary, 1992) and customer contact (Jensen, 1990, Lambert, et al., 1998).

Often, there are subgroups of different actors in the channels. These subgroups, or sub-channels, are collections of actors that are more strongly connected to each other and have stronger connections and influence on each other. Subgroups can occur for any number of reasons, e.g. geographical proximity, handling of a certain brand or product type, similar functions, close competitors. See for example Wilkinson (1973) or Jensen (1993).

The channel also exists as a part of the surrounding environment, which constantly affects and influences the channel. Each individual actor in a channel might be a member of several marketing channels, and also have a choice on leaving a channel or trying to enter another channel. This interdependence between the channel members also shows that the channel members are interdependent of each other to achieve their goals. However, the output of the channel that reaches the final customer is what ultimately determines the channel's competitive power. Normally, a customer is less interested in the actual channel that brought him the product but focuses on the end product. This service level output is what determines a channels viability in the long run. The real competition in the market place is, therefore, not between individual actors, e.g. between two producers, but between entire channels (Christopher, 1992, Stern and El-Ansary, 1992). See also Porter’s classical value chain theory (Porter, 1985).

The channel theory described above has its basis in the physical transfer of products from producer to consumer. However, a combined transport channel is a service channel rather than a physical channel, since transport is a service. There is a debate on whether service channels are radically different from physical product channels or not (Järvinen, 1998). However, service channels are commonly considered to be shorter with fewer intermediaries and have more direct sales, as it is difficult to distribute services. Logistics services (as a function) are commonly not included in a service marketing channel (Bowersox and Cooper, 1992, Järvinen, 1998, Stern and El-Ansary, 1992).

3.3 Modelling Technologies

Goods transport models can vary greatly in size and technology depending on the purpose of the models. Due to the obvious geographical connection to transport modelling, many transport models are encapsulated in a GIS-like map interface with connections to databases for input and output data. Behind the graphical interface, there are three main approaches to goods transport modelling: simulation, optimisation and network modelling (D'Este, 2001), although combinations do exist and the boundaries are not well defined.

3.3.1 Optimisation

Optimisation is a process in which an attempt is made to find the optimal solution to a problem. Optimisation in real-world industry problems is often referred to as operations research (D'Este, 2001). In reality, the word optimisation should not be interpreted as referring to the real optimal solution, but rather a satisfactory solution to the problem. Since optimisations are based around a model of the problem, and all models contain simplifications and assumptions, the real world optimal solution is not reached. Not even the mathematical model itself might always be solved completely. For smaller problems, it might be possible to find an optimal solution to the mathematical optimisation model, but this is seldom the case in the more complex real-world models, where only a satisfactory solution can be reached, mainly because of mathematical difficulties. Optimisation is best suited for complex large-scale strategic problems as the models generally cannot be made very detailed.

In classical mathematical optimisation (see for example Nash and Sofer (1996)) the system is described as mathematical functions. The properties that you wish to maximise or minimise, e.g. cost or environmental effects, are described in a mathematical function, called the objective function. Further mathematical functions are added to describe the constraints in the system, e.g. that the goods should be delivered on time. To formulate an optimisation model, three questions are required (D'Este, 2001, p. 525).

1. What is the desired outcome (objective)?
2. What aspects of the system can be controlled or varied (decision variables)?
3. What limits are there on what can be done (constraints)?

The optimisation, then, tries to find the maximum (or minimum) value of the objective function without violating any of the constraints. Advanced mathematical theory ensures that the real mathematical optimum has been reached. The calculations required to solve the optimisation might be very complicated and, thus, take a very long time. The strength of using optimisation is, of course, that, if properly used, it gives the real optimal design. However, since optimisation is a strictly mathematical operation, it only takes into consideration what is included in the objective function and its restrictions. A difficulty is to express the level of detail present in the real world as a mathematical function. In a complex system such as a national transport system, there are literally thousands of variables affecting the system and its performance. Naturally, these cannot all be included in the function, since they are difficult to quantify and to identify. If one would try, the model would also probably prove too complex to solve. In complex transport optimisation models, solving the model is often considered the most difficult task and much mathematic research has been done in developing solution methods for different types of transport optimisation problems. For a review of different models and solution methods in freight transportation optimisation, see Crainic and Laporte (1997), Crainic (1998), Cordeau, Toth and Vigo (1998), Ball et. al. (1995a, 1995b) and Magnanti and Wong (1984).

Closely related to the traditional optimisation methods are the heuristics methods. In fact, most advanced optimisation models use some kind of heuristics to make the model solvable. The heuristic solutions are based on "smart guesses". They work by using rules of thumb until a satisfying solution is reached. All alternatives and solutions are not examined, but the method "guesses" that certain potential solutions are not relevant to examine further. In a heuristic solution, there is no guarantee to find the optimal solution, but instead it is possible to gain a lot in speed, since heuristic solutions normally are relatively fast. Heuristic methods, also, generally make it possible to solve more complex problems. Reeves and Beasely define heuristics as (Reeves, 1993, p. 6):

> *A technique which seeks good (i.e. near optimal) solutions at a reasonable computational cost without being able to guarantee either feasibility or optimality, or even in many cases to state how close to optimality a particular feasible solution is.*

An example of a simple heuristics is to solve the travelling salesman problem[24] by always going to the nearest customer that has not been visited. More advanced heuristics are used to solve the mathematical optimisation problems, as described above. However, by using a heuristic solution procedure it is also possible to build a model without any defined mathematical objective function or delimitations. In the travelling salesman heuristics described above, the objective of the model is only expressed indirectly through the design of the heuristic rule of thumb. Assumptions like that simplify the problem, but the risk is simplifying the problem so much that it no longer represents reality or letting preconceptions of the problem guide the design of the rule of thumb to a too large extent.

3.3.2 Simulation

In a simulation, a, normally graphical, model of the system is being designed, where the appropriate causal links and costs are included. The

[24] The travelling salesman-problem is a classical optimisation problem where a travelling salesman is going to visit a number of customers, while trying to keep the total travelled distance as short as possible. All customers have to be visited once, and only once, and the problem is to determine the best order to visit them.

model is intended to mimic the behaviour of the real-world system. The intention is that the model shall react to change and other types of input in the same way as the real system would. Simulation is defined as (Banks, 1998, p. 4):

> *Simulation is the imitation of the operation of a real-world process or system over time. Simulation involves the generation of an artificial history of the system and the observation of that artificial history to draw inferences concerning the operating characteristics of the real system that is represented.*

A simulation does not optimise the system, but only tests its performance with the given input parameters. The inputs are often combined with random distribution of the performance of the system components, e.g. delays. The model is, then, re-run several times to get different random data thus showing the dynamics under different situations, e.g. when random delay occurs at two locations at the same time. The models are often made more detailed to properly model the system. Simulation models are often used to answer "what-if" questions, particularly in complex and dynamic systems. Several benefits may be expected from using simulation (Pegden, et al., 1995, p. 9):

- New policies, operating procedures, decision rules, organizational structures, information flows, etc. can be explored without disrupting ongoing operations.
- New hardware designs, physical layouts, software programs, transportation systems, etc. can be tested before committing resources to their acquisition and/or implementation.
- Hypotheses about how or why certain phenomena occur can be tested for feasibility.
- Time can be controlled: it can be compressed, expanded, etc., allowing us to speed up or slow down a phenomenon for study.
- Insight can be gained about which variables are most important to performance and how these variables interact.
- Bottlenecks in material, information, and product flow can be identified.
- A simulation study can prove invaluable to understanding how the system really operates as opposed to how everyone thinks it operates.

- New situations, about which we have limited knowledge and experience, can be manipulated in order to prepare for theoretical future events. Simulation's great strength lies in its ability to let us explore "what if" questions.

However, there are also drawbacks of using simulation (Banks, 1998, Pegden, et al., 1995):

- Model building requires specialized training. The quality of the analysis depends on the quality of the model and the skill of the modeller. Model building is an art, and the skill of the practitioners varies widely.
- Simulation results may be difficult to interpret. Since most simulation models use randomly affected inputs, it is often difficult to determine whether a result is caused by a significant relationship in the system or the randomness built into the model.
- Simulation modelling can be time consuming and expensive.
- Simulation may be used inappropriately, in cases when an analytical solution is preferable.

Simulations can basically be divided into two groups, discrete and continuous simulations (Banks, 1998). A discrete simulation, which is the most common type, is focused on the entities, e.g. a customer or lorry, in the simulation and when they change state, i.e. something happens to them. Simulations do not have any continuously running clock, but advance stepwise between the different events that cause a change in an entity. A continuous simulation has a continuously running clock and simulates every moment, even if no activity occurs. The choice of simulation type depends on the aspects being modelled in the system (Banks, et al., 2001). A transport system can be viewed as a discrete system where the entities change state at distinct moments in time, e.g. departure from a terminal. Although possible to model as a continuous system, e.g. continuously running vehicles, this approach is not very appropriate.

A large number of standard simulations software are available on the market. Most simulation software today are graphical simulators using icons and objects, combined with traditional computer programming, to create almost computer game like representations of the systems being modelled. These standard simulators can be adapted to a wide variety of problems.

3.3.3 Network Modelling

Network models represents the transport system as a set of nodes, e.g. a terminal, connected through a set of links, e.g. roads or goods transfers. Each type of transport mode and vehicle type is represented by its own link with individual characteristics. The links are connected by transfer links to represent allowed transfers, see Figure 11 from the NODUS software system.

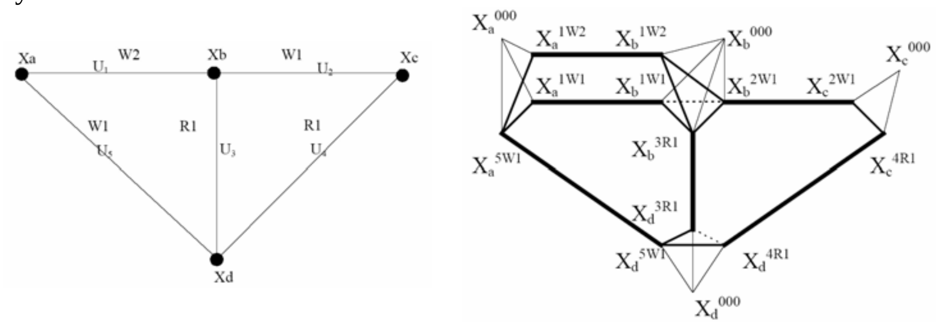

Figure 11 Simple real network and corresponding virtual network in the NODUS software (TERMINET, 2000, p. 93-94)

Each link and node is assigned certain characteristics, e.g. costs and delay functions. Similarly to the optimisation models, an objective function and constraints are constructed based on the network representation and the optimisation is solved. Network models are best suited for strategic planning of transport systems. For further description and examples of network models see Guélat, Florian and Crainic (1990), Jourquin and Beuthe (1996), Crainic and Laporte (1997) and Crainic (1998).

3.4 Data Sources

It is important to consider the data availability when developing a model. Naturally, it is of no use to develop a model just to find that there is no data of satisfactory quality to input in the model. Data sources can be of two well known main types, primary data sources and secondary data sources. As there are several good secondary data sources available, and the main purpose of this thesis is the model development and not collection of primary data, mainly secondary data sources will be used. However, some primary data will also be collected in a large survey.

3.4.1 The Survey Goods Transports in the Swedish Industry

A survey of the transport purchasers in the Swedish manufacturing and wholesale industry was carried out together with PhD candidates Bernt Saxin and Catrin Lammgård as a part of the overall thematic research project (see chapter 1). The joint survey, *Goods Transports in the Swedish Industry,* covered the transport pattern of the transports, including goods volumes, transport destinations, modes of transport, transport contracts, decision-makers, etc. The survey also covered how the transport buyers evaluate different aspects of logistic services (such as delivery time, price etc) and environmental issues and the current status of the services. The main interest in the survey for the current modelling project was to collect transport flow data and get a general overview of the needs and demand for the Swedish transport industry. The purpose of doing a joint survey was to make it possible to mobilise the resources necessary for undertaking a high quality survey and enable statistical analysis to establish relationships between the different parts of the survey. The main work on the survey was done by Bernt Saxin and Catrin Lammgård, who had the most questions in the survey.

The survey was conducted in 2003 and focused on outbound goods transports in the Swedish manufacturing and wholesale industry. The target population was Swedish manufacturing and wholesale companies with outgoing goods transport exceeding 150 kilometres stratified into six groups. See Table 2. The survey was very extensive and contained 30 main questions, but when including sub-questions and attitudes towards various items, the total was 155 questions over 9 pages. It took about 25-60 minutes to answer the survey, depending on the statistics available. The survey was accompanied by a hand signed introduction letter from Professor Arne Jensen. The survey is available in Appendix 11 and Appendix 12 (the original Swedish survey and an English translation).

	Number of employees		
Industry type	**Small-size**	**Medium-size**	**Large-size**
Manufacturing	10-99	100-399	400-
Wholesale trade and commission trade	5-19	20-99	100-

Table 2 Stratification based on number of employees at local units and industry code

A telephone initiated survey method with double sampling was used. A random selection of 1 800 local units was requested from Statistics Sweden's (SCB) Business Register. The term local unit is not equal to company, since many companies have more than one local unit. A local unit is each address, building or group of buildings where the company carries out economic activity. This is a more appropriate selection when looking at geographically distributed transport, than just selecting the head office of a company. As the business register does not contain information on transports, the sample received from Statistics Sweden also included local units that were not in our target population, i.e. did not have transports exceeding 150 kilometres. To determine which of the 1 800 companies that were in our target population, all companies where contacted by telephone and asked whether they had transports exceeding 150 kilometres or not (including those that were not selected to answer the survey in the second sampling). In this way, we could determine exactly which elements in our sample that were in the target population. A random stratified sample from the initial sample provided by Statistics Sweden was made and these selected units were contacted and asked to answer our survey. The strata sizes for medium and large sized manufacturing local units, and large sized wholesale local units, were selected to include all local units of that size in Sweden. This was because most local units in those strata had a substantial amount of transports, and thus large influence on the transport system. In the remaining strata, about 85% of the local units were randomly selected. See Table 3.

	Total local units in Sweden	**Estimated total local units in Sweden in target population**	**Total initial sample from SCB**	**Number of local units in target population in SCB sample**	**Contacted in target population for survey**	**Number of responses**	**Final response rate**
Small manufacturing	3 503	2 244	345	221(64%)	183	58	32%
Small wholesale	6 711	3 385	345	174 (50%)	148	48	32%
Medium manufacturing	970	787	345	280 (81%)	279	183	66%
Medium wholesale	1 721	1 063	345	213 (62%)	192	55	29%
Large manufacturing	242	222	242	222 (92%)	221	131	59%
Large wholesale	178	131	178	131 (74%)	131	92	70%
Total	13 325	7 832	1 800	1 241	1 154	567	49%

Table 3 Sample sizes and response rates

Before the survey was sent out, all respondents were contacted by telephone. The main reason was to identify the correct respondent at the local unit, i.e. the person in charge of purchasing transports. The respondents could have different positions in different companies or even be located at a different company or a head office. The telephone call also helped to increase the response rate by establishing a personal connection with each respondent and securing a promise that they should answer the survey. Finally, the telephone call also gave useful background information of the transport situation and how the logistics function was organised within the local unit, as well as within the company. The telephone calls thus helped to increase the quality of the data, since it is certain that the surveys were answered by the right respondent and covering the selected local unit. The method proved to be very successful but also very time consuming. The method was particularly time consuming since it often required several phone calls to reach the right respondent. More information about the telephone initiated survey method used can be found in Lammgård, Saxin and Flodén (2004) and Lammgård (2007).

Three reminders were sent and the final response rate was 49%. However, looking only at large wholesale and large and medium manufacturing strata, the final response rate was 64%. These three groups of companies have the largest volumes of goods transported and it is, therefore, very important to get a high response rate from them. See also Figure 12. The response rate can be considered to be very high, as most similar surveys only reached a response rate of 20-25% (Lammgård, 2007).

Initial data from the survey was presented in Saxin, Lammgård and Flodén (2005) and further data will be presented in this thesis. More results from the survey have also been presented by Catrin Lammgård in her PhD thesis (Lammgård, 2007) and will be presented by Bernt Saxin in his forthcoming PhD thesis and articles. Results from the survey are also presented and used in this thesis[25].

[25] In sections 1.3, 4.1, 6.3, 6.8, 9.1, 9.2 and 9.3.

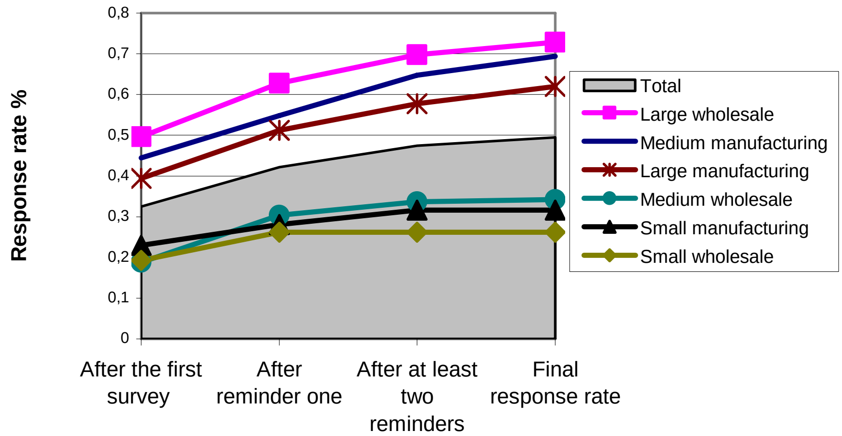

Figure 12 Total cumulative response rate divided per stratum

3.4.2 Secondary Data Sources

Several secondary data sources are available. The sources will be explains in more detail during development of the input data set in chapter 9 but also briefly be listed here. Transport flow data is available from the Swedish Institute for Transport and Communications Analysis[26] (SIKA) and from the forwarders themselves. Both the main forwarders and SIKA have agreed to share flow data with this project. Cost data is available from SIKA and previous research reports, mainly by Enarsson (1998, 2001, 2003). Environmental data is available from SIKA and the transport industry organisation the Network for Transport and Environment (NTM) but also from the national rail and road administrations. SIKA, NTM and the rail and road administrations make their data available on their homepages. Of course, the general data availability decreases the more detailed data that is requested. However, the model is mainly intended as a strategic model and

[26] SIKA is a government agency responsible for the national Swedish transport statistics and cost estimates for the national transport planning and infrastructure investment.

should thus be run at a fairly high level of aggregation and generalisation, at which data availability should not be any problem[27].

3.5 Principles of Model Validation

To validate a model is a complicated task. There are three parts of a model that needs to be validated. First, the underlying conceptual model of the system studied. Second, the translation of that model into a working computer model and, third, the actual computer model (Lehman, 1977). The validation of a computer model consists of three general steps: verification, validation and evaluation (Banks, et al., 2001, Gass, 1983, Lehman, 1977, Pegden, et al., 1995).

3.5.1 Verification

Verification concerns debugging of the computer program and establishing that the program runs “as intended” (Gass, 1983). The important question in verification is “does the program operate correctly?” and not “does this program adequately represent its model and produce output that resembles the real world?” (Lehman, 1977, p. 224).

3.5.2 Validation

Validation tests the agreement between the model and the real world being modelled, considering the assumptions and generalizations made in the model. However, validation is not a simple task. Normally, a comparison can be made between known data from the real world system and the output of the model. Unfortunately, this is not possible for the current model, since it focuses on the potential of the system and not to replicate the behaviour of the current system. These types of models that focus on the future and non-existent systems can never be completely validated, but only invalidated (Quade, 1980). The focus in the validation process must, therefore, be on trying to invalidate the model, i.e. prove it wrong. Quade states (1980, p. 34): ”When you have tried all the reasonable invalidation procedures you can think of, you will not have a valid model… You will, however, have a good understanding of the strength and weaknesses of the model… Knowing

[27] Note that the model can also be run on smaller system if data are available, e.g. for a transport operator with detailed data about their own transport operations.

the limits of the model's predictive capabilities will enable you to express proper confidence in the results obtained from it."

In the theory of science, the principle of invalidation is well known and best explained by Popper (2002). If your hypothesis is that all swans in the world are white, it is better to try to find one black swan than to determine the colour of all swans in the world.

The model should, therefore, be tested for reasonableness. Tests for continuity, consistency, degeneracy and absurd conditions (Pegden, et al., 1995) are first be carried out, followed by a major model behaviour test. Continuity checks that small changes in the input parameters result in equally small and appropriate changes in the output. Consistency checks that essentially similar model runs should produce essentially similar results. Degeneracy checks that, when certain features of the model are removed or unused, the model output should respond as if it was removed. The test for absurd conditions check that absurd conditions does not occur during the model run, e.g. negative number of trains. It also checks that absurd inputs return the appropriate output. These tests for reasonableness are closely related to the verification process of the model (Pegden, et al., 1995) and can be carried out as a part of the verification process.

3.5.3 Evaluation

Finally, a model evaluation must be performed to determine that the finished model meets the requirements set up for the model and that it is possible to run, e.g. computer requirements, input data availability, etc.

4 A Conceptual Model of the Combined Transport System

Looking at the description of the transport system in chapter 1, a root definition of the transport system studied can be given as “a system to deliver the transport service of combined transport to the transport customer”. Previous conceptual models of the transport system include models by Jensen (1990) and Woxenius (1994). Jensen divides the combined transport systems into administrative and physical systems. See Figure 13. A complex interdependence between the systems does exist. The physical boundaries are adjustable depending on how well the administrative system performs, and vice versa. A successful administrative system could, for example, create a demand for an extended rail network, new terminals, better rail cars, etc. On the other hand, a change in the physical system, e.g. a reduction in loading capacity, would affect the administrative system. Interdependences within the systems themselves also exist. A better designed timetable could, for example, attract new customers, which would force recourses to be moved to serve these new customers, resulting in a reduction in service and lost customers in other parts of the system.

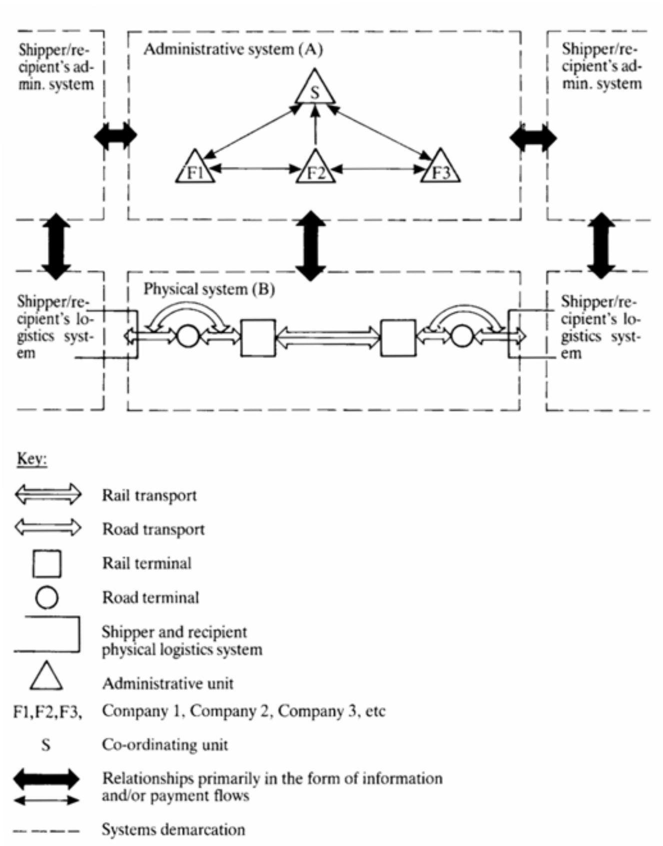

Figure 13 Jensen's general model of the combined transport system (Jensen, 1990, p. 43)

Systems thinking has been used by many researchers to study complex logistical and transport systems, for example by Waidringer (2001) and Woxenius (1994). Woxenius uses systems thinking from Churchman (1968) to construct a high level model of the European combined transport system. See Figure 14, below.

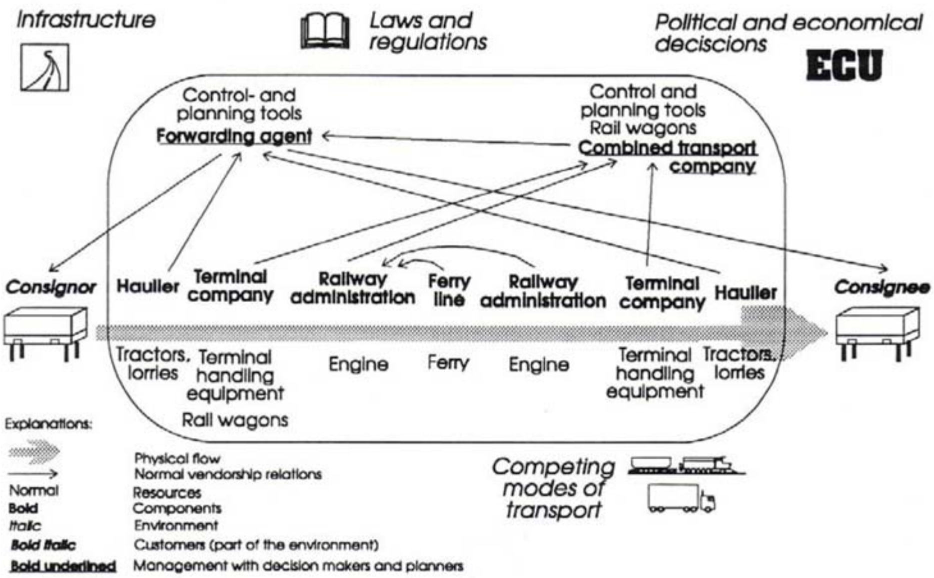

Figure 14 A systems model of the European system for combined transport (Woxenius, 1994, p. 58).

4.1 The Actors in the System

It is clear that the shaping of a combined transport system is a process influenced by many actors. When analysing a system like the combined transport system, it is important to determine which actors are central to the function of the channel. There are several different ways to describe the combined transport system. A simple description was given in the introduction in chapter 1.1. A number of actors can be identified from looking at this description, other models (e.g. Jensen (1990) and Woxenius (1994) described above), and the description of the industry in chapter 1.3. The actors can roughly be divided into four groups with regard to a given system.

- Influencing actors (actors trying to influence the system without any direct power)
  - e.g. lobby groups, media or competing transport modes
- Framework actors (actors setting the framework)
  - e.g. government or local authorities

- System actors (actors in the transport system)
    - e.g. terminal companies, forwarders, railway companies or road hauliers
- System output receivers
    - e.g. transport customers such as sender or receiver.

In many cases, however, an actor can be involved in several groups depending on the situation, e.g. a forwarder buying a transport service on behalf of a consigner. This is also dependent on the system boundaries of the system chosen to study, for example if the end receiver is included in the system studied or not.

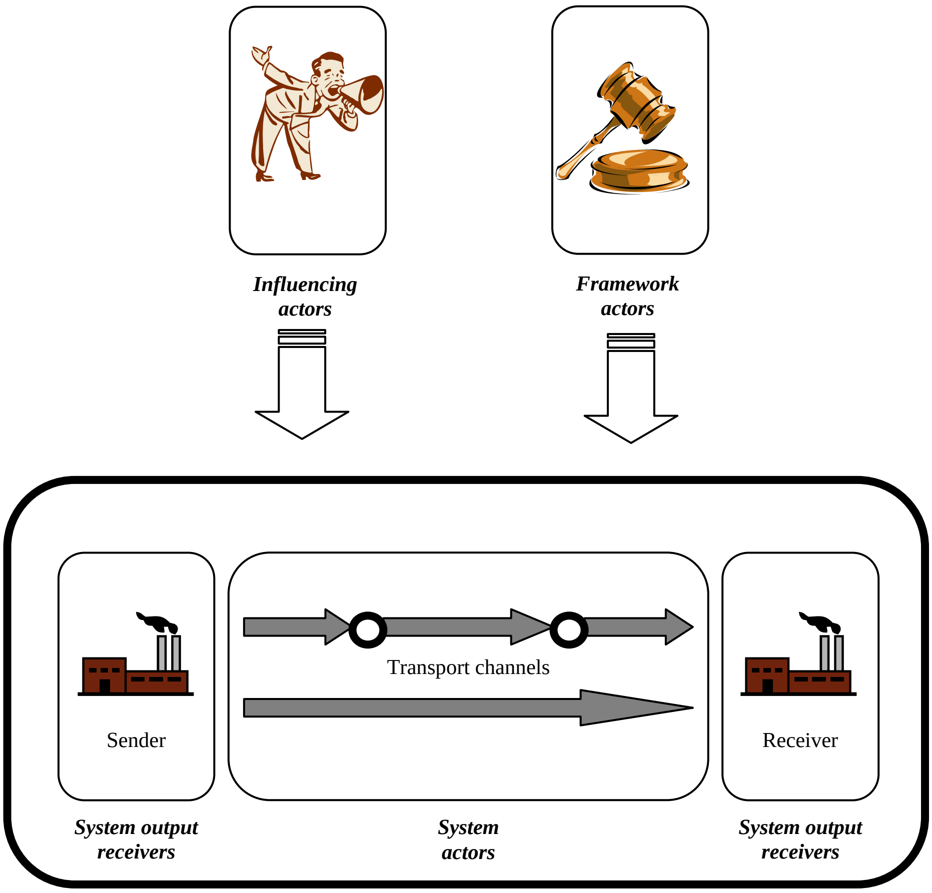

Figure 15 The actors

When looking at these actors, it is apparent that their goals in the channel will differ. The influencing actors, who try to influence the system in their direction, are the group with the most differing goals. This includes lobby groups or politicians with a wide range of goals and reasons to influence the transport system, such as environmental concerns or regional politics. Actors in this group may be anything from directly hostile towards the combined transport system to complete advocates for the system.

The framework actors, who set the framework for the transport system to work in, are a group with fairly uniform overall goals, but shifting tactics to reach them. This group includes all government agencies and authorities with a direct power to change the prerequisites of the system, for example rail and road administrations or the national legislative body. As this group is a part of the national administration, they can be assumed to have the national welfare and development as their prime concern, thus building an efficient transport system focusing on contributing to a socially, culturally, economically and ecologically sustainable development, as stated in the Swedish transport policy (Swedish government, 2006). However, as is well known, the notion of national welfare and the appropriate ways to get there differ greatly.

The system actors are the primary participants in the channel and have a more direct interest in the system. The companies will have an interest in the long-term survival of the system, for example by maintaining transport quality and meeting customer requirements. As they are commercial enterprises, they can be assumed to be required by their stockholders to maximise their profits like any other company. However, this does not automatically imply a short-term profit maximisation, but also include other factors to secure the long-term survival of the system. Members in this group also have a choice as to whether they want to be a part of the system or not. The combined transport system exists in competitive situation with other transport system, such as the traditional road system. A road haulier could, for example, decide to leave the combined transport system and enter the traditional road system, if the combined transport system does not meet his goals in a satisfactory way compared to other alternatives.

The system output receivers could, depending on the boundaries of the system studied, be anything from the end customer of the commodity transported to a local haulier making a pick-up at a terminal. As a group, the system output receivers are the most influential actors. As on any other market, the customers' requirements have to be met. Like all other actors, the system output receivers might leave the system, i.e. choose another mode of transport, if their goals are not met in a satisfactory way compared to other modes. A number of studies have been made on the criteria used by transport customers to select transport alternative. In most studies, on-time deliveries and price are rated as most important, see e.g. Ljungemyr (1995). However, for shippers working in a JIT-environment, frequency and flexibility emerge as important decision factors (Bolis and Maggi, 2002). Results from the survey Saxin, Lammgård and Flodén in this research program (see chapter 3.4.1), show that price, meeting delivery times, knowing how to handle the goods and being flexible are important factors.

Research shows that most shippers do not take any interest in the actual transport or modal choice of the shipment (e.g. Sjögren (1996)). Most are satisfied as long as their general requirements of delivery time, price, transport quality, etc. are met. Some, however, have more specific requirements, such as environmental requirements or preference for a specific operator. In general, the more goods they send, the higher their interest in the transport (Woxenius, 1994). The survey by Saxin, Lammgård and Flodén also shows that the end transport customer has little interest in the mode used for his transport. The transport customer mainly focuses on quality and price factors. The modal choice, therefore, mainly resides with the forwarder (or the forwarder's subcontractor[28]). This means that the forwarder's / transporter's criterion is used to select the transport mode and the transport customer's criterion is used to select the forwarder, based on the transport service offered.

Naturally, all actors are also influenced by their dependence on a specific mode or type of transport. A forwarder or own-account transport department will, for example, only consider combined transport as an alternative means of transport, thus focusing on an overall efficient transport system, independent of the transport mode. Similarly, a road/rail terminal company is likely to have a greater interest in the combined transport system than a road haulier with other potential markets. A further discussion on power in the combined transport system can be found in Sjögren (1996).

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[28] The forwarder might allow the subcontractor to make the actual modal choice, which should be interpreted as the forwarder having the actual power to make the modal choice, but chooses not to exercise that power. The subcontractor would not be able to make the modal choice if this was not allowed by the forwarder.

As can easily be seen, these many goals and objectives might, to some extent, be contradictory. However, a general, common, goal for all involved actors that have decided to stay in the system can be considered to be to have an efficient and competitive combined transport system. The exact way of reaching the goal, and the notion of an efficient system, vary between the actors.

4.2 The Marketing Channel for Combined Transport

To illustrate the marketing channel for combined transport, a division must first be made between the marketing channel for the transport service and the logistical channel of the actual transport (the service). In essence, what is manufactured and sold is the logistics channel. It is interesting to note that both channels most often have the same channel leader, i.e. the forwarder. The forwarder does not necessarily have to be physically involved in the logistical channel because of the use of subcontractors, but can still be the channel leader by its position in the marketing channel for the service. The competitive situation in the market is very interesting, since the forwarders control both the combined transport logistics channel and the all-road logistics channel. The forwarder, thus, acts like the wholesaler of the logistics service, see Figure 16. The transport customer is also positioned in both the logistics and the marketing channel, since the transport customer is often also the shipper or receiver of the goods. When own-account transport is used (or when the transport customer contracts a transport company directly), this represents a vertical integration in the channel, where a department at the transport customer assumes the role of the forwarder.

The channel leader in this case is clearly the forwarder, who controls all major power sources in the channel (dependence, reward and punish, expertise and customer contact). The dependence is high and the forwarder has the possibility to select who should be included in the transport chain. The forwarder also has the customer contact and the expertise of how to design and market transport solutions. Road hauliers and rail companies have a large expertise in their field, but they are exchangeable for the forwarder, at the same time as they are dependent on the forwarders expertise to gain customers. The leadership of the logistics channel of the transport service provided is one of the key factors in obtaining power and channel leadership in the combined transport marketing channel. The low involvement in the transport decision among most transport customers is one of the main reasons why this strong position is possible.

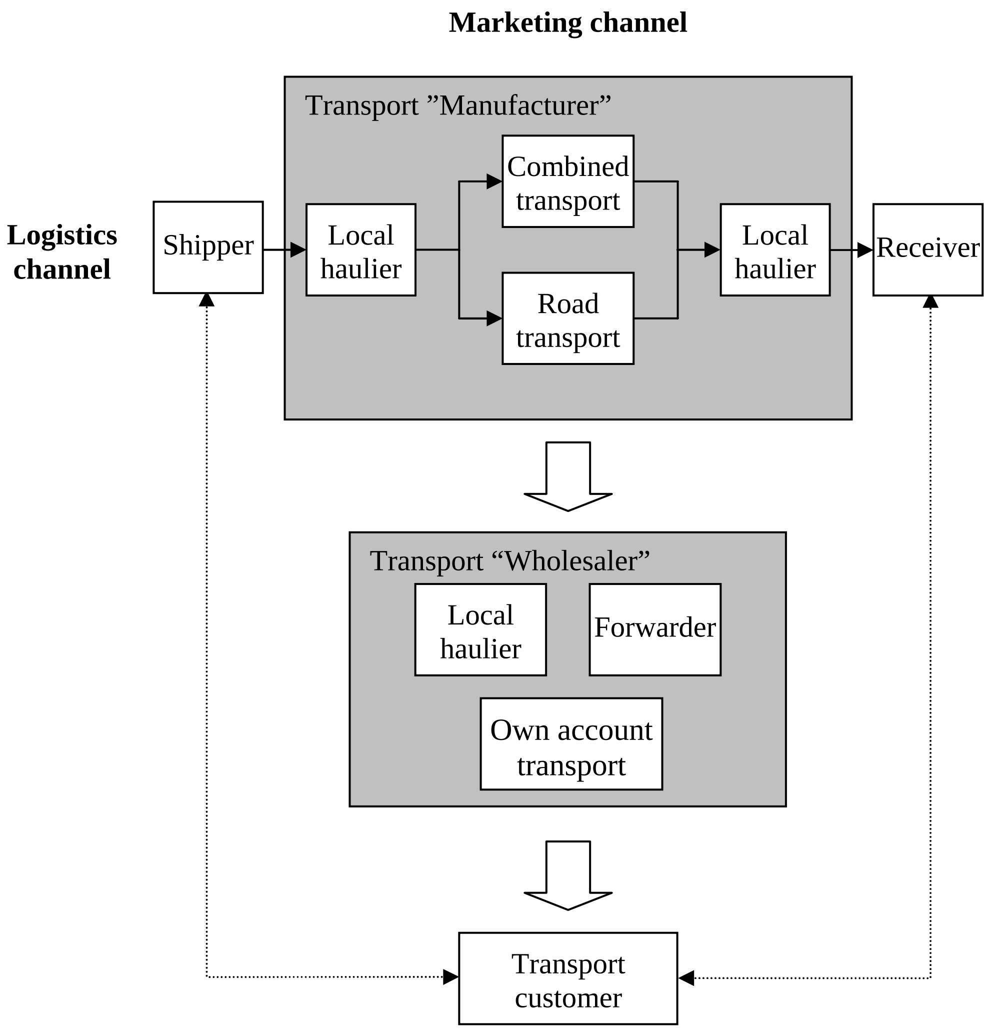

Figure 16 The marketing channel for a long-haul logistics channel

The transport customer potentially has great power in the channel, but generally chooses not to utilize its power as, for most customers, transport is a low-level routinized decision. Companies with a greater interest in the transport (which normally equals greater volumes) normally arranges own account transport, thus assuming the role of a forwarder (“wholesaler”) with direct connections to the transport companies (“manufacturer”). As discussed previously, the transport customer mainly focuses on quality and price factors and has little interest in the actual transport mode used. Combined transport is, thus, a part of the marketing channel for the generic transport service as an “invisible” subcontractor. The transport customer, therefore, does not see any specific combined transport logistics channel, but only the general transport service logistics channel. Considering the marketing channel for combined transport, it is, therefore, appropriate to look at it as a part of the marketing channel for a general transport service, where the transport customer selects transport according to the service output from the transport channels offered by forwarders.

It is interesting to note that the marketing channel does not contain any functional specialist participants. This is in line with theory that service marketing channels are shorter with more direct sales. Some support specialists probably occur (e.g. financing) but the primary participants dominate the channel.

The marketing channel can also be combined with the conceptual model of the combined transport system to further increase the understanding of the combined transport system. This conceptual model can be used as a framework to position the Swedish combined transport industry in its context in Swedish society and the Swedish transport industry. Also, the model can be considered a conceptual model of a general intermodal transport system.

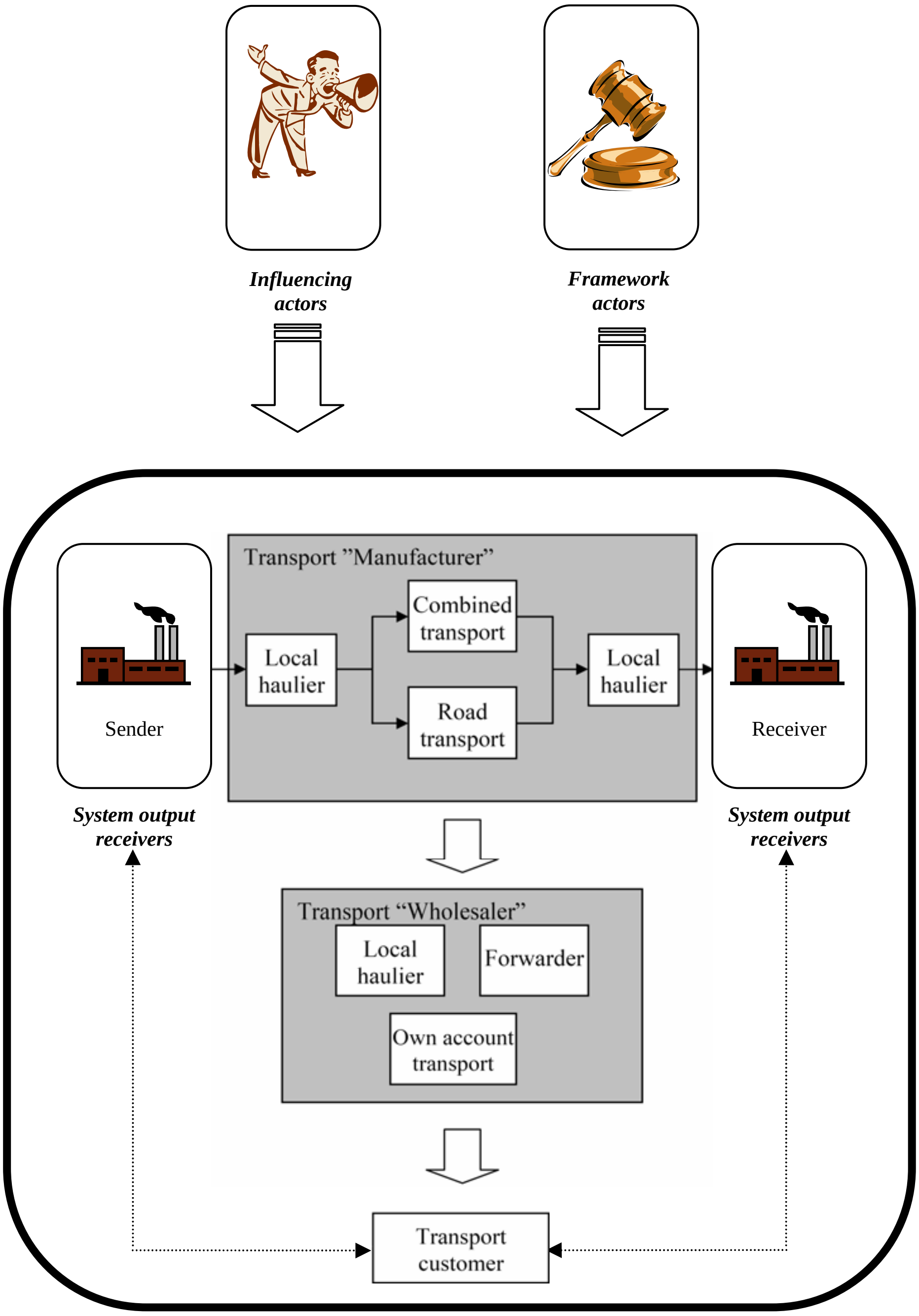

Figure 17 A conceptual model

4.3 Model boundaries selected

The boundaries for the main model can be determined from the conceptual model above.

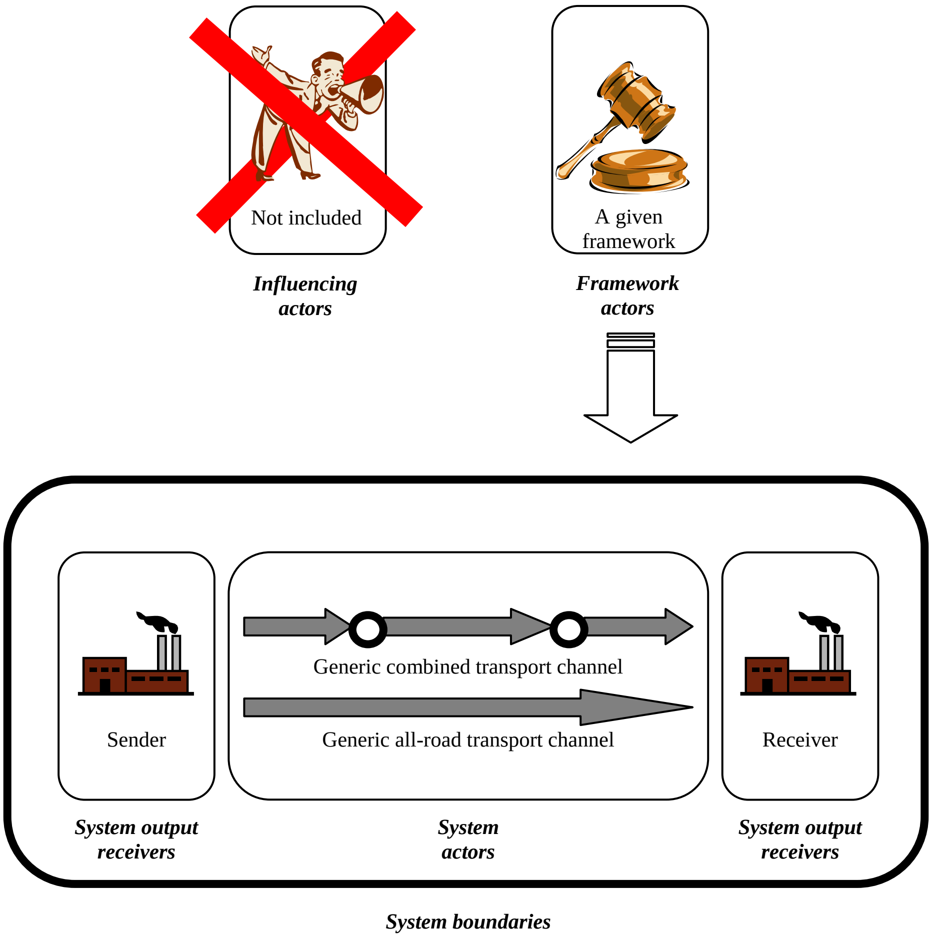

Figure 18 System boundaries

4.3.1 Influencing Actors

Influencing actors are not included at all. The only exception is the traditional all-road transport system that is included as a benchmark for the combined transport system. As previously mentioned, the model is based on a competitive situation where traditional road transport and combined transport compete for a given transport demand. As focus is on combined transport, only the parts of the traditional road transport system that are relevant in a comparison with the combined transport system will be included. The road transport system is considered to be given in the model, following the well known transport times and system design.

4.3.2 Framework Actors

Framework actors are not directly included in the system modelled. Their influences, e.g. legal requirements, are regarded as a given framework to the system. However, the actors themselves are not included in the system.

4.3.3 System Actors

System actors are included as a generic group of combined transport system actors or all-road transport system actors. The actors are viewed as two competing channels of actors, either combined transport or all-road transport. The individual companies within the competing modes of transport (e.g. DHL or CargoNet) will not be considered separately. Note that nothing excludes an actor from being a part of both channels. The system actors are modelled according to their physical performance in the system, i.e. the transport they perform, as the focus of the modelling is on the performance of the transport system and not on the behaviour of the individual system actors. No attempts will be made to model or control individual actors in the system. The modal choice is determined by the potential output from the two channels of actors.

The current market structure of the transport industry in Sweden will not be regarded as fixed, since the model is a strategic model. On a long-term strategic level, the transport industry can be expected to adapt to the customer's service demand, either by a changing behaviour by the existing companies or by new entrants in the market. This means that the added services, e.g. on-line booking, arrival notifications, etc. can be expected to be provided at the same level for both channels, as the technical and management possibilities are the same.

4.3.4 System Output Receiver

The system output receivers are determined as the sender and the receiver of the goods in the shipment.

5 Selection of Modelling Technology

As shown in the methodology chapter and review of previous models, the models by Nozick and Morlok (1997) and Jensen (1990) are the closest existing models for the current type of modelling. This indicates that the optimisation type of models is the most appropriate for this modelling. The network models also show some promising aspects, but they are intended for modelling with a more overall strategic focus than the current modelling. The models by Jensen and Nozick and Morlok will, therefore, be examined in more detail and investigated if they can be extended or further developed to match the current modelling needs.

5.1 The TOFC-Model

Nozick and Morlok's TOFC-model (trailer-on-flat-car) is designed for medium term planning for combined transport between road and rail, but it can be adopted for the current research purposes, which is also supported by the authors in many comments and suggestions in the article on how the model could be extended. Nozick and Morlok's original model consists of a basic TOFC-model, which tries to minimise the cost of transporting a known flow of ITUs via combined transport using an objective function with three parts. Part one is the cost for satisfying transport demand, part two is the cost to reposition an empty trailer and part three is the cost to reposition an empty rail car. Nozick and Morlok's model looks at the ITUs scheduled for transport, the time they are available for pick up and when they have to reach the receiver. It assumes a fixed train schedule and that the cost to transport an ITU between two terminals at a given time is known. The constraints are that the goods are delivered on time, the conservation of flow for ITUs and rail cars and that all ITUs and rail cars are integer valued.

This basic model can be extended to take into account other factors, such as different types of ITUs and terminal capacity constraints. The extensions are included in Nozick and Morlok's article. A heuristic solution process was also developed and tested, which gives good results in short run times. The basic model and heuristics were tested by Nozick and Morlok in systems with up to ten terminals, 1800 trailers and 900 flatcars. No run required more than ten minutes. The TOFC-model is designed to be used in a North-American context for medium-term (one week to one month) planning by the operator of a combined transport system. The purpose is to plan the day-to-day operation of a fixed combined transport network. This differs from this project's long-term strategic decision support model, which compares direct road transport and combined transport. Therefore, some adjustments have to be made to take into consideration the situation in the Swedish system and to include train scheduling and assignment. I have developed an adjusted model of Nozick and Morlok's model, which was published in Jensen, Brigelius and Flodén (2001a). The model was adjusted to include all goods that potentially could be transported by combined transport, consolidated into ITUs at the point where the ITU can select between road transport and combined transport. Also, the time available for transport is not specific for each shipment, but fixed for each transport relation and time period. A comparison was also added with all-road transport, where the combined transport must meet at least the same delivery time as the all-road transport and, of course, have a lower cost in order to be selected. The closed system for ITUs where empty ITUs are repositioned to the next shipper was excluded, since the ITUs in Sweden are not owned and managed by the combined transport company but by individual trucking companies or shippers who, at the same time, are the ones that decide the mode of transport and manage the haul to and from the terminal. An ITU can, therefore, also be used for other purposes than combined transport, such as serving as an ordinary trailer for road transport outside the combined transport system. Fixed trains, i.e. the trains are never uncoupled, are also assumed in the adjusted model, which made it possible to exclude the empty rail car repositioning. Train scheduling was also added to the model. A given number of trains was assigned to each train route, and was optimally scheduled by the model. The model was initially developed for only one type of ITU and rail car, but can easily be extended to include several types of ITUs and rail cars. The model was developed in the optimisation software GAMS, like the original Nozick and Morlok model. Unfortunately, the size of the model made it very difficult to solve. Systems with up to approximately 10 O/D-points could easily be solved, but above that, the size of the model proved too much for ordinary desktop PCs, for which the model is intended. A full validation of the model was, therefore, not completed. More information on the adjusted TOFC-model, including the mathematical objective function and constraints, can be found in Jensen, Brigelius and Flodén (2001a).

5.2 The Jensen model

The Jensen model was implemented and tested on a subset of the Swedish combined transport market in the early-1980ies (Jensen, 1990). Since the market share of combined transport is relatively low, the heuristics finds it appropriate to let the model represent the change in costs caused by an increased market share of combined transport, i.e. a transfer of goods from door-to-door road transport to combined transport, when starting by transferring the goods with the largest cost savings. The focus in the heuristics is on the change of the total system cost incurred by the system. This creates an initially growing, and then decreasing cost savings function of the modal transferred freight volume. The increasing costs for the rail system (including terminals) forms an increasing function of the transferred freight volume. The function will have discrete jumps representing the large fixed cost where, for example, an extra train is used. The objective function will calculate the sum of the differences between the cost increase in the rail system (K_1) subtracted by the cost savings in the road system (K_2) for all train routes and then subtract the sum of the cost increase for all combined transport terminals, since one terminal may be used by several train routes. Note that the road system includes both the all-road transport system and the road transport part of the combined transport system. The largest cost saving will be found at the objective functions maximum point (X_1) and the largest transfer of freight, with no increase in system cost, will be found where the objective function (K_2-K_1) equals zero from the positive side (X_2).

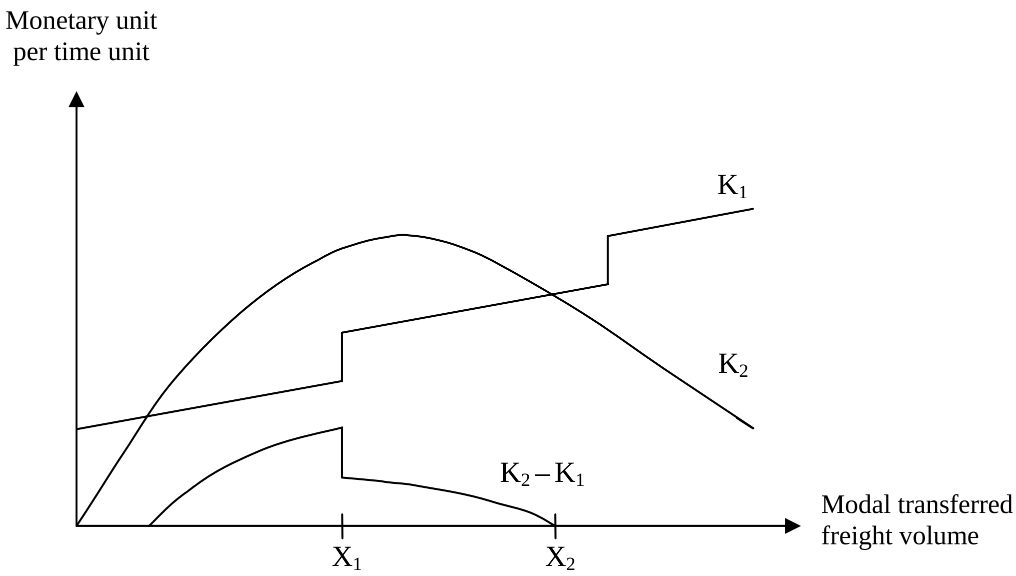

Figure 19 The cost functions (Jensen, 1990).

The model uses an optimum seeking method on the difference between reduced costs in the road system and increased costs in the rail system. This generates optimal solutions for cargo volume, train frequency, market share, etc., since all alternatives are tested. The transport delivery times of combined transport are required to meet the delivery times of traditional road transport. The model will calculate one (average) time period of 24 hours. Only one type of ITU and rail car can be used simultaneously. However, differences in loading capacity between traditional road transport and intermodal ITUs are considered. The model considers the potential costs of created redundant capacity in the road transport system and the loss of compensation traffic, i.e. when a lorry picks up additional goods from a third location in an unbalanced flow. The terminals are considered to be able to meet the increase in combined transport with their present equipment without capacity constraints. The computer model was tested on the major combined transport links in Sweden (114 origin/destination (O/D) areas and six terminals).

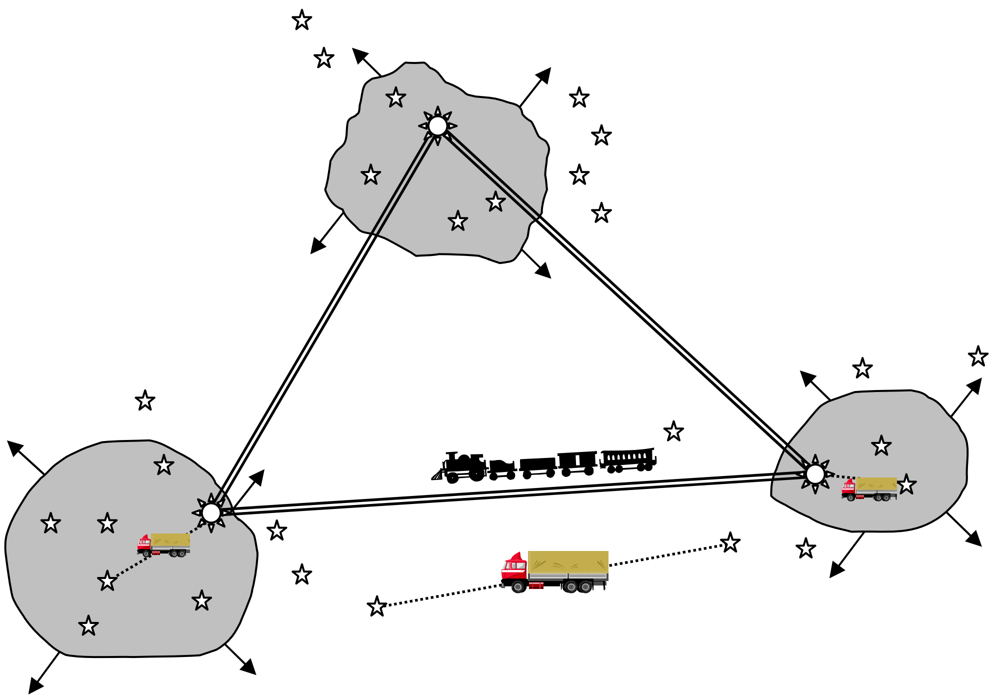

Figure 20 System expansion

The heuristics works by cumulatively increasing the traffic areas for combined transport around the terminals with the transport links (in both directions) that give the greatest net saving for the overall transport system, i.e. all terminals are considered simultaneously. In the model, this is represented by the greatest saving in driving distance. This is repeated until either the train capacity is full or no more net saving can be achieved by transferring goods to combined transport. The rail system is then changed to another possible operating policy (e.g. number of trains, departure times, etc.) and the heuristics is repeated for this new train combination. Note that each train combination includes all trains in the entire rail transport system. When no more train combinations are possible, i.e. when the train capacity equals the total transport demand, the best train combination is selected. The model and heuristics is explained in detail in Jensen (1990). See also the flow chart in Figure 21(Jensen, 1990, p. 318).

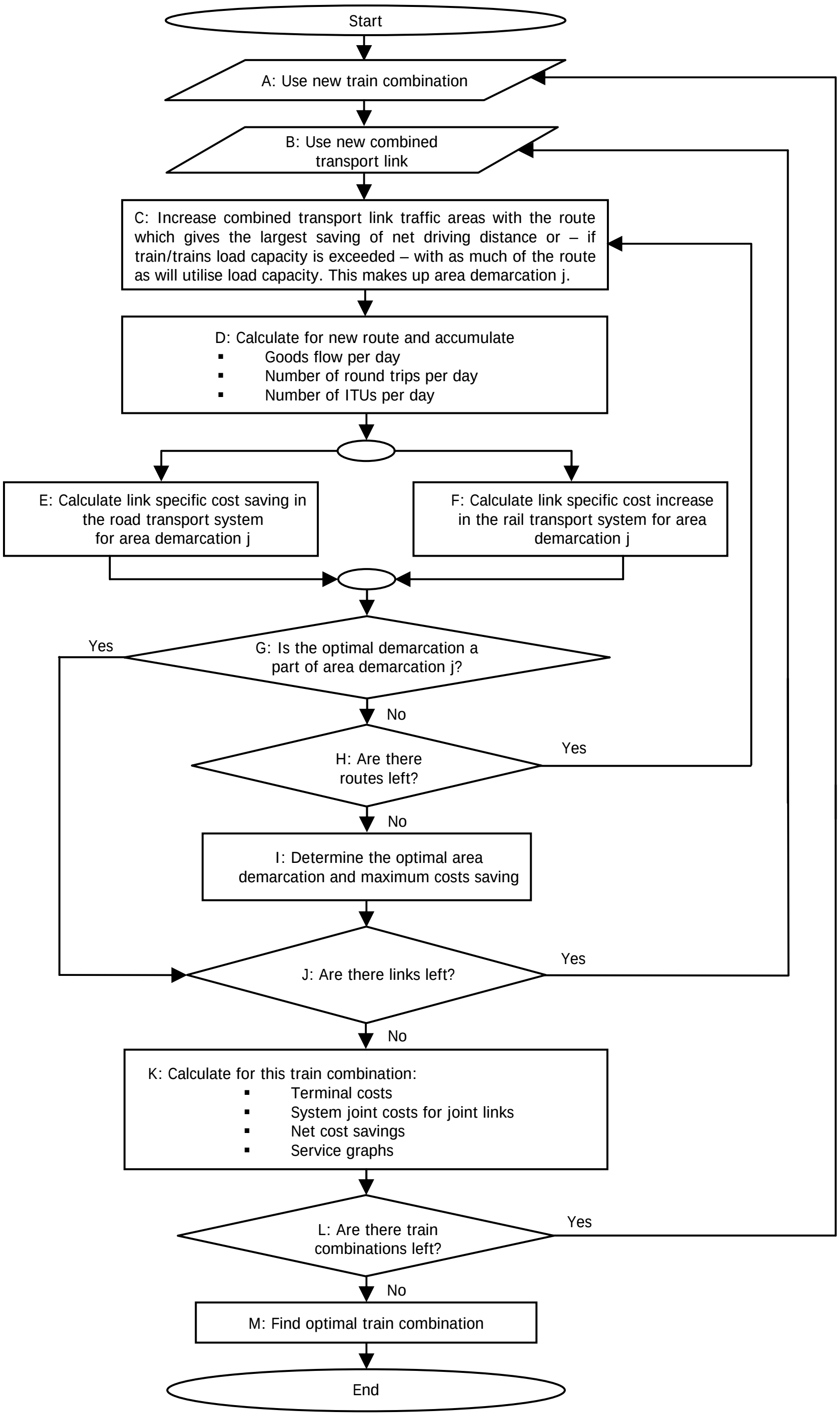

Figure 21 Jensen model heuristics

5.2.1 Input

In the Jensen model, demand is input as volumetric weight[29] between destinations, and later in the model converted to lorries and ITUs. The costs are input as costs for a certain number of selected cost units e.g. driver salary costs, lorry fuel costs, etc. The actual transport cost is then calculated in the model based on a very extensive empirical study made by Jensen into the cost structure of the Swedish transport industry (e.g. load factors, terminal efficiency, costs, etc.). See Jensen (1990, chapters 8-10) for a detailed description.

Control parameters are used to control the model behaviour. The model uses the following control parameters:

- Type of calculation
  Business economic or social cost
- Terminal open hours
  03-08 and 16-21 or 05-08 and 17-20
- Goods flow balance
  Real goods flows or balanced flows
- Market share
  Allows a certain percentage of the goods not to select combined transport, even if it is the most favourable alternative.
- Alternative utilization of released lorry capacity
  The percentage of road transport capacity that is made redundant that cannot find any new occupation
- Compensation traffic
  The percentage of additional goods that a lorry in the road transport system can pick up from a third location in an unbalanced flow

5.2.2 Output

The output from the Jensen model is the best train combination, the modal split measured in volumetric weight, the savings in the road transport system and the increased cost in the combined transport system for each train route.

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[29] "Fraktdragande vikt" in Swedish. The weight of low density goods is converted to a chargeable weight based on the volume of the goods. A calculation converts the actual weight of the shipment to a new "imagined" weight for charging freight in accordance with how much capacity the shipment occupies on the lorry. Also known as cubic weight or dimensional weight.

A service table is also output, showing percentage of time overdraw for combined transport deliveries compared with road transport.

5.2.3 Possible extension of the model

The heuristics of the Jensen model is expected to be able to handle much larger problems than those in the original model. There is nothing to indicate that the heuristics would not be able to handle the size of the current intended model, particularly considering the advances in computer technology during the last 20 years. However, several parts of the heuristics and all of the input data, e.g. cost structure and capacity measures, cannot be used due to changes in the industry over the last years and partly different model aims.

5.3 Selection of modelling technology

The Jensen model has been identified as the existing model most closely resembling the intended model. In particular, the heuristics used in the Jensen model is identical to the needs in the current model. The size of the original model also indicates that the heuristics will be able to handle the size intended in the current model. A heuristic model based on the basic heuristics of the Jensen model is therefore selected as the modelling technology. The current model will be based around the general heuristics of the Jensen model with its comparison between the cost increase in the combined transport system and the savings in the road transport system, with gradually increasing market areas around the terminals. The new model will be named the Heuristics Intermodal Transport Model or, abbreviated, the HIT-model.

6 HIT-model Foundation and Characteristics

Based on the basic heuristics, the research question, the current transport system and trends some important factors for the Heuristics Intermodal Transport model (HIT-model) design can be identified. These important factors will be reviewed in this chapter. The chapter shows both the theoretical background and the model solution selected as they are difficult to separate. Consideration has also been given to the sub-aim of building a model that can be used for future research in other projects. By fulfilling this sub-aim, it becomes possible to use (and/or further develop the model) for more general applications in intermodal transport. Model flexibility has, therefore, been emphasised and possible future model uses considered. The possibilities to acquire input data and the possible quality of the input data have also been considered. There is no point in building a detailed model in a certain aspect, if no input data for that aspect can be acquired with a satisfactory quality. A general consideration in the model design has also been not to build the model more complicated than necessary. A model must try to identify and focus on the key issues being modelled and not model complexity just for the sake of having a complex model. When the word optimisation is used, it should not be interpreted as finding a strict mathematical optimum, but rather as a satisfactory heuristics “good enough” solution. See chapter 3.3.1.

A lot of work was put into defining this model structure and working out suitable solutions for the model. It is impossible to describe all thoughts and alternative ideas considered during the process. This chapter shows only the results of a very long and arduous thought process.

6.1 Model Flexibility

The transport system is very complex and its future developments are hard to predict. It is, therefore, important to aim at making the model as flexible as possible. This will allow the user to test a wider range of scenarios and conduct a better sensitivity analysis. This means that as little input as possible is set to fixed values. The model user should be able to freely determine the cost estimations, number and location of demand points and terminals, transport times, capacities, number of lorries and train types and, of course, the transport demand. These are also very important aspects in designing a competitive transport system and finding its potential. The model user needs to be able to easily test potential changes to the transport system, e.g. adding a new terminal, increasing train speeds, increasing terminal capacities, etc.

6.2 Model Definitions

The model uses demand points, demand occurrences, transport links, train routes and train loops.

A demand point is a geographical location that has a demand for transport, e.g. a municipality.

A demand occurrence is defined as the amount of goods to be transported from demand point A to demand point B at a given time. The demand points are the origin and destination of the goods. The time is the time when the goods is ready to be dispatched.

A transport link is the connection from A to B, i.e. the origin and the destination for the demand occurrences. Note that A to B and B to A are two different transport links. There can be several demand occurrences on a transport link. See Figure 22.

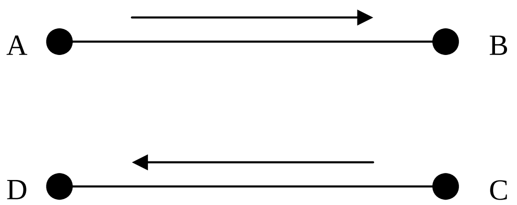

Figure 22 Transport link A to B and transport link C to D

A train route is the connection between two combined transport terminals, e.g. from terminal X to terminal Y and from terminal Y to terminal X. Note that X to Y and Y to X are the same train route. See Figure 23

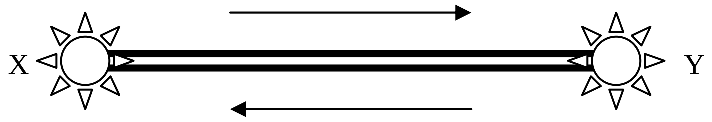

Figure 23 Train route XY

A train loop is an individual train assigned to a train route. A train loop T is the time table of a physical train, e.g. depart X at time 1, arrive Y at time 2, depart Y at time 3, arrive X at time 4, etc. See Figure 24. There can be several train loops on one train route.

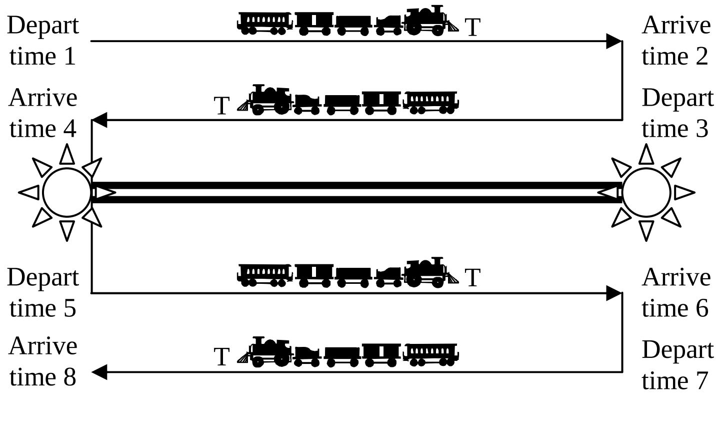

Figure 24 Train loop T

A train departure is a departure of a train from a terminal at a certain point in time. Each train departure belongs to a train loop, e.g. the train on train loop T should depart from terminal X at time 1. A train loop must consist of at least one train departure, but, normally, consists of several train departures.

In summary, assume that the demand occurrence of 20 tonnes at 8 a.m. from demand point A that is to be sent to demand point B, i.e. it is on transport link A to B. It is transported to terminal X where it is sent by train to terminal Y, i.e. using train route XY. The demand occurrence is sent by train loop T on the departure leaving terminal X at 11 A.M. See Figure 25.

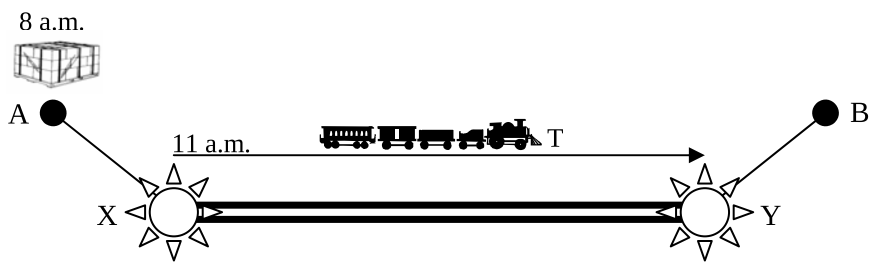

Figure 25 Definitions summary

6.3 Modal Choice

One of the most important aspects of the modelling is to determine what types of modal choice criteria should be allowed in the model, since this will govern the choice of input data to the model and the computations made within the model. As the modal choice is the focus of the model, the factors that are important in the modal choice are also the variables that are important in the model. Note that the variables are factors that are considered, which is separate from the actual valuation of the variable. The variables to use are built into the model, while the valuations are input by the model user in the input data set, e.g. the variable is cost per km and the valuation is 10 SEK.

The first step is to determine whether one, or several, variables (objectives), should be considered in the modal choice and, if several variables should be used, what these variables are dependent on (e.g. time or distance dependent). It should also be decided whether only one variable should be considered at a time or if several variables should be considered simultaneously in a multi-criteria analysis.

The modal choice selection has been studied in many research projects. The results from the survey by Saxin, Lammgård and Flodén (see chapter 3.4) show that price, meeting delivery times, knowing how to handle the goods and being flexible are important factors. The most important aspects of the transport offer for the respondents when selecting transport provider were similar for all company sizes. From some of the questions on quality dimensions, it was clear that reliability were considered most important. All companies have ranked among the top three priorities that the transport provider "performs transports on time agreed upon" and "fulfils its´ commitments". Resource- and capacity dimensions (such as geographical coverage, ability to deliver at an even quality level, ability to adjust to large volume variations) were ranked between number 4- 6 for manufacturing companies and slightly higher for the wholesale companies. Communication and accessibility to information were considered among the top three items for manufacturing companies, while ranked somewhat lower by wholesale companies. For the big wholesale companies, it is the other way around: capacity is ranked somewhat higher than accessibility to information. The respondents also distributed 100% among four factors according to their importance when their local unit selects transport solution for the outbound transports: price, transport time, on-time delivery, and environmental efficiency. 58% of the weight was then attributed to price, 21% to transport time and 17% to on-time delivery. Finally, 5% of the weight is attributed to environmental efficiency. It is also evident that the price is more important for smaller companies and environmental aspects are more important for larger companies. It is interesting to note that one of the lowest prices is not one of the basic demands[30], although the respondents give price a 58% significance when selecting transport. A conclusion can be drawn that price is important, but it does not have to be one of the lowest prices. It is more important to have the basic transport demand met. This is obvious since a transport service that does not perform a useful transport is of no use to the transport buyer. The results support previous research that shows that price is not the only priority. Price is thus only important after the basic criteria are met.

The modal choice studies, in particular the survey by Saxin, Lammgård and Flodén, show that the transport buyer first evaluates that the transport company can perform the transport satisfactorily (fulfilment of

[30] Ranked 11th most important factor in a list of 33

commitments, delivery on time, geographical coverage, easily accessible, etc.) and after that looks at the price for the transport service. From a modelling perspective, the important factors are the on-time deliveries and the price. It can be assumed that both transport modes can match the basic criteria as they are mostly related to management issues (accessibility, communication, keeping of promises, etc.). Both systems have the ability to deliver the same transport quality and meet these basic requirements. Capacity issues and geographical coverage are parts of the transport system that the model is intended to design, and can thus not be allowed to restrict the modal choice.

The main modal choice will, therefore, be made on price in the model, after the basic assumption is met that the combined transport system must match or outperform the road transport system's delivery times. "Price" is, in the model, represented by cost (business costs or social costs) as the pricing policy can be affected by an abundance of different factors. It is considered that combined transport can deliver the same transport quality as all-road transport, since there are no technical obstacles to prevent combined transport from doing so. On a strategic time frame, the actors in the combined transport system can be expected to adapt to the transport quality demanded by their customers, see chapter 4. Also, there are many other factors that might affect the modal choice, such as prejudices, tradition, marketing and personal relations. These factors are much more difficult to measure, but from a strategic potential perspective they are not relevant. The purpose of the model is to show the potential of combined transport and not to show how to reach the potential. If the model shows a good potential in a certain system, it is recommended to do more research on how that system can be realised.

6.4 Cost Factors

Cost calculation is not an exact science and the types of costs included and their estimation can vary greatly between different calculations. However, what is interesting from a model design aspect is not directly the actual valuation of the costs, but what cost variables to use and what they are dependent on. These variables can then be used to design the model while allowing the actual values of cost variables to be input by the model user for each scenario run in the model. The cost variables relevant to the model are the factors connected to the operational activities of the transport system. Note that there is a difference between cost and price, where the price charged for a transport can be affected by many more factors than the actual cost of transport[31]. The model considers only the cost of transport.

Cost structure in the transport industry can, as in most other industries, be divided into fixed costs and variable costs. The division into fixed and variable costs is completely dependent on over what time period the system is studied. Rent for a terminal area is, for example, a fixed cost on a day-to-day basis, but a variable cost over a 20-year period, where there is a choice to close the terminal. Similarly, if a decision has been made to operate a train according to a certain timetable during the next year, the cost of operating the train can be considered a fixed cost during that year. The fixed costs are, thus, really variable costs that can be considered fixed for the chosen time period. Many of the fixed costs are also shared costs, e.g. general administration, which either have to be considered jointly for the entire business or allocated to suitable cost units, e.g. lorries.

Looking at different cost calculations in the transport industry (e.g. Sveriges Åkeriföretag (2004), SIKA (1999b, 2002e), Hensher and Brewer (2001), RECORDIT (2000), Enarsson (1998), Banverket (1997), Tarkowski, Ireståhl and Lumsden (1995), Button (1993) and Jensen (1990)) shows that the variable costs can be further subdivided into costs variable by time and distance transported. Commonly mentioned time dependent costs are financial costs, salary costs, vehicle taxes and insurance. Commonly mentioned distance dependent costs are tires, fuel, maintenance, kilometre taxes, and rail infrastructure fees. As mentioned above, some of these costs are regarded as fixed costs in many calculations, depending on the time frame.

Apart from these direct operating costs, transport also causes substantial external costs. External costs are caused by external effects which occur when (Button, 1993, p. 93)

> *the activities of one group affect the welfare of another group without any payment or compensation being made.*

Note that external effects, by definition, can be both positive and negative. Much of these external effects can be attributed to environmental pollution, see chapter 6.5, but there are also many other external effects, for example,

[31] See e.g., Button (1993), Hensher and Brewer (2001) or Engström and Stelling (1998).

noise, visual intrusion (e.g. destroying a beautiful view), risk of accidents, barrier effects from a road. Button (1993) makes a division into technological externalities and pecuniary externalities. Technological externalities are effects caused direct by the production or consumption, e.g. building a road destroys a beautiful view, while pecuniary effects are indirect effects, e.g. when traffic diverted to the new road takes potential customers away from a garage on the old road, causing reduced income for the garage. A further distinction can be made between pollution and congestion, where pollution is where the external effect affects actors external to the medium, e.g. plants killed by exhausts fumes. Congestion is when the external effect affects actors that are also using the medium, e.g. private motorists caught in queues caused by lorries.

The notion of external effects is also closely linked to the social cost perspective and valuation of costs. The social cost perspective aims at (Bohm, 1996, p. 12)[32]

> *taking into consideration all individuals' appraisals of, in principal, everything produced or consumed / used, i.e. not only the purely material aspects*

Society, in this perspective, includes not only the government and public sectors, but all citizens and companies in the society. Social cost valuations of transport are commonly made, particularly in conjunction with infrastructure investments and as a part of political decision processes. The valuations aim at including the external effects in the decision process, where the external effects are included as some monetary estimation[33]. Naturally, it is very difficult to find a fair way to valuate these aspects. For example, if building a new road will destroy the local habitat of a small frog threatened by extinction, how should this be valued? More information of different theories to give a monetary estimation to these effects and what external factors to include can be found in SIKA (2002e), Trafikministeriet (2002), INFRAS/IWW (2000, 2004), RECORDIT (2000), Banverket (1997), Maddison, et al. (1995), Button (1993) and Hanley and Spash (1993). For more information on the principles behind social cost calculations in general,

[32] Translated from Swedish.
[33] Social cost valuation can, of course, also be non-monetary, but the general aim is to include as much factors as possible as monetary. A division can be made between social cost calculation, where everything is included at monetary values, and social analysis where none-monetary values are included.

see, for example, Bohm (1996), SAMPLAN (1995), Button (1993) and SIKA (2002e).

From a modelling point of view, it is important to conclude that the external costs can also be divided into fixed costs and variable costs dependent on time and distance, as in the case with the operating costs. Common time dependent external effects are visual intrusion, barrier effects and shorter travel times. Common distance dependent external effects are accident risks (deaths, injuries etc.) and environmental effects. As with the operating costs, there are no fixed answers to the question what factors should be included. Transport, for example, pays special transport taxes to try to internalise the external effects. Some calculations assume that these taxes cover the cost of infrastructure, pollution, etc. and, therefore, do not include these external costs. Others state that taxes paid should not exempt from considering the external effects or that the taxes do not cover the real costs, and, therefore, consider the costs external. Similar reasoning also occurs around special environmental taxes and VAT. See for example SIKA (2002e), Maddison, et al. (1995), Button (1993), SAMPLAN (1995), Banverket (1997), Leksell (1996) or chapter 9.9 for a further discussion on taxes in social cost calculations. Trafikministeriet (2002) have a review of how taxes are considered in national societal calculations in different countries.

The cost structure in the model is, therefore, most appropriately based on the division into time dependent costs and distance dependent costs. Since the model is focused on the operating costs, the costs will be divided onto the operating activities and its resources. As mentioned in the previous description of the combined transport system, the main activities are road transport, terminal handling and rail transport. The costs will, therefore, be divided onto lorries, terminals and trains (in the three steps: trains, rail cars, use of rail cars) as distance dependent costs and time dependent costs. Shared costs can be allocated down to these units or considered jointly as fixed system costs, see below and also chapter 8.

The costs for using a new train are divided into three steps. First, the costs to add a new train to a train loop, second the costs to add a new rail car to the train and, third, the costs to use the rail car, i.e. run the rail car with something loaded on it. Since the model shall be able to determine the number of trains and train lengths to use, a correct cost representation to use in the modal choice must include the obvious fact that it is more expensive to add a new train (with a single rail car) to a train loop than to add the new rail car to an already existing train. This can also be seen by the stepwise increasing cost curve in the heuristics (see chapter 5.2). This cost structure enables the model to represent the higher cost (per rail car) to run a short train and ensures that no trains are added to the model until the start-up costs for the new train are compensated. This is particularly important when running long train loops as any new train is assumed to be inserted on the entire train route, thus causing a high start-up cost on a long train loop. The three cost levels are aggregated to form the total cost[34].

In the event that shared fixed costs are present in the combined transport system that cannot be allocated to individual ITUs, these costs must be considered jointly for the rail transport system, e.g. rent for a terminal. These fixed costs must be added to the aggregated transport system costs as a lump sum at the start of the model run, since the modal choice is based on the aggregated cost and cost saving. These costs are, thus, never allocated to individual ITUs. If several train routes use the same shared fixed resources, e.g. several train routes using the same terminal, a division of the shared fixed costs among them must be done externally in the model input. The costs must, therefore, be known at the start of the model run[35]. See chapter 9.7.3.

6.5 Environment

The model is intended to show the transport system from a business economic perspective, a social cost perspective and an environmental perspective. The economic perspective is easily modelled by using different estimations of the costs in the system. The environmental perspective is partly included in the social cost perspective, since a large part of social costs derives from environmental effects, e.g. health problems, climate change and effects on plant life. However, due to the large attention in society (politics, media, public awareness, etc.) given to specific types of environmental effects, e.g. types of pollution, these direct environmental effects will also be included. The emissions could also be calculated after the model run, by using the then known modal split and lorries used, but the

[34] The cost to run a train with ten rail cars, of which seven are loaded, is thus: Cost for new train + cost for new rail car * 10 + cost to use a rail car * 7.
[35] If the model output should result in that no combined transport is used on a train route where a fixed terminal cost is inserted, a new allocation of the fixed costs should be done and the model re-run with the fixed costs removed for that train route and no combined transport allowed for the train route.

great interest motivates including them directly in the model. A review of research made in the environmental effects of transport, emission measurements and reports shows that a number of environmental emissions are commonly reoccurring (e.g. Grennfelt, et al.(1991), Blinge (1995), Flodström (1998), Demker, et al.(1994), Scania (2000), Schenker (2003)):

- Carbon dioxide ($CO_{2)}$ pollution in grams/km
- Nitrogen oxides (NO_x) pollution in grams/km
- Sulphur (SO_2) pollution in grams/km
- Hydrocarbons (HC) pollution in grams/km
- Particulate matter (PM) pollution in grams/km
- Carbon monoxide (CO) pollution in grams/km
- Energy consumption in kWh/km

In particular, these emissions are used by Swedish transport industry's environmental association NTM (Nätverket för Godstransporter och Miljö - The network for transport and environment) (NTM, 2005) which, with its free on-line emission calculator NTMCalc,[36] has become something of an industry standard.

The emission will be treated in the same way as the costs in the cost calculations. They will, thus, be allocated to lorries, terminals and trains (in the three steps: trains, rail cars, use of rail car) and can be defined for each type of lorry, terminal and train. All emissions will be regarded as distance dependent. The model will not consider the weight loaded on each lorry, etc.

The fact that emissions can be treated in the same way as costs makes it possible to make direct environmental optimisations simply by switching variables in the input data, e.g. by inputting CO_2 emission data in the cost variables.

6.6 Lorries, ITUs, Trains and Rail Cars

The type of lorries used has grown increasingly important when comparing road transport and combined transport. The Swedish road transport system can, since a few years, use up to 25.25 meter long lorries with a total weight

[36] http://www.ntm.a.se/ntmcalc/ See also chapter 9.8.

of 60 tons. This makes road transport very competitive[37], since the marginal cost of running a bigger lorry is rather small, but it also means that its competitiveness will vary greatly depending on the type of lorry used. Nelldal (2000) calculates that the break-even point between combined transport and road transport has moved from 350 kilometre rail haulage for a 40 ton EU lorry, 500 kilometres for a Swedish 51.4 ton lorry to 850 kilometres today for the new 60 ton lorries. This makes it possible that combined transport can be competitive against road transport on different distances for different types of ITUs and lorries. A possible hypothesis is, for example, that combined transport is more competitive against international goods loaded in shorter European trailers, than against domestic goods loaded in the long and heavy 25.25 m lorries. This is a very interesting modelling aspect, particularly since there are ongoing discussions to allow the longer lorries in all of the EU. This, also, means that the catchment area around a terminal will not be a continuous area, but that the area, and also individual demand points, can be divided between road transport and combined transport depending on the lorries and ITUs used. Similarly, the type of lorries used in the combined transport system affects its competitiveness. The model will regard each possible vehicle combination (lorry + ITUs) as a separate type of lorry. The type of ITU used is thus given by the lorry used. The ITUs on a lorry will be kept together during the model run.

Determining the types of lorries to use in the system is, therefore, also very much a part of determining the potential of combined transport. It will, therefore, be assumed that both transport systems will try to use the most appropriate type of lorries, but it will be possible to define what type of lorries that can be chosen from for each transport relation. However, the use of many different types of ITUs also requires the rail system to use different types of rail cars to carry the different ITUs. This means that the selection of railcars to use will be a result of the selection of lorries. The need for rail cars will be represented in the model by the length of rail car required by each ITU type. This will also make it possible to give a better representation of the requirements of different ITUs in the rail system, since the length required are separate from the actual length of the ITU. A heavy ITU could, for example, be defined to need the length of an entire rail car to represent weight restrictions. Similarly, a trailer could be defined to use an entire rail car even if the trailer itself is shorter, as is normally the case with trailers.

[37] About 30% lower tonne-km cost compared to a normal European 40 ton lorry (Nelldal, 2000).

ITUs with a low load factor[38] or low-density goods will also be better represented. The types of lorries and trains that can be used are unlimited. Different types of lorries can be defined for all-road transport and combined transport.

It is also possible to restrict the types of lorries allowed to use between two destinations. If, for example, it is known that a certain type of lorry is not used on a route, the model can be restricted from choosing that lorry type. This can also be used to model that different types of cargo require different types of lorries[39]. This, also, makes it possible to ban a certain transport mode for a certain destination by simply not allowing any lorries for that mode on the transport link. The model will, then, disregard the modal choice rules and assign the demand to the selected mode (and inserts the necessary train capacity[40]). This gives a restricted optimisation where the remainder of the model operates according to the modal choice rules. The function can also be used to calculate the costs of a system with an already given modal choice. The allowed lorries can be defined individually for each transport link (A to B), transport mode and time period. The time periods can also be set freely for each transport link.

Each lorry type (including ITUs) has its own costs and length requirement on the train. Each train type consists of a certain number of length units in loading capacity which is deducted when an ITU is loaded. It is assumed that all types of ITUs can be loaded freely on all rail cars. Individual rail cars are not considered in the model, i.e. ITUs can be loaded over the “gap” between physical rail cars. However, this effect can be partly counteracted by selecting a rail car length demand for an ITU that corresponds to the physical rail cars required[41].

The number of trains to be used and their departure time is also an important aspect of designing a combined transport system. To let the model freely and

[38] A low load factor can be represented by stating a lower maximum load for lorries in certain transport relations and time periods.
[39] Extra, parallel, transport links (A-B) are defined for the different types of cargo, with different allowed lorries. The demand is then divided between the links.
[40] Demand assigned to combined transport is sent with the first train to depart after the demand has arrived at the terminal. Alternative trains are not considered, since there are no all-road transport alternative to use to determine what trains are allowed.
[41] A detailed modelling on how to load individual ITUs on rail cars is a too high level of detail for a strategic model. The problem is also very complex considering the number of different types of ITUs, rail cars and number of possible combinations among them, in particular since the entire train loop must be considered when selecting rail cars.

exactly decide all train departures and time tables is a very complicated problem and not necessary in a strategic model. It is satisfactory to determine roughly the best departure time of a train, rather than the exact second. This is particularly the case since the use of time periods and time gaps allows the departure and arrival time of the demand to be adjusted to match the train's departure time, see chapter 6.8. Train departure times are, therefore, handled by giving the model a number of allowed train loops to choose from. A number of suggested train loops are input to the model and the model decides which of these loops are to be used and how long the train on each loop should be. By selecting an evenly distributed number of possible train loops, a satisfactory train system can be calculated. The model can also be set to allow several trains on the same train loop (a given number, a minimum number, a maximum number or unlimited), as an alternative way to model several train loops close to each other. This also reduces the model run time. It is not recommended to run the model with too many loops close together, as this level of detail is too high for a strategic purpose, see also chapter 7.2.

It is recommended that the train departures are kept together in closed train loops (from A to B to A to…) with the same number of rail cars in both directions, to avoid problems in unbalanced flows. If, for some reason, the model should need to be run without closed loops, this can be modelled by simply inputting each departure as an separate "train loop" in the input data. Unbalanced flows would otherwise result in an unrealistic accumulation of rail cars in one end of the flow and a shortage of rail cars in the other end. The cost of returning the rail cars must affect the combined transport system as this is a direct effect of transferring goods to the combined transport system. These empty haulage costs are, thus, represented by using closed train loops, i.e. the same train length in both directions. The specialised combined transport rail cars also have a limited usage outside the combined transport system. This also simplifies the cost calculations for the rail transport and eliminates the need to consider shunting between trains[42]. Train loops operating on several train routes, e.g. A to B to C to B to D, etc. can also be run in the model. However, train route optimisation can, then, naturally not be used, since the train routes affect each other.

When using closed train loops where train capacity is made available to the entire train loop, it is necessary that both directions of the train route are

[42] A complete optimisation of rail cars usage by transferring rail cars between trains and empty haulage is a very complicated mathematical problem. See Joborn (1995, 2001).

given an equal representation in the input data set[43]. A higher cost saving in one direction would otherwise be over or under represented. A train should thus, if possible, run A to B as many times as it runs B to A, i.e. “close” the loop. This can also be achieved by running the model over an extended period of time so that the effects of unbalanced flows are negligible. This can be a preferable strategy if it is difficult to “close” all loops in a train system at the same time.

6.7 Terminals

Terminal activities are important to consider in the system. However, it is not the intention here to include a detailed model of terminal activities, since the focus is on the overall system and not on how to operate a terminal. A large number of models and studies have also already been made on terminal operations, see e.g. Sjögren (1996), Kondratowicz (1993, 1990), Tsamboulas (2001), Hedin, Victor and Strandberg (1991), Rizzoli, Fornara and Gambardella (2002), Yun and Choi (1999), Ballis and Golias (2002). The terminal will, therefore, be regarded as a “black box”. Costs are defined per ITU handled at the terminal and are regarded as a given cost for handling a single ITU of a specific type at the terminal. Different costs can be defined for each ITU type at each terminal. Fixed terminal costs can also be defined for each train route, see chapter 6.4. No time delay is included for the terminal handling, since the time to handle an ITU is just 5-6 minutes (see chapter 9.7.3). It is assumed that the terminal first unloads the ITUs that are in a hurry to be picked up.

Terminal capacity is not considered, since the necessary terminal capacity can be calculated from the output of the model. It is assumed in the model that the terminal has the capacity to handle all ITUs without delay. The terminal capacity needed will thus be an output from the model and not a constraint.

To determine which terminal to use, each demand point is assigned to a certain terminal in the model input. The assignment can be different for different transport relations, e.g. A to B is sent via terminal 1, while A to C

[43] Assume that direction A-B has a cost saving of 100 and direction B-A has a cost saving of 10. If A-B is run twice and B-A is run once, then the total cost saving for the loop is 210. If B-A is run twice and A-B is run once, then the total cost saving is 120.

is sent via terminal 2. The terminals in Sweden are located so far from each other that the assignment is simple.

All-road terminals are not considered. The costs for these terminals, if they are used, are considered to be included in the all-road costs. Only 10% of the goods volumes (in tons) in Sweden are sent via a terminal, although 70% of the shipments are sent via terminals (Jensen, 1990).

6.8 Time

Time has become an increasingly important factor in the transport industry. An important factor for this is the increasingly streamlined and centralized production and warehousing in the industry today. However, the focus on time is not always on pure optimisation (e.g. the faster transport, the better), but rather on meeting a basic set of criteria. The survey by Saxin, Lammgård and Flodén shows that on-time deliveries are ranked as the most important factor of 33 factors, when selecting transport company. In another question in the survey, 17% of the weight when selecting a transport company was attributed to on-time deliveries and 21% to the transport time. Thus, 38% of the weight was time related. However, the importance of on-time deliveries should not be confused with a need for faster transport. The transport company often have an agreed time window that the delivery should be made within, e.g. between 9 a.m. and 9.30 or sometime during the day. The time windows can vary greatly in length. Short time windows are often planning and capacity constrains when receiving the goods, e.g. a limited number of loading docks and personnel, where the important aspect is the on-time delivery and not the transport time. It is, thus, important to know exactly when the goods will arrive, but less important if it is e.g. in the morning or in the afternoon[44]. Thus, there is a difference between the agreed delivery time window and the greater potential time window in which the delivery time window can be placed, e.g. the delivery should be made sometime during the next day (potential time window) and it is agreed to deliver between 9.00 and 9.30 (delivery time window). The agreed delivery time window is a matter of negotiation between the transport company and receiving company. From a modelling perspective it is the greater potential time period that is of interest. Technically, both all-road transport and

[44] Naturally, there are goods flows where the exact delivery time is important, e.g. in JIT-flows for the car industry.

combined transport as the possibility to meet an agreed delivery time window.

There is also a difference between delivery times (i.e. when the goods is delivered to the receiver) and transport times (i.e. the time needed to perform the actual transport) that is very important to include in the modal choice in the model. An over night transport might, for example, arrive at the receiver at 4 a.m., but if the receiving company is closed and cannot receive the shipment until 8 a.m., then the delivery time must be regarded as 8 a.m. This is particularly important when comparing road transport and combined transport in Sweden, since much of the competition occurs on over night transport. The often longer transport times in combined transport compared to all-road transport can here be absorbed by the later delivery times.

As shown in chapter 6.3, one of the modal choice criteria is that combined transport must match or outperform the delivery times in all-road transport. The comparison is thus relative to all-road transport. However, as shown above, a comparison between the delivery times cannot be made directly minute by minute, as it is not normally so that a transport that is, for example, five minutes faster is significantly better. A later delivery by combined transport is, thus, not necessarily a delay, but can in many cases be regarded as an equivalent delivery time. Two alternative modelling methods will be used to represent this: delivery time windows or comparative delivery time gaps. The methods can be used individually or simultaneously.

6.9 Delivery Time Windows

Delivery times will be compared using user defined delivery time windows for each transport relation. A time window is a certain time period, e.g. from 8 am to 10 am. User defined means that it is set by the model user in the input data. This means that if combined transport can deliver a shipment in the same time windows as all-road transport, then the transport modes are considered to have equivalent delivery times. As the modal choice requires combined transport to match or outperform all-road transport, combined transport is also allowed to arrive in a previous time period[45]. In Figure 26, both all-road transport and combined transport can deliver the shipment within the same time window. Road transport delivers first, but combined

[45] In reality, earlier delivery times could always be arranged to match later all-road delivery simply by delaying the goods at the terminal.

transport also delivers before the end of the time periods. Thus, both modes have equivalent delivery times for the shipment and the modal choice criteria that combined transport must match or outperform the delivery time by all-road transport is met.

Figure 26 Delivery time windows

The delivery time windows can further be set to allow an overlap between two time periods. This is done independently of the time windows above. The overlap is a period of time between two adjacent time periods that is shared between the periods. The shared overlap period is considered to belong to the one of the time periods that gives the greatest delivery time window for combined transport[46].

6.10 Comparative Delivery Time Gaps

The comparative time gaps make a direct comparison between the exact delivery time by all-road transport and the delivery time by combined transport. If combined transport can deliver the shipment inside a user defined[47] time gap from the delivery time by all-road, then the delivery time of combined transport will be considered equivalent. Earlier delivery by combined transport is always allowed. A time gap is a certain period of time, e.g. one hour. This takes into account that the acceptance of a later delivery time probably is greater if it is only a slight difference from the delivery time of the road transport system. Figure 27 shows an example of where

[46] This depends on in which time period the all-road transport arrives. If all-road transport arrives in the time period before the overlap, then the overlap belongs to that time period, i.e. extending the allowed time period for combined transport. If all-road transport arrives inside the overlap, then the overlap belongs to the next time period, i.e. the entire next time period is allowed for combined transport.

[47] The time gaps are set for each of the time windows used for the delivery time windows, i.e. the time window the all-road transport arrives in determines which comparative time gap to use. If only the comparative time gaps should be used, then the time windows should be shorter than the gaps used.

combined transport delivers within the comparative time gap and is, thus, considered equivalent to all-road transport.

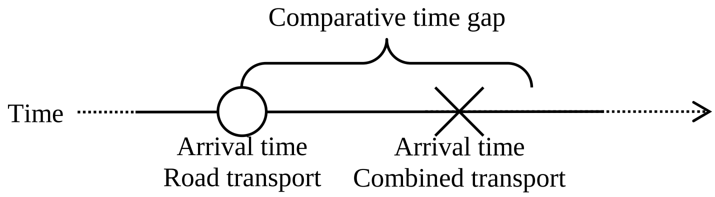

Figure 27 Comparative delivery time gaps

The comparative time gaps can also be used in combination with the delivery time windows to reduce the marginal effects when, for example, a shipment is disqualified from combined transport for arriving five minutes after the end of a long delivery time window, but still only is delivered slightly later than all-road transport. If both delivery time windows and comparative time gaps are used simultaneously, it is enough that one of them is satisfied for the delivery time to be considered equivalent to all road transport.

6.11 Departure Time Windows

A similar modelling will also be used for the departure times. The departure time for all-road transport is given by the input data, i.e. the time for the demand occurrence. However, it is unrealistic to assume that shipper the does not have any flexibility in adjusting the departure time, especially since the departure times set in the input data most often is expected to be based on average statistics[48]. Combined transport is dependent on meeting the train's departure times at the terminal and since, normally, there only are a few departures per day, the departure time from the demand point becomes very important. The model must, therefore, be given some flexibility to adjust the departure time from the sending demand point to match the available train departures. Departure times windows and comparative departure time gaps, similar to the time windows and gaps used when comparing delivery times, will therefore be used. The methods can be used individually or simultaneously. The time windows and gaps used are the same as for the arrival calculations.

[48] Data availability makes this the most likely option. However, the model could also be used by a transport operator or shipper with detailed flow data.

The combined transport departure times from the sending demand point can be adjusted inside a user defined departure time window. Later departure times for combined transport are always allowed[49]. See Figure 28 where both combined transport and all-road transport has equivalent departure times.

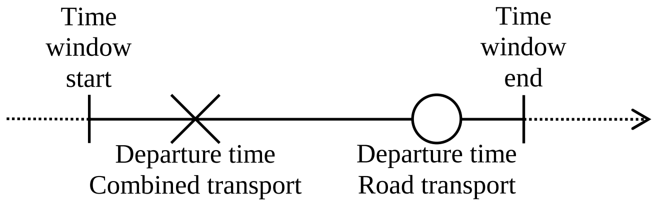

Figure 28 Departure time windows

As with the delivery time windows, a shared overlap time period between two adjacent time windows can be used. The shared overlap is considered to belong to the time periods that gives the greatest time window for combined transport.

6.12 Comparative Departure Time Gaps

A comparative departure time gap allows combined transport to depart earlier than all-road transport as long as it is within the time gap. Later departure times for combined transport are always allowed. See Figure 29 where the model has determined that an earlier departure time for combined transport is more appropriate, e.g. to catch an early train at the terminal. The suggested departure time is within the allowed time gap. Thus, the suggested departure time is allowed.

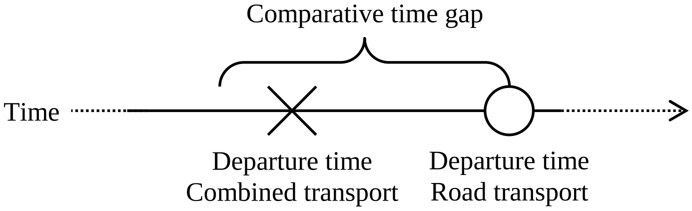

Figure 29 Comparative departure time gap

[49] In reality, later departure times could always be arranged to match all-road departures simply by departing the same time as all-road transport and allowing the goods to wait at the terminal.

6.13 Operating window

Together, the time periods and time gaps form an allowed time window for combined transport in which to operate, i.e. the time window between the earliest allowed departure time and latest allowed delivery time. Two examples of operating windows can be seen in Figure 30.

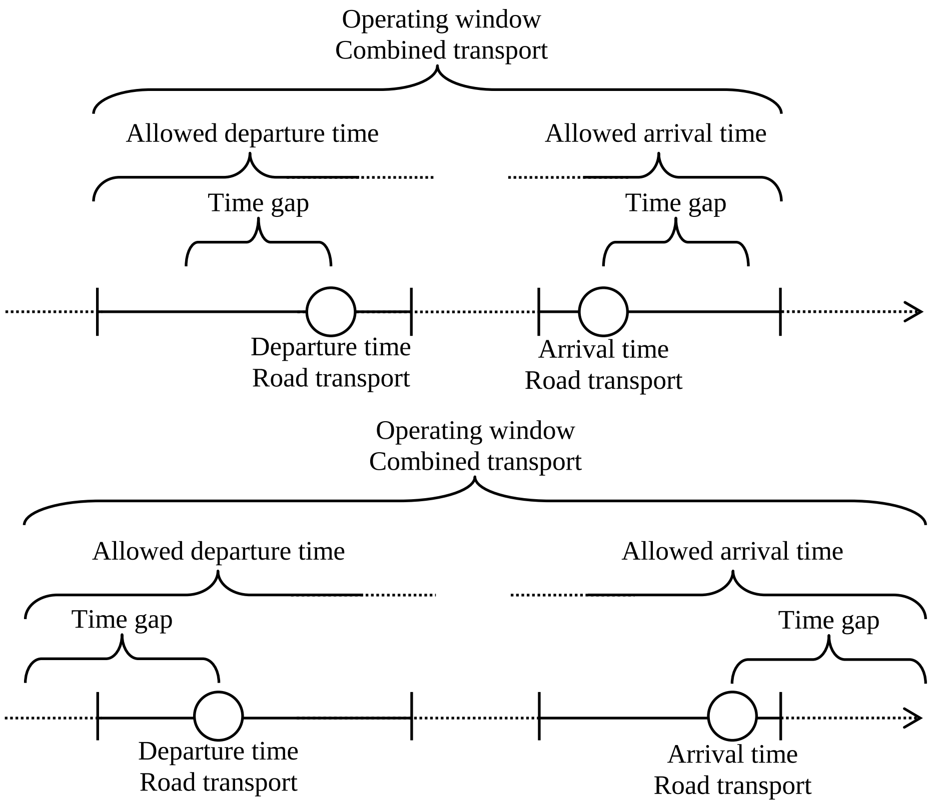

Figure 30 Examples of operating windows for combined transport

The figure shows both the time windows and the comparative time gaps. In the first example, the comparative time gaps are within the allowed time windows. The operating window, thus, follows the time windows, since they give a more generous operating window. The time gaps will, then, not affect the operating window. In the second example, the comparative time gaps stretch outside the time windows. The time windows are then disregarded, and the operating window follows the comparative time gaps[50].

The time system in the model is implemented using a continuous time scale. Each demand occurrence and train departure can freely, and independently of each other, be set to any time. The time windows and time gaps can also be defined individually for each transport link and time. A decimal system is, for mathematical simplicity, used for all time measurements, e.g. 1 hour and 30 minutes are calculated as 1.5 hours. Note that the model itself does not use any running, continuous or discrete, clock.

6.14 Open System

The combined transport system will be regarded as an open system. The combined transport system operates on an open market where the ITUs are not owned and managed by the combined transport company but by individual trucking companies or shippers who, at the same time, are the ones that decide the mode of transport and manage the haul to and from the terminal. An ITU can, therefore, also be used for other purposes than combined transport, such as serving as an ordinary trailer for road transport outside the combined transport system. Empty haulage should, therefore, not be explicitly considered in the model. Also, the model focuses on the difference between all-road transport and combined transport and the number of empty haulages is expected to stay the same with a transfer of goods to combined transport. In the event that a model user would like to include empty haulage, it can be included in the transport demand. However, note that the trains are considered to run in closed loops, see chapter 6.6.

6.15 Demand

The demand to transport is defined as a number of demand occurrences, each consisting of a sending location, a receiving location and a weight equivalent to transport. The demand occurrences can represent anything from an individual shipment to an aggregation of shipments and locations, depending on the modelling needs and data quality available. For example, smaller

[50] Naturally, the selection between time windows or time gaps can be mixed, e.g. that time windows are used to set the allowed departure time and time gaps are used to set the allowed arrival time.

shipments in the general cargo system might be included first after they have been collected and aggregated to larger shipments (since this phase is the same for both combined transport and all-road transport) while, in other situations, it might be more appropriate to aggregate all demand to a common geographical level.

The sending and receiving locations represent the geographical locations that the demand should be transported between. Each demand occurrence can freely, and independently of each other, be set to any time. Any weight equivalent can be used as long as lorry capacity is defined in the same unit. The model converts the demand occurrence to a number of lorries. All geographical locations are defined by their individual distances. The model uses a pre-calculated table of distances between all destinations and terminals.

Each demand occurrence is allowed to be split between several different train departures, and also between all-road transport and combined transport. However, an individual lorry, and its ITUs, cannot be split, since this is not realistic. All ITUs on a lorry are, thus, kept together.

The model aims at modelling the entire Swedish transport system for combined transport. Currently, the system consists of 16 terminals. The Swedish transport industry also uses a system where Sweden is divided into 484 so called primary areas[51], or demand points, for their transport planning, pricing, etc. The model should be able to handle at least that system size, although aggregation of demand points almost certainly will occur, e.g. due to very small goods volumes or positions very close to each other. The exact number of demand points and terminals to use is set by the model input. Model flexibility also allows for the model to be used on single train routes and/or few demand points.

6.16 Control Parameters

Some control parameters are used to control the behaviour of the model. Five specific control parameters are used, in addition to the control possibilities made possible by varying the general input data as described above.

[51] "Primärorter" in Swedish.

The optimisation type parameter selects between if business economic data should be used in the calculations or if social cost data should be used. Note that this only affects the data used in the heuristics process. Both types of data are always calculated in the model output.

The system optimisation parameter decides if the model should try to optimise the system according to each train route or according to the entire transport system, i.e. the entire system in the input dataset. Looking at the cost function curves in Figure 19, the difference is if a common cost curve will be drawn for all train routes, or individual curves for each train route. If an entire transport system optimisation is used, all train routes are considered jointly and the best total transport system is designed. Note that this means that large cost savings in one part of the transport system will help fund unprofitable transports in other parts of the system, if a maximum transfer of goods is also selected.

The maximum transfer or lowest cost parameter decides if the model should try to find the system with the lowest total cost (X_1 in Figure 19 on page 63) or the system that transfers the most goods to combined transport without an increase in total system cost (X_2 in Figure 19). When a lowest cost optimisation is selected, only demand that gives a positive cost saving is sent by combined transport. Note that the setting of the system optimisation parameter will then not affect the results, as the lowest cost system cannot be improved by cross subsidising[52]. Any transport in the combined transport system with a negative cost saving would only increase the transport system cost, irrespectively of on which train route it occurs. However, when trying to transfer the as much goods as possible without an increase in total system costs, also demand with a negative cost saving can be sent by combined transport, until the total cost saving for the system turns negative.

The cost control parameter allows combined transport to be a given percent more expensive or demands it to have a given percent lower cost than all-road transport in order to be selected. This, thus, adjusts the modal choice and can be used for sensitivity analysis. Looking at Figure 19 this means that, e.g. if a certain percent more expensive combined transport is allowed, the model will continue past X_1 and transfer more demand to combined transport.

[52] A slight difference might occur due to how shared fixed costs are handled. See chapter 7.2.1, chapter 10 and footnote 60.

The market share parameter adds a random disturbance to the modal choice. A given percent of the demand that has been assigned to combined transport is randomly reassigned to all-road transport[53]. This can also be used for sensitivity analysis.

Apart from the specific control parameters described above, there are also a number of other different settings possible for the model, as described previously in this chapter. These can also be regarded as control parameters, e.g. time periods used, lorry types allowed, banning of a certain mode, number of demand points used, number of terminals, the use of shared fixed costs, etc.

6.17 Measurement Units

No fixed measurement units are built into the model, e.g. ton, kilometre or €. The model accepts any units, as long as they are used consistently. E.g. if kilometres per hour are used for speed, all distance data must be input in km and time must be measured in hours.

6.18 Computer Technical Model Design

To transform the model design described previously into a working heuristics computer program required the model design to be adapted and adjusted into what was feasible to implement in the computer program being developed. This was an ongoing and interactive process where the technical details in the model design were developed, such as how time should be calculated. The computer programming itself, i.e. the source code, is not discussed in this thesis, since this would be too comprehensive and it is also not the purpose of this research. The finished computer model contains about 14 000 lines of code. The computer programming was a very complex and time consuming task. All programming work has been done by the author of this thesis.

The model is built from scratch in C++, which is the standard programming language today. The programming software Microsoft Visual Studio .NET

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[53] Each time something is assigned to combined transport, a random generator returns a number which determines if it should be reassigned to all-road transport. No train capacity etc. is then added.

2003 was used. The input and output files to the model are ordinary text files. A user-friendly model interface is built in the standard database software Microsoft Access. The interface uses simple fill in boxes and automatically formats the input data into the necessary input files, runs the model and displays the output files. See Figure 31 for examples of the user interface.

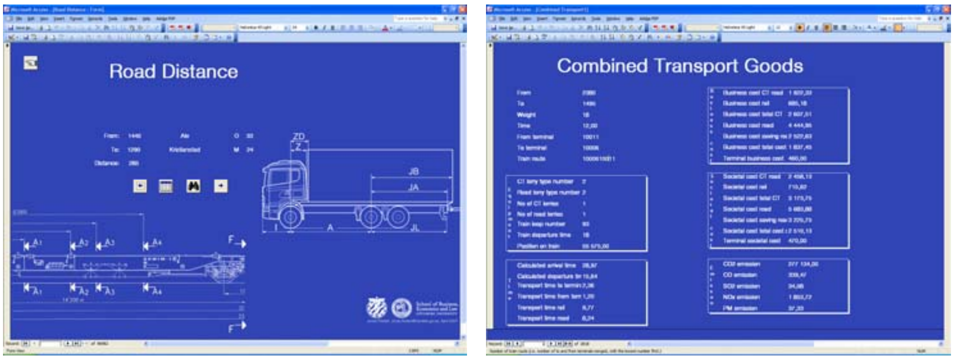

Figure 31 User interface in the Access model interface

Database software is specialised in managing large amounts of data, which makes it perfect as an analysis tool for the model output and also reduces the risk of input errors. Microsoft Access can also import and export data to and from all standard data formats.

The computer program follows the heuristics described in chapter 7 and is divided into a number of sub modules. Much effort was put into making the program as dynamic as possible. The program dynamically allocates all memory in order not to waste any memory space. This is important when working with large data sets, as is the case in this model. The model uses classes and objects to store the data. In developing computer software systems today, this object-orientation is the most commonly used method. It is based on the principle that the system is divided into objects, each carrying certain attributes and abilities. The objects are representations of real or abstract things in the real world being modelled, for example a lorry. Different types of classes exist to represent each type of object, e.g. trains are represented by a train class. Each instance, or occurrence, of the class, then, represents one instance of that type, e.g. one train. Each class instance stores all relevant data for the object represented, e.g. train speed, loading capacity, etc. These objects and classes are, then, linked together in relationships to form the greater system. Classes and objects are used in the computer program to represent the transport system being modelled, where demand occurrences, lorries, trains, terminals, time periods and distances are stored as classes and objects. Each demand occurrence is, for example, stored as a class instance containing to destination, from destination, departure time, arrival time, cost, environmental effects, assigned mode, etc. As the demand class instance passes through the model and the data is calculated, the data is stored inside the class instance. The class instance is, then, passed on through the functions in the computer model until it either ends up on a train (i.e. is linked to a train class instance) or in the all-road system. All along, the demand occurrence picked up and stored all data relevant for itself.

6.19 Summary of Model Features

This section will give a short summary of the features of the model. The full description was given in the previous sections, but a short summary is given here for the benefit of the reader.

The model can determine the modal split between traditional all-road transport and combined transport. It is also possible to run the model as a cost calculation tool, where the modal split is externally given. The modal choice assumes that the transport mode giving the lowest transport cost is selected. However, combined transport must offer, at least, the same delivery times as all-road transport. Time windows and time gaps, in which the delivery times are considered equal, are used to compare delivery times between the modes. The model can perform the calculations according to either societal economic costs or business economic cost. The environmental effects of the transport system are also calculated. The model can also be set to either perform the modal split calculations for each train route or jointly for the entire system. The model can also search for either the system that sends the most goods by combined transport without increasing the total system cost, compared to a system with only all-road transport system, or to search for the lowest cost system. The number and types of lorries and trains that can be used are unlimited. It is possible to impose restriction on the types of allowed lorries. Restrictions regarding allowed lorries, delivery times, departure times, etc. can be set individually for each transport link and time period. The length of a time period can further be set individually for each transport link. The allowed number of trains on a train loop can be set to a given number, a minimum number, a maximum number or unlimited.

Trains are regarded as a number of possible loading meters, without considering individual rail cars. The modal split can also be controlled by a number of control parameters. A random disturbance can be added in the modal choice, where not all demand assigned for combined transport is actually sent by combined transport. The cost calculations can also be controlled to force combined transport to have a certain percentage higher or lower cost than all-road transport in order to be selected. Further control over the model can be achieved by manipulating of the input data, e.g. testing the effects of different cost valuations.

7 HIT-Model Heuristics and Validation

The model heuristics explain the way the calculations work. The heuristics will first be explained in text with a simplified flow chart. The simplified flow chart is also shown in Appendix 1 and the full flow chart is shown in Appendix 2. This is then followed by a calculated example of the heuristics. The focus here is on the heuristics used in the calculations and this should not be interpreted as an exact flow chart of how the computer program technically operates. Naturally, the computer program follows the calculation heuristics, but the intention here is not to give a detailed description of the programming techniques used.

The model heuristics is built around four main blocks, see Figure 32. First, the data is loaded into the model from text files generated by the user interface in Microsoft Access and some preparatory calculations are made. This is, then, followed by the modal choice calculations to find the lowest cost transport system. If selected, the model continues to calculate the transport system which transfers the most weight to combined transport. Finally, the data output files are written.

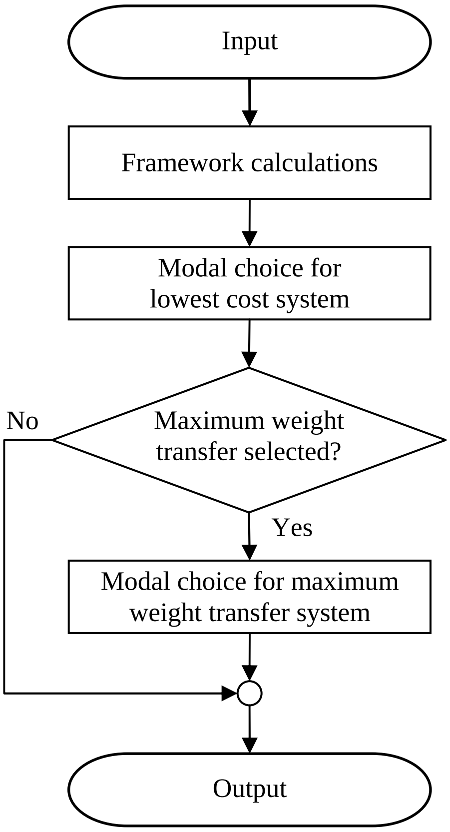

Figure 32 The main building blocks of the model heuristics

7.1 Framework calculations

After loading the input data, the heuristics starts by looking at each demand occurrence (origin, destination, time ready for transport, weight). The best all-road transport lorry, and number of lorries needed, is determined by calculating the transport cost for all types of allowed lorries. The lorry type that gives the lowest transport cost is then selected. Note that it is assumed that the entire demand occurrence should use the same type of lorry and it is the total cost for all lorries used to transport the demand occurrence that decides the best lorry type, i.e. the summary of all lorries needed for the transport. Integer number of lorries are used, i.e. if the capacity of 1.2 lorries is needed, then 2 lorries are used. In the same way, the best combined transport lorry is selected for the same demand occurrence using road, terminal and rail costs for the lorries[54]. Note that the selection of lorry also includes the ITUs to be used as they are included in the lorry type. The

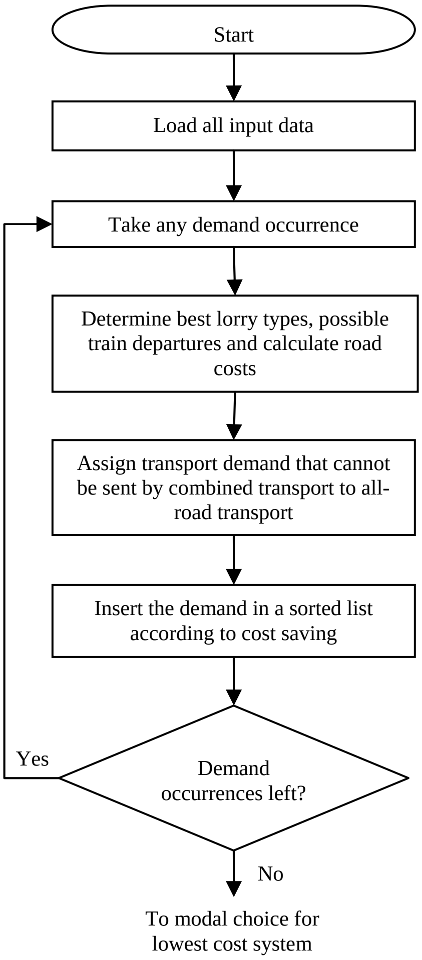

Figure 33 Framework calculations heuristics

[54] Note that cost calculations for the rail system here are only relative to compare the lorries. Fixed costs and costs to add new train capacity are not considered. The rail costs used are the costs for the first train to depart after the lorry has arrived at the terminal. The model might later select another train, possibly with other costs, for the lorry. However, only the variable costs for using an existing rail car are used, which are very small and only expected to vary very marginally. A complete cost calculation is made later in the model.

heuristics then continues by checking the delivery time constraints, i.e. that the delivery time for combined transport should match or outperform the delivery time from all-road transport. This is done by making a list of the possible train departures this demand occurrence can use without violating the time constraint. The possible train departures are the train departures input in the input data that the model can choose among. This is done by calculating the delivery time for the demand occurrence if it was sent by each train departure. At the same time, the departure time from the shipper to match the train is calculated[55]. The heuristics starts with the train first to depart after the lorry has arrived at the terminal and continues to check train departures forward and backwards in time until the delivery time constraints are violated. See chapter 6.8 on the use of time periods and the possible constraints[56]. This gives a list of the train departures that this demand occurrence is allowed to use. The list is saved for each demand occurrence.

When the lorry types and allowed trains have been determined for all demand occurrences, they are put on a list and sorted according to the potential cost savings in the road transport system by meter rail car needed for the demand occurrence if it should be transferred to combined transport (cost all-road transport minus cost road part of combined transport). A comparison with the train length required by the lorry's ITUs is used, since train capacity is the limiting and expensive resource in the system and needs to be used to the best extent. If a train route optimisation has been selected, a separate list is used for each train loop. Otherwise, a common list is used for the entire transport system. The sorted list is used to determine the order in which the demand occurrences should try to be sent by to combined transport.

The heuristics has also checked that there are allowed train departures for the demand, that the sending and receiving terminal is not the same and that the cost saving in the road transport system has not already violated the total cost saving constraint (if lowest cost optimisation is selected)[57]. If not,

[55] The departure time which is the latest that the goods can depart from the shipper and still make it in time for the train.

[56] Each train loop is only allowed to be used once for each demand occurrence due to the waiting list system used in the heuristics, see chapter 7.2.1. This is not expected to impose any noticeable restrictions, since it would require extreme settings for a train to meet the delivery time criteria on two separate departures.

[57] The train system is always a cost. If the cost savings in the road transport system alone (all-road cost - combined transport road cost) cannot meet the cost constraints (normally that combined transport should have a lower total cost), adding more costs will only make it

combined transport is not an option and the demand occurrence is assigned to all-road transport and not inserted in the sorted list. Similarly, if no all-road lorries are allowed, then the demand occurrence is directly assigned to combined transport and the necessary train capacity is directly inserted[58].

7.2 Modal Choice

In this step, the model starts with the sorted list of demand occurrences where the first demand occurrence in the list has the best potential cost saving, if sent by combined transport compared to all-road transport. The heuristics starts by selecting a train route (or the entire system if a total system optimisation is selected). The fixed cost for the train route (or system) is added to the aggregated cost and cost savings for the train route. The fixed cost for a train route represents the costs for the train route that cannot be assigned to an individual ITU, e.g. rent for a terminal. See chapters 6.4 and 9.7. The sorted demand list for the train route (or system) is selected and the heuristics starts by selecting the demand occurrence first on the list, i.e. with the highest potential cost savings. Note that the demand occurrences are selected in order of their cost saving and not by time, geography, etc. A demand for the last train departure can, for example, be selected before a demand for the first train departure.

The modal choice is done differently if searching for a lowest cost system (X_1 in Figure 19 on page 63), or the maximum transport of goods without an increase in total cost (X_2 in Figure 19). The model first follows the same heuristics until the lowest cost system is reached. The model then changes heuristics if maximum transfer is selected.

7.2.1 Lowest Cost System

The heuristics takes the selected demand occurrence and first checks if there is available capacity, i.e. already added rail cars that are empty on this

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worse. This demand occurrence will, thus, have a negative cost saving. Note that if maximum transfer optimisation is selected, then some demand with negative cost saving can be sent. Then these demand occurrences remain in the heuristics.

[58] This will affect and partly invalidate the modal choice heuristics. See chapter 6.6.

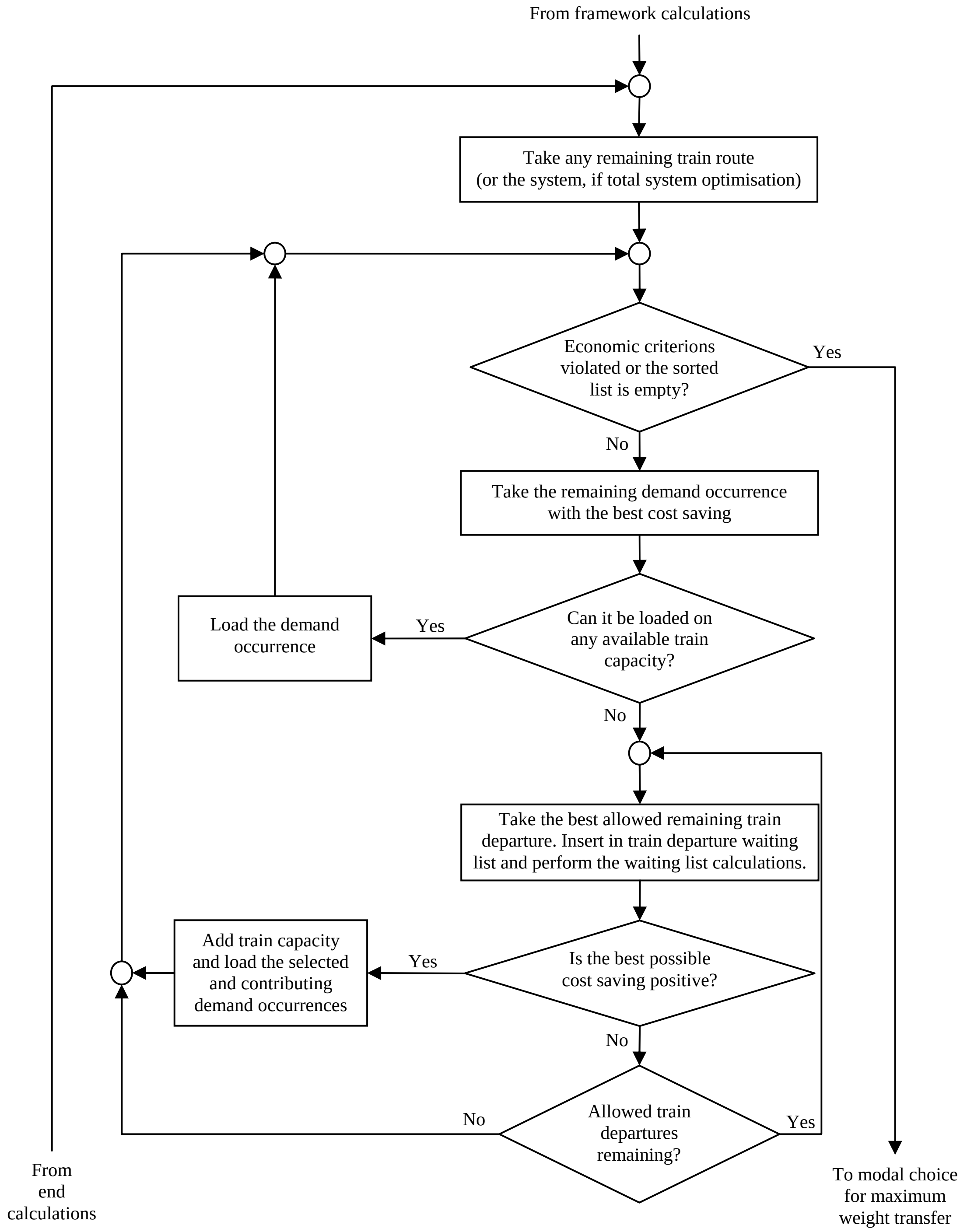

Figure 34 Lowest cost system heuristics

departure[59], for at least one of its lorries on any of the allowed trains for the demand. If so, the train is loaded, and, if necessary, the demand occurrence is split. Splitting means that the demand that can be loaded is transferred to its own demand occurrence and loaded on the train, while the remaining demand stays in the selected demand occurrence and continues in the heuristics. If the entire demand occurrence has been loaded, the next instance on the list is selected.

If something remains of the demand occurrence, the heuristics continues by determining if any new train capacity should be added to carry the demand. The heuristics tries to add the train capacity that has the lowest cost. The allowed train departures for the demand occurrence are therefore sorted according to the cost of adding the capacity for one more lorry on the train loop (including if a new train is required or only new rail cars). Note that the cost is for the entire train loop, since each train loop is assumed to consist of the same train set for the duration of the entire loop. Any new rail car added to the train loop will, thus, run the entire train loop and be available on all departures on the train loop. When searching for the transport system with the lowest cost, it cannot be allowed to add train capacity that as not been fully “financed”, i.e. do not give a positive cost saving. It is, therefore, necessary to consider the cost savings jointly for the entire loop when deciding to add new capacity. It is likely that several demand occurrences will be needed to meet the economic requirements to add new capacity, e.g. when a new train is needed. The cost savings generated by several demand occurrences (either on the current departure or on any other departure on the train loop) might then be needed to compensate for the high start-up costs of a new train. The new train should, thus, not be inserted on the loop until the cost is compensated by a cost saving[60] (or if other criterion is set, e.g. that

[59] Rail cars are always inserted on the entire train loop simultaneously. Thus, they might be used on some departures, but be empty on others. The model can also be run with a given train system where the number of rail cars to use are given and inserted by the model input, see chapter 6.6.

[60] Note that the fixed costs for the terminal are not considered in this comparison. The fixed costs are only included in the aggregated costs, as it would be unrealistic to demand that a single train loop (i.e. the first to add capacity) should cover the entire fixed costs. Under extreme circumstances it could be possible for a train route to never reach a positive aggregated cost saving, i.e. curve K_2-K_1 will never reach a positive value since the fixed costs are higher than the best possible cost saving. However, this is checked by the model after the lowest cost system has been determined. The demand assigned to combined transport is then reassigned to all-road transport, the trains are removed and the costs are recalculated. The exception is if a fixed number of trains or least number of trains have been inserted on the

combined transport is allowed to have a certain percent higher cost)[61]. The heuristics uses a waiting list for each train departure to collect demand occurrences until new train capacity can be added. The waiting list for a train departure is simply a list of demand occurrences that can be sent with that train departure but where the economic constraints are still violated, i.e. no capacity can be inserted. The waiting lists and cost calculations are explained in detail below. The allowed train departures are tested one by one according to the train list sorted above[62] until either the cost saving on a train departure allows for train capacity enough for at least one lorry in the demand occurrence to be inserted, or all allowed departures have been tested. Naturally, the demand occurrences can be split if not enough train capacity for the entire demand occurrence can be financed. When a departure with enough cost saving is found, the corresponding train capacity is inserted and the demand occurrences are assigned to combined transport. If the selected demand occurrence has been split, i.e. not everything could be loaded, then the heuristics continues by checking the remaining allowed train departures for the remaining part of the demand occurrence. If a demand occurrence cannot be loaded on any train departure, it is left on the waiting lists.

The heuristics then continues by selecting the demand occurrence with the second best potential cost saving in the sorted lists above and repeats the tests above, as long as there are remaining demand occurrences. When all demand occurrences for a train route has been tested, the demand still waiting on the waiting lists are assigned to all-road transport. The next train route is then selected etc. See Figure 34.

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train route by the input data. Since this is a given rain system that should be run, it is then allowed for the maximum cost saving to be negative. This test is also not performed if a total system optimisation is selected, since all trains route are to be considered jointly then.

[61] If two train departures are very close together, the departure that first can “finance” a locomotive will have an advantage over the other departure (i.e. lower cost as the locomotive already has been financed). This will cause lorries to select this departure. It is therefore not recommended to input several train departures very closely together, since the selection between these train departures not necessarily will be optimal. This level of detail is also not relevant in a strategic model. It is recommended to use the function where several trains are allowed on the same departure instead.

[62] If several train departures have the same cost, the train to depart first after the demand has arrived at the terminal (without adjusting the departure time from the sender) is used first. This is followed by trying later departures and, after that, earlier departures. E.g. if there are allowed train departures at time 15, 18, 21 and 24 and the demand arrives at the terminal at time 20, then the departures are tested in the sequence 21, 24, 18 and 15.

Waiting lists and cost calculations

The waiting lists and cost calculations require are more detailed explanation. When determining if new capacity should be added, the heuristics first takes the allowed train departure with the lowest cost (according to the train list sorted above). The demand occurrence is inserted at the end of the waiting list for the departure and the heuristics calculates if the total cost savings from all waiting lists on the train loop together can "finance" new train capacity (i.e. everything waiting at the different departures on the train loop are considered together). If not, the same demand occurrence is also inserted on the waiting list for the next train departure in the list and the calculation is repeated[63], etc. The same demand occurrence can thus be inserted on several waiting lists, but is naturally removed if it is loaded on a train.

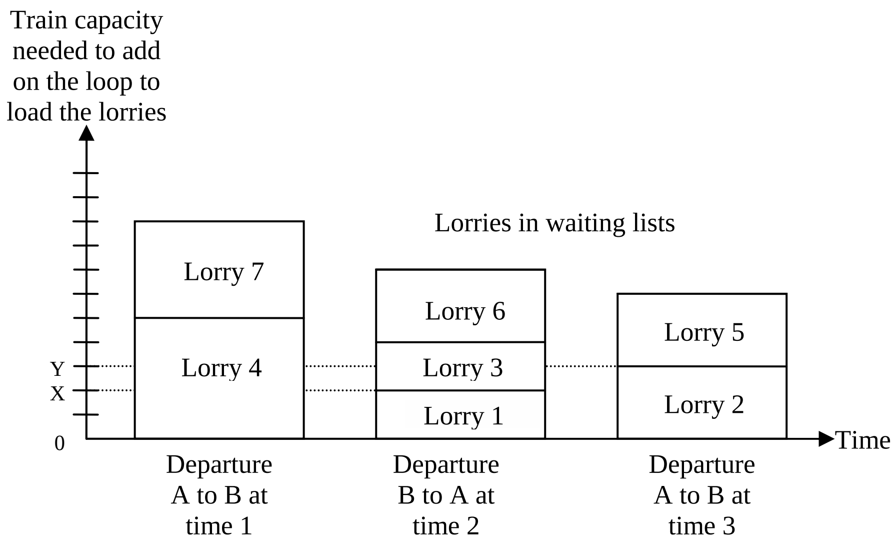

Figure 35 Waiting lists for a train loop

When calculating the cost saving on the waiting lists, the heuristics starts by determining the possible train capacity to add. The heuristics is not allowed to split a lorry between two train loops, but a demand occurrence can be split as long as the individual lorries stay intact. The ITUs on a lorry are, thus, kept together. Train capacity can therefore only be added to the train loop in multiples of lorry lengths. The possible train lengths are thus the end of each

[63] Since each demand occurrence only is allowed on one departure on each train loop, there is no risk of counting the cost saving twice.

lorry on the waiting lists. Figure 35 shows an example of a train loop with three departures and their waiting lists. The x-axle is the different departures, and the y-axle is the train capacity (i.e. rail car length) required for the lorries on the waiting list. The smallest train capacity that can be added is the capacity for lorry 1, i.e. capacity X. The next train capacity possible to add is capacity Y, i.e. the length of lorry 2. The cost savings in the road transport system[64] from lorry 1 is thus compared with the cost of adding train capacity X to the entire loop and send the lorry with combined transport[65]. This gives the cost saving for adding train capacity X. Next, the combined cost savings from lorry 1 and 2 (which are the lorries that can be loaded on capacity Y) are compared with the cost to add train capacity Y, which gives the cost saving for adding train capacity Y, etc. This continues by testing to add train capacity for each of the remaining lorries on the waiting list until either all lorries have been tested or the cost saving in the road transport system for all remaining lorries on the waiting list is negative[66]. The highest of the calculated cost savings from the waiting list (i.e. the cost saving if adding train capacity X or Y, etc.) is selected and, if the cost saving is positive[67], the associated train capacity is inserted and the lorries are sent by combined transport. If necessary, the demand occurrences are split. The heuristics then continues to test the remaining allowed train departures if the best cost saving was negative and, thus, nothing was transferred to combined transport, or if the selected demand occurrence from the sorted list above was split, i.e. something of the demand occurrence remains to be tested.

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[64] Cost saving in direct road when transferring the demand to combined transport minus cost for the road transport part of combined transport.

[65] Terminal handling costs for the ITUs and the costs to use a rail car.

[66] If the cost saving in the road system already is negative, then adding more costs from the rail system cannot make the total cost saving positive.

[67] If the cost control parameter is used, i.e. if combined transport should have a X% lower or higher cost compare with direct road transport to be selected, this means that the cost saving must be higher than X% of the costs of transporting by direct road transport. Note that X might be negative, thus allowing demand with a negative cost saving to be transferred to combined transport. During the calculations for the lowest cost system, this comparison is made for each waiting list.

7.2.2 Maximum Weight Transfer

When searching for the transport system with the maximum transfer of goods[68] to combined transfer without an increase in total system cost (X_2 in Figure 19), there is also a possibility to transfer goods with a negative cost saving to combined transport, since the negative cost saving of this demand is compensated for by the positive cost saving of previously transferred demand. The heuristics follow the same heuristics as for the lowest cost optimisation above until the lowest cost system is reached (but naturally without assigning all remaining demand to all-road transport). This is to ensure that all demand with a positive cost saving is transferred before attempting to transfer the demand with a negative cost saving. The same heuristics as when searching for the lowest cost system cannot be used, since the cost saving will never turn positive and there is, thus, no clear sign to determine when some demand on the waiting list should be transferred to combined transport. The heuristics will, therefore, focus on adding train capacity to the train loop that will cause the least negative cost saving.

After the lowest cost system has been determined, the heuristics starts by selecting a train route (or the entire system if a total system optimisation is selected) and transferring all demand from the sorted demand list to the waiting lists for the train departures (but without trying to insert any train capacity). The heuristics then determines the train loop that has the lowest negative cost saving for adding goods to the train loop, and adds train capacity and goods to that train loop.

This is done by, for each train loop, calculating the total cost of transferring the first lorry on the waiting list for all departures on the train loop to combined transport (including the cost to add new train capacity). However, as not all lorries are of equal length, train capacity for the longest of the first

[68] Transfer of goods is here represented by number of lorries (or more exactly the length of the ITUs, since the lorries are sorted according to cost saving per meter rail car used in the previous steps) transferred to combined transport. The model does not consider the weight loaded on each ITU during the modal choice. However, the weight loaded on individual ITUs is not expected to vary significantly. The interest in searching for maximum transfer of goods lies mainly in environmental aspects which largely depends on the number of lorries used, rather than the exact weight loaded on them.

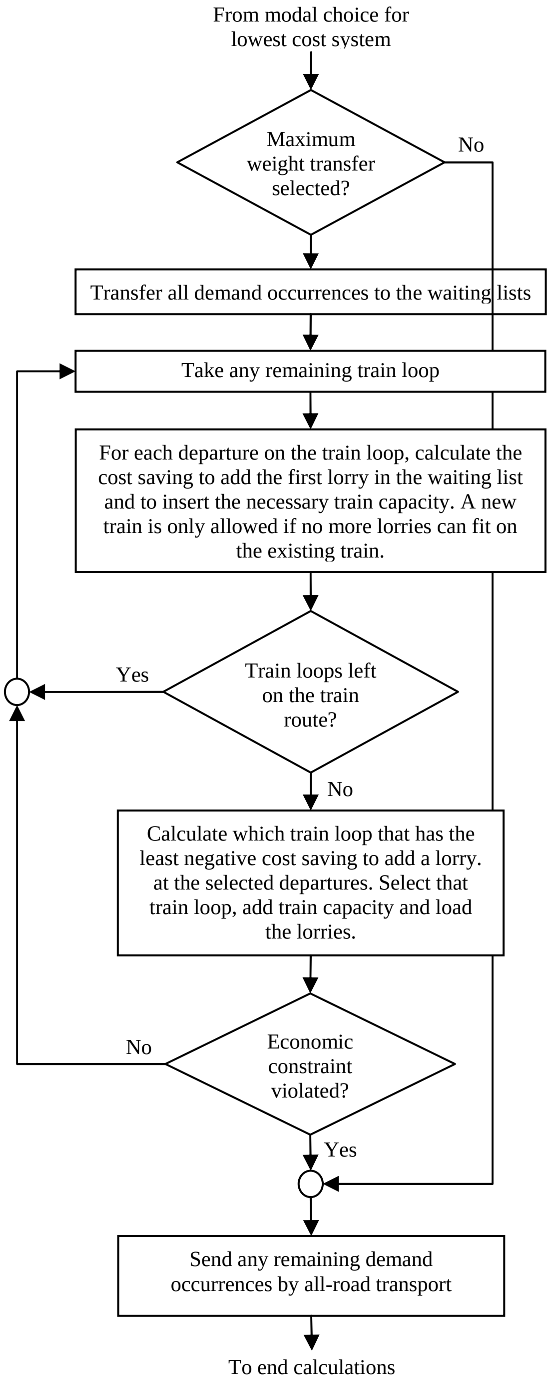

Figure 36 Maximum weight transfer heuristics

lorries on the waiting lists is selected[69]. The exception is if a new train would be required to load the longest lorry, while it would be possible to add the shorter lorries without a new train. The heuristics tries to avoid the high start-up costs of a new train and, therefore, only allows a new train to be added if no more lorries can be added to the previous train[70].

These calculations are repeated for all train loops on the train route, and the train loop with the least negative cost saving per rail car meter is selected. The first lorries on the selected train loop are then assigned to combined transport and train capacity is added. If necessary, the demand occurrences are split. This maximum weight transfer heuristics is repeated until the economic constraints (while considering the control parameters[71] and other constraints) are violated, i.e. the aggregated cost saving is zero for the train route (or system)[72]. Any remaining demand occurrences on the waiting lists are then assigned to all-road transport. See Figure 36.

7.3 End Calculations and Output

If train route calculations have been selected, then the model checks if there are any train routes left that has not been tested. If so, then the model selects the next train route and returns to the lowest cost calculations. If not, the output files are written and the model run ends. See Figure 37.

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[69] This means that several of a shorter ITU can be loaded if there is a large length difference. I.e. if the lorry for departure A is 10 length units long and the lorry for departure B is 20 length units, then train capacity for 20 length units is selected and (if the next lorry in the waiting list also is 10 length units) two of the shorter lorries from departure A are loaded.

[70] Assume that, for example, train capacity enough for a short ITU can be added to a train without requiring a new train. There are both short and long ITUs (which cannot fit on the train) standing first in the waiting lists for the departures on the trail loop. The heuristics then only considers the short ITUs. A new train is not allowed to be added until the short ITUs have been assigned to combined transport, i.e. the train has been fully utilised. Otherwise, the high cost of a new train required for the long ITUs might prevent the short ITUs from being sent by combined transport.

[71] The cost control parameter allows X% difference of the total aggregated cost from the cost if all demand had been sent by direct road.

[72] The cost saving will never be exactly zero, since the heuristics uses integer lorries. In many cases, the heuristics will also stop adding capacity when a new train is needed, since the large extra cost of a new train will push the aggregated cost saving past zero. This will cause the aggregated cost saving to stop a bit above zero. Also, sometimes there might just not be enough goods that could be transferred to combined transport due to time constraints.

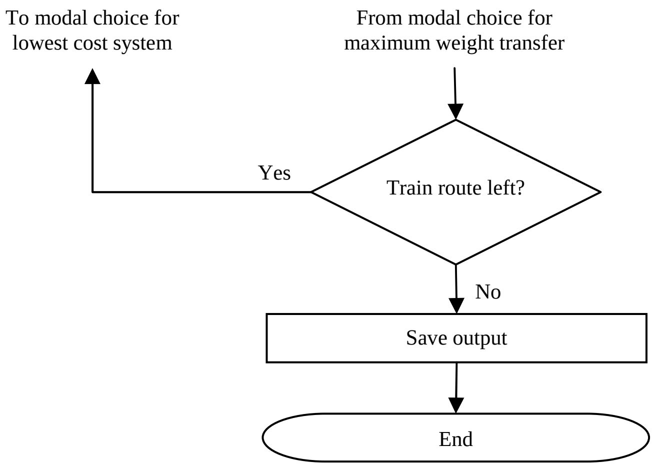

Figure 37 End calculation heuristics

7.4 A Calculated Example

A simplified calculation example might clarify the heuristics. The calculation data have been adjusted to give a simplified example that highlights the basic heuristics. All numbers are fictitious.

Assume that a transport system consisting of a large number of demand occurrence and train loops. This example will focus on two of the demand occurrences. Demand occurrence D consists of 50 tonnes and demand occurrence E consists of 40 tonnes. They both occur at the same time and should be sent to the same destination, however, the demand occurrences are completely separate and are not transported together. Both demand occurrences have the same all-road transport distance to the receiving destination and the distance to and from the terminals is also the same. Both use the same train route and there are two alternative train departures they both can use (departures N and M). There are also two types of lorries to choose among. Type A is a trailer lorry with one ITU (i.e. the trailer) and can load 20 tonnes. Type B is a swap body lorry with two swap bodies (i.e. two ITUs) and can load 25 tonnes. The same type of lorries are used for both combined transport and all-road transport. The cost for both lorry types is 100 for the transport to and from the terminals (25 for one transport leg and 75 for the other) and 300 for the all-road transport. Both lorry types take up the same capacity on the train. The cost to handle one ITU at the terminals is 50 (20 at one terminal and 30 at the other) and the variable train cost to transport an ITU is 5 for a swap body and 10 for a trailer. The cost to insert train capacity on the train loop for one trailer (or two swap bodies) is 500. See Figure 38 and Figure 39.

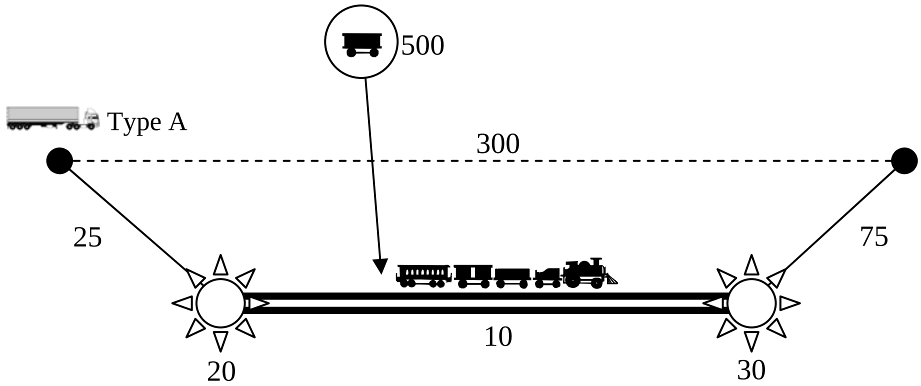

Figure 38 Costs for lorry type A

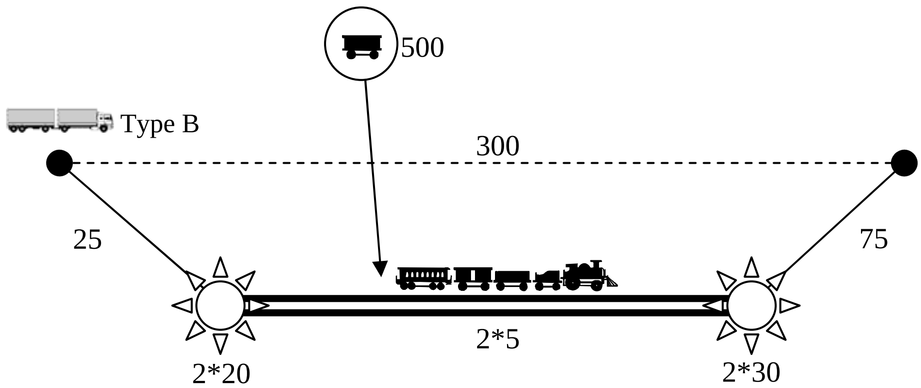

Figure 39 Costs for lorry type B

First, the best type of lorry is determined. Demand occurrence D can either use 3 lorries type A (50/20 = 2.5 = 3 lorries) or 2 lorries of type B. The cost for transport to and from the terminals is, thus, 3*(25+75) = 300 for lorry type A and 2*(25+75) = 200 for type lorry B. However, lorry B consists of 2 ITU and, thus, costs 2*2*(20+30) = 200 at the terminal and 2*2*5 = 20 for the train transport, which gives a total cost of 420. The same cost for lorry A is 300+3*1*(20+30)+3*10 = 480. The best lorry for combined transport is, thus, lorry type B. This is compared to the cost for an all-road transport of the demand occurrence to determine the potential cost saving. There are two alternative lorries for the all-road transport. In this example, the all-road lorries are identical to the combined transport lorries. The all-road transport cost is 300 for each lorry, i.e. 3*300 = 900 for lorry type A and 2*300 = 600 for lorry type B. The best lorry type for all-road transport is, thus, lorry type B. The potential cost saving for demand occurrence D is 600-420 = 180, i.e. the cost difference between the best alternative in combined transport and in all-road transport. The calculations are summarised in Table 4 and Table 5.

The same calculation for demand occurrence E in combined transport is 2 lorries and 2*(25+75)+2*1*(20+30)+2*10 = 320 cost for lorry type A. For lorry type B, 2 lorries are used and the cost is 2*(25+75)+2*2*(20+30)+2*2*5 = 420. Lorry A is, thus, the best alternative for combined transport. The all-road transport cost for both lorry type A and B is 2*300 = 600. Any of the lorry types can, thus, be selected for all-road transport. The potential cost saving for demand occurrence E is 600-320 = 280. These calculations are performed for all demand occurrences in the system. The combined transport lorries selected are, thus, 2 swap body lorries type B with a potential cost saving of 180 for demand D and 2 trailer lorries type A with a potential cost saving of 280 for demand E.

Lorry type A, trailer					
Lorry data		**Activity**	**Cost per ITU**	**Cost per lorry**	**Total cost**
Demand	50 tonnes	Road transport to terminal	-	25	3*25=75
Loading capacity	20 tonnes	Terminal handling one	20	1*20=20	3*20=60
Number of lorries	50/20=2.5 →3 lorries	Rail transport	10	1*10=10	3*10=30
Number of ITUs per lorry	1	Terminal handling two	30	1*30=30	3*30=90
		Rod transport from terminal	-	75	3*75=225
		Sum combined transport	-	*160*	*480*
		All-road transport	-	300	3*300=900

Table 4 Calculations for demand occurrence D and lorry type A

Lorry type B, swap body					
Lorry data		**Activity**	**Cost per ITU**	**Cost per lorry**	**Total cost**
Demand	50 tonnes	Road transport to terminal	-	25	2*25=50
Loading capacity	25 tonnes	Terminal handling one	20	2*20=40	2*40=80
Number of lorries	50/25=2	Rail transport	5	2*5=10	2*10=20
Number of ITUs per lorry	2	Terminal handling two	30	2*30=60	2*60=120
		Rod transport from terminal	-	75	2*75=150
		Sum combined transport	-	*210*	*420*
		All-road transport	-	300	2*300=600

Table 5 Calculations for demand occurrence D and lorry type B

Next, the lorries should try to be sent by combined transport. The demand occurrence with the highest potential cost saving compared to the train capacity needed (all lorries take up equal train capacity in this example) is demand occurrence E. This demand occurrence is therefore selected first. Departure N is tested first. Since previously[73], there is already a train and some rail cars inserted on the train loop. There is enough capacity available for one trailer on the departure. One of the two trailers in the demand occurrence is then assigned to the train. It is then calculated if any new train capacity can be inserted on the train loop for the other trailer. The cost to insert new capacity equal to one trailer (or two swap bodies) is 500, which is less than the potential cost saving. No new capacity can, thus, be inserted on the train loop. A copy of the remaining trailer is then put on the waiting list for the train departure (departure N) and the other possible train is tested (departure M on the next train loop). This departure has no available capacity, the waiting list is empty and the cost to insert new capacity for one trailer is also 500. Since trains operate on closed loops, any new capacity is added to the entire train loop. This train loop consists of two departures, the current departure M and another departure K. On departure K, there is

[73] In this example, the transport system consists of a large number of demand occurrences. Some of them has a higher potential cost saving than the studied occurrences D and E and has, thus, already been tested if they can be sent by combined transport.

already another trailer on the waiting list with a potential cost saving of 300. Individually, the two trailers do not generate a cost saving large enough to have any new train capacity inserted, but together they generate a positive cost saving of 280+300-500 = 80. They can, thus, be sent by combined transport. Train capacity for one trailer is, therefore, added to the train loop and the current trailer on departure M and the trailer on the waiting list on departure K are assigned to the train. Since the trailers are on two different train departures, then can both share the same new capacity on the train loop. The copy of the trailer inserted on the waiting list on departure N is deleted.

7.5 Model Validation

The model validation follows the steps laid out in chapter 3.5. The model validation consists of three main steps. Validation of the underlying conceptual model, validation of the translation of that model into a working computer model, and validation of the actual computer model. The first two steps has been discussed in the previous chapters and also at a number of seminars, research meetings, internal reports and conferences (Flodén, 2001, Flodén, 2002a, Flodén, 2002b, Flodén, 2002c, Flodén, 2004, Jensen, et al., 2001a, Jensen, et al., 2001b) The model has also been discussed continuously with thesis supervisor professor Arne Jensen and Dr Lars Brigelius, both with very long experience from transport modelling and combined transport.

The actual computer model has been validated through the three steps of verification, validation and evaluation. Verification (debugging) was made continuously during the programming phase. After each programming step and subroutine of the model was completed, it was tested with different sets of data to ensure full functionality before continuing towards the finished model. The finished model was, then, tested with several input data sets, designed to involve all parts of the model.

The validation step (agreement between the model and the real world) has consisted of tests for continuity, consistency, degeneracy and absurd conditions. As these tests are closely related to the verification of the model, they where carried out during the verification. The data sets used in the verification was therefore designed to also represent the different test for reasonableness.

A major model behaviour test was designed to validate the final model. The focus was on testing all functions of the model and to see that they returned the expected results. The test used three main scenarios, one small, one medium size and one large. The functions and control parameters of the model were tested by varying the settings/input data for that element. For the small size data set, all data was also calculated by hand to ensure that the model output was correct. Unfortunately, this was not possible with the larger data sets.

The small data set consists of two terminals, three demand points at each terminal, 36 demand occurrences per day (two shipments per day between all demand points at the different terminals) and was run for a 30 day modelling period.

The medium size data set consists of ten terminals, ten demand points at each terminal and 3 000 demand occurrences (three shipments per day between all demand points at the different terminals) and was run for a 30 day modelling period.

The large size data set used was the data set developed to represent the current combined transport system in Sweden (see chapter 9) and consisted of 14 terminals, 2 127 transport links with four shipments per day and was run for a 30 day modelling period.

The model was found to work correctly and it returned the expected result for the different data sets. A graphical validation can be made by plotting the cost curves from the model output and comparing them with the theoretical cost curves (see chapter 5.2).

As can be seen in Figure 40 and Figure 41, the output cost functions corresponds very well to the theoretical cost functions. This further validates the model. Figure 41 shows the actual output data from the model and plots the costs and cost saving of each individual demand occurrence for one train route. The data is from a model run with a maximum transfer of goods optimisation. In the beginning of the curve, the total cost saving is negative which is expected due to the fixed terminal costs that is inserted at the beginning of the model run.

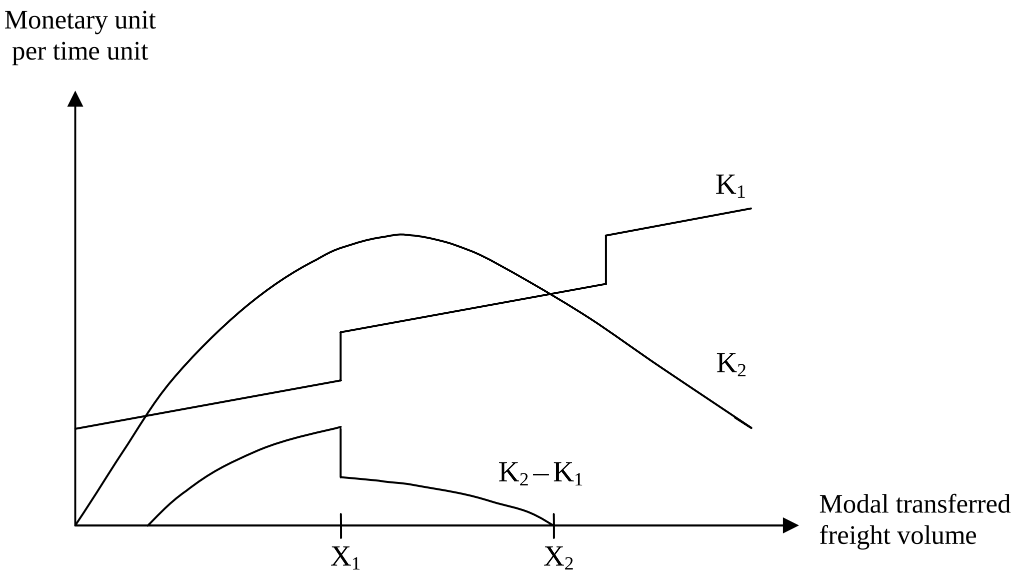

Figure 40 Theoretical representation of the cost functions

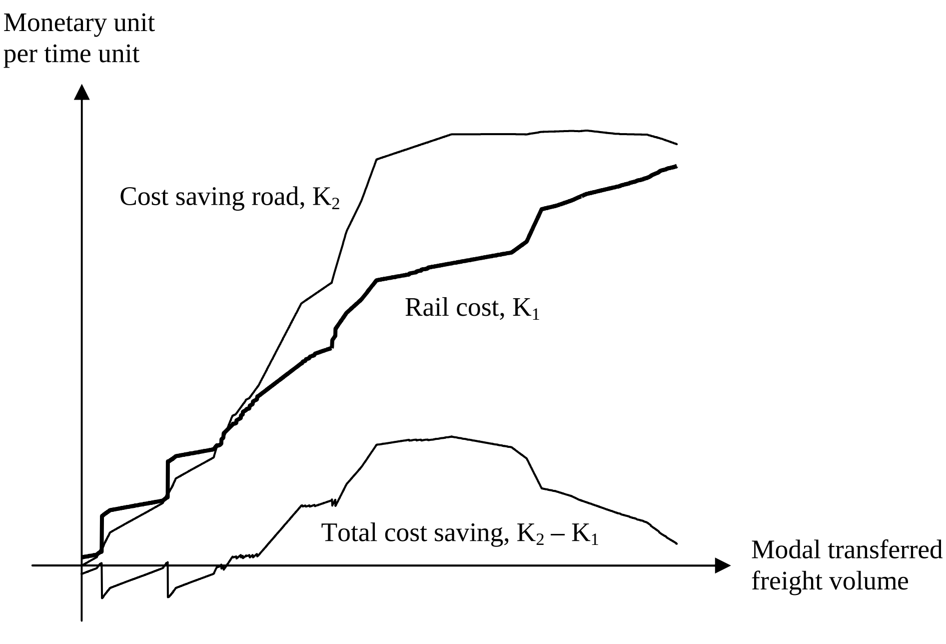

Figure 41 Model output cost functions

The heuristics then adds a new train to the train loop as soon as the total cost saving reaches past zero[74]. As can be seen, the total cost saving curve does not reach exactly zero, but stops on a slightly positive cost saving. The costs of adding the necessary train capacity to transfer more goods to combined transport would have caused the total cost saving to turn negative. This was therefore not allowed by the heuristics. Three trains are used on the displayed train route, which can be clearly seen as “jumps” in the rail cost. Two train are inserted in the beginning of the curve and one close to the end.

The final step in the validation process is the model evaluation to determine that the finished model meets the requirements set up for the model and that it is possible to run. The purpose of the model is to be used for determining the potential for combined transport in Sweden (see chapter 2 for the exact research question). It can be concluded that the model is well adapted for this problem. The development of the input data set and the model runs and analysis conducted later in this thesis validates that the model meets the set up requirements and can answer the research question. The model, and all assumptions made, is also described thoroughly in this thesis which facilitates further uses of the model in other research projects.

[74] The “jumps” in the cost curves do not occur at the first demand occurrence being loaded on the new train capacity. This is caused by that the heuristics assigns the demand occurrences to combined transport in groups. As explained previously, the heuristics collects the cost savings from several demand occurrences, in order to “finance” the high cost of new rail capacity. This group of demand occurrences are then assigned to combined transport simultaneously. However, the plotted cost curve shows each individual demand occurrence, and not groups of demand occurrences. When plotting the cost curves, the sequence the demand occurrences within a group are “loaded” on the train (i.e. where they are put on the cost curve) depends on the internal workings of the computer program and how the trains are stored there. The model assigns the complete costs of the new train capacity to the demand occurrence that caused the train capacity to be inserted (i.e. the demand occurrence that contributed with the last cost saving). This demand occurrence is, not necessarily, the first demand occurrence to be loaded on the train in the group. Note that this does not affect the heuristics, since the heuristics assigns the demand occurrences to combined transport as a group. The first part of the curves, thus, represent fairly large groups of ITU being assigned to combined transport at the same time, although the demand occurrences are plotted individually on the curve. The groups are particularly large around the points where a new train, i.e. a large train cost that need to be “financed”, is inserted. When the total cost saving starts descending, a different heuristics is used. The demand is then assigned to combined transport in smaller groups (more or less only the length of one lorry at a time). This causes a much smother curve.

8 Data Structure

This chapter shows an overview over the input and output data used in the HIT-model. The background and overall structure of the model has been previously explained in chapter 7.

8.1 Input Data

The input data to the model consists of transport demand, road distances, rail distances, terminal areas, terminal data, train types, all-road lorry types, combined transport lorry types, allowed train loops, allowed lorries, time periods and control parameters. The cost data in the input data follows the division described in chapter 6.4 into business economic cost, social cost (with time dependent costs and distance dependent costs) and environmental data. Costs are business economic costs and social economic costs. Environmental data are CO_2, CO, SO_2, NO_x, PM, HC, energy consumption and monetary estimation. A decimal system is used for all time data. All input data can be set to any reasonable arbitrary value and an unlimited number of demand points, demand occurrences, train types, lorry types, terminals, etc. can be used[75].

[75] Computer programs always contain constraints to some extent. The current model is built flexible and dynamically allocates memory and resize the storage structure when needed. However, some constraints are set when the source code is compiled into a running program. For example, the variable that contains lorry type numbers (used to identify the type of lorry, e.g. a trailer lorry is called type 2) is a “short unsigned int” that has a maximum storage capacity (i.e. the largest number the variable can hold) of 65 535, which means that 65 535 different types of lorries can be used (the variable identifies lorry types, not individual lorries). The variable could easily be extended to, e.g. an “unsigned int” to hold 4 294 967 295 by just changing one line in the program. The possible model size is thus unlimited, but might require the program to be recompiled if extreme models should be run. Since a computer always reserves memory space for the largest possible number in a variable,

8.1.1 Transport Demand

Transport demand is the demand to transport. It is input with origin and destination, weight to transport and time ready for transport. This is the demand for which the modal split shall be determined.

8.1.2 Road Distance

Road distance is the road distance between all demand points and between the demand points and their assigned terminal.

8.1.3 Rail Distance

Rail distance between all terminals.

8.1.4 Terminal Areas

The terminal that each demand point is assigned to.

8.1.5 Terminal Data

Costs and environmental data for each terminal. Handling costs for each lorry type at the terminal.

8.1.6 Shared Fixed Costs

Shared fixed costs and environmental data for each train route, or the entire system if a total system optimisation is selected.

8.1.7 Train Types

Cost, capacity, environmental and speed data for each train type. Cost data divided into cost for new train, new empty rail car unit on train and transporting something on a rail car unit. Capacity is set as maximum train length.

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all computer programs are compiled to hold no more than the expected variable sizes to avoid wasting memory.

8.1.8 All-Road Lorry Types

Cost, capacity, environmental and speed data for each lorry type.

8.1.9 Combined Transport Lorry Types

Cost, capacity, environmental data, speed and length required on train for each lorry type. Note that the type of ITU used is included in the lorry type.

8.1.10 Allowed Train Loops

The possible train loops that the model can choose from. Each train loop is input with departure times, train type, number of trains allowed on the loop (a given number of trains, a minimum number of trains, a maximum number of trains or an unlimited number of trains). The train loops are numbered.

8.1.11 Allowed Lorries

The lorry types that are allowed to be use between two demand destinations and the time window they are allowed. Input both for all-road lorries and combined transport lorries.

8.1.12 Time

The time periods and time gaps set for each transport link. Start and end times for the time windows and the length of the allowed time gaps.

8.1.13 Control Parameters

Parameters used to control the behaviour of the model. Selects between business economic calculation and social cost calculation, total system optimisation and train route optimisation, maximum transfer to combined transport and lowest system cost, and sets cost control parameter and market share parameter.

8.2 Output Data

The model output data consists of combined transport demand, road transport demand, train loops and aggregated data. The data is output for each individual demand occurrence, train departure and train loop.

8.2.1 Combined Transport Demand

The combined transport demand contains the demand occurrences, or parts of them, that have been assigned to combined transport. For each individual demand occurrence, the output contains origin and destination, weight transported, original input time ready for transport, calculated departure and arrival time, arrival time if the demand should have been sent by all-road transport, train departure and loop used, position on train, transport time to and from terminal, transport time train, lorry type and number of lorries used, lorry type and number of lorries used if the demand should have been sent by all-road transport, environmental effects (CO_2, CO, SO_2, NO_x, PM, HC, energy consumption, monetary estimation), business economic and social costs divided into cost for the rail transport, terminal cost, cost in the road part of combined transport, cost if all-road transport would have been used, total cost, cost saving in the road transport system and total cost saving. All demand occurrences are also given a serial number in the order they have been assigned to combined transport.

The original input demand occurrences might have been split between several trains or both modes. If a demand occurrence have been split is shown by a variable (yes or no). The split parts of the original demand occurrence are output as separate demand occurrences. The original input demand and the other parts of the split demand can, if necessary, be identified by looking at the origin, destination and time originally ready for transport variables.

The model also outputs if the reason for selecting combined transport were that the input data did not allow any all-road transport lorries for the demand occurrence and if the demand occurrence was transferred during the first part of the heuristics, i.e. the lowest cost system, or the second part, i.e. maximum transfer of goods without a total cost increase.

It should be noted that the cost of inserting new train capacity is assigned to the last demand occurrence in the group of demand occurrences that caused the train capacity to be inserted when searching for the lowest cost system. If the cost saving from several demand occurrences is needed to finance new train capacity, the total cost of the train capacity is thus assigned to the last demand occurrence that caused the combined cost saving to make it possible to insert the train capacity. This must be remembered when looking at the costs for individual demand occurrences. The model outputs a second serial number where demand occurrences transferred together are given the same number to facilitate the analysis. When searching for maximum weight transfer, the cost for new train capacity is assigned to each individual ITU. If no ITU is loaded on a departure, then that capacity cost is assigned to the first ITU to be loaded on the train loop, i.e. on the train departure earliest in time on the loop.

8.2.2 Road Transport Demand

The road transport demand contains the demand occurrences, or parts of them, that have been assigned to all-road transport. The output contains origin and destination, weight transported, original time ready for transport, lorry type and number of lorries used, lorry type and number of lorries used if the demand should have been sent by combined transport, the variable costs if the demand should have been sent by combined transport[76], environmental effects of the transport (CO_2, CO, SO_2, NO_x, PM, HC, energy consumption, monetary estimation), if the demand has been split, business economic and social costs for the road transport. All demand occurrences are also given a serial number in the order they have been assigned to direct road transport.

The model also outputs the reason why the demand occurrence was not sent by combined transport. The reasons are: Same sending and receiving terminal, No trains allowed at all on train route (user constraint), No combined transport lorries allowed (user constraint), Combined transport cannot meet time constraints, Market share parameter forced road (user constraint), No more trains allowed to insert on any of the allowed departures (user constraint), Combined transport too expensive[77]. It should

[76] The variable costs are the road haulage costs to and from the terminal, terminal handling and the cost to use the necessary rail car capacity on the train. The exception is if no combined transport lorries or trains departures are allowed for the demand. Then, naturally, no costs can be calculated.
[77] Combined transport too expensive is actually divided into several sub reasons to indicate where during the model run the cost constraints are violated. These are if the road transport

be noted that the reasons are not necessarily mutually exclusive, e.g. a demand occurrence might violate both the delivery time constraint and the economic constraint. The reasons are prioritised in the order they are listed here, e.g. if the delivery time constraint is violated, then that is listed as the reason and the demand occurrence is not tested any further. See also chapter 7. This must be considered when analysing the output reason.

8.2.3 Train System Data

The train system selected is output as the selected train loops to use with the number of trains, total length of rail cars on the train, business economic cost, social cost, environmental effect (CO_2, CO, SO_2, NO_x, PM, HC, energy consumption, monetary estimation) and total goods weight on train. The same data is also output for each individual train departure, including available capacity on each departure.

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costs alone violates the cost constraints (lowest cost optimisation only), road transport + variable train costs violates the constraints (lowest cost optimisation only), if the demand occurrence is inserted in the train departure waiting lists but cannot support any new capacity. Further, it is also outputs if the reason is that the demand first was assigned to combined transport but later reassigned to direct road transport since the fixed terminal costs where to high, i.e. the aggregated cost saving never became positive (see footnote 60).

9 Data Set

A data set representing the current transport system was created to be used in the model to test the model and determine the potential of combined transport in Sweden. A data set is the collection of input data and parameter settings that is to represent the real-world system to be modelled in the computer model. The data set combines with the computer model to create the full model of the transport system used to answer the research questions. The data set, thus, contains the system size, transport demand, infrastructure and geographical data (rail network, road network, terminals, demand points, etc.), equipment (lorries, trains, etc.), costs data, environmental data, time windows, etc. See chapter 8.1 for all input data. Note that the computer model can be run with different data sets. In this research, the data set represents the current transport system in Sweden at a strategic level.

9.1 Time Period

The survey by Saxin, Lammgård and Flodén shows that aggregated transport demand in tons is evenly divided across the weekdays. However, the transport demand is significantly lower during the weekends, see Table 6. Therefore, the focus of the data set is on weekdays (Monday to Friday). This is also in line with the current combined transport system which has very limited services during weekends (CargoNet, 2005c).

Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
19.2%	19.0%	17.9%	17.5%	18.2%	4.0%	4.2%

Table 6 Demand distribution across the week in tonnes

The length of the data set period must be long enough to correctly represent the effects of unbalanced goods flows. Higher cost savings in one direction would otherwise be over or under represented, see chapter 6.6. A train must thus, if possible, run A to B as many times as it runs B to A, i.e. “close” the loop. The length of the modelling period needed is dependent on the data set used. A data set with more balanced goods flows will require a shorter modelling period.

Considering a departure time in the evening, the longest possible door-to-door combined transport in Sweden runs over three calendar days (pick-up in the afternoon day one and delivery in the morning day three). The longest train loop is, thus, four days (departure in the evening day one, arrival in the evening day two and departure again in the evening day three and arrival in the evening day four). Unfortunately, a least common time denominator cannot be found for all train loops, i.e. not all train loops can be “closed” at the same time, since new trains depart every day on the train routes. The model will, therefore, be run during such long time periods that any effect of “open” loops will be negligible. This will also reduce the effects of any ITUs waiting at the terminals at the start or end of the model run. Tests were carried out by gradually extending the modelled period until the effects from extending the time period further were negligible on the results. The benefits from extending the modelled period are rapidly decreasing with the length of the period. The model was tested with 7 days, 14 days, 30 days, 60 days, 91 days and 181 days data sets. It was found that extending the data set further than 60 days will only improve the result with less than 1% when searching for the lowest cost system. The modelling period was, thus, decided to 60 days, i.e. two months. See Figure 42.

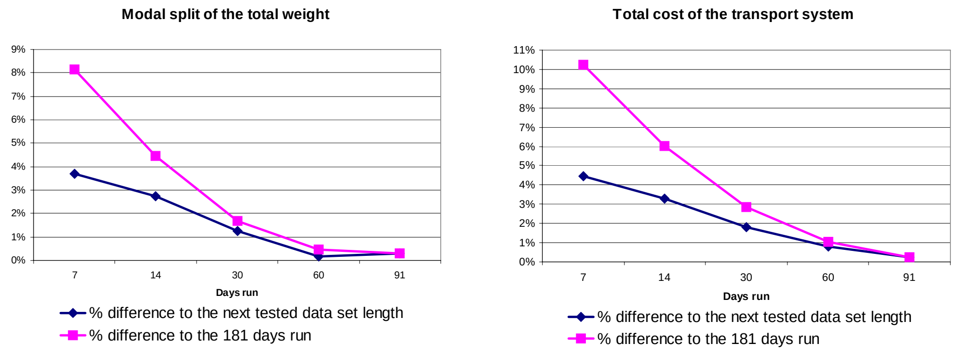

Figure 42 The decreasing effect of extending the modelling period

Since, the modelling focuses on weekdays, it will be considered that all days are weekdays, i.e. weekends are not considered. The reason for the model to run over a long time period is only to reduce the effects of “open” loops and not to model full weeks. The model output should be considered to represent typical weekdays in the combined transport system.

The data set will represent the year 2001, because the most data is available for 2001. The major demand databases are for the year 2001. Much cost data, particularly in the social cost calculations will also be collected from SIKA (The Swedish Institute for Transport and Communications Analysis), which is the national agency responsible for determining the cost levels used in the official societal calculations in the transport sector. The latest data released by SIKA uses the cost level for 2001. The transport sector has not undergone any major changes since 2001 that would affect the potential of combined transport in any drastic way.

9.2 Demand Data

The demand data must represent the transport demand on a fairly detailed geographical level. The collection area around a terminal is, in most cases, smaller then 100 kilometres and also depends on the direction of the collection haulage. If the collection is made away from the final destination (e.g. the demand is going north, but first have to travel south to get to the terminal), then combined transport becomes less competitive compared with direct all-road transport than if the collection is made in the same direction as the final destination, i.e. if the total distance to transport is increased (Niérat, 1997). See Figure 43.

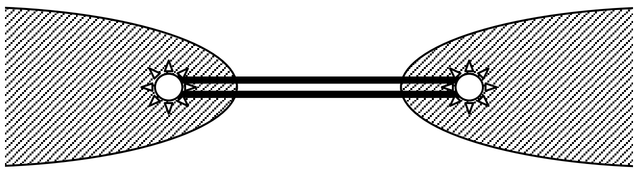

Figure 43 The principal shape of the competitive collection area around a train route

The geographical level of detail must be high enough to adequately represent the increasing and the decreasing cost savings curve from the heuristics. The

290 Swedish municipalities[78] (kommuner) have, therefore, been selected as an appropriate level of detail. See Appendix 9 for a map. The municipalities have the advantage of being smaller and closer together in denser populated areas and larger in less populated areas. This gives an appropriate higher level of detail in densely populated areas with more goods transports and fits well with the current terminal structure where terminals are located close to large population centres. Each municipality has a significant degree of political and administrative autonomy and is also commonly used as a grouping in public statistics and accounts.

Several data sources for demand data exists, and will be reviewed in this chapter.

9.2.1 Export and Import

Goods with an origin or destination outside Sweden must also be considered. 25% of the outgoing shipments in tons (SIKA, 2001a) have their origin or destination outside Sweden. To completely disregard that goods is not appropriate, since it is very much a part of the Swedish transport system. However, the focus of this research is on the domestic Swedish transport system and to completely include the European goods in full detail would require the model to be extended to a full European scope. The export and import goods are, therefore, considered to be aggregated at the border crossing. Goods to/from mainland Europe are considered aggregated to Trelleborg, goods to/from Denmark are aggregated to Helsingborg, goods to/from Finland are aggregated to Stockholm or Umeå, depending on which is closest. Goods to Norway are aggregated to Göteborg or Hallsberg, depending on which is closet. Goods to/from Russia and the Baltic states are aggregated to Stockholm. Goods to/from the rest of the world are aggregated to Göteborg, which is the largest port in Sweden, as almost all goods with a destination outside Europe are sent by ship. The other aggregation locations have been selected as the combined transport terminal locations that is closest to the sending/receiving country and where transport links to the country currently exists. If there are several potential locations, e.g. Helsingborg or Malmö to Denmark, then the location with the largest goods flows have been selected. Statistics from Øresundsbron (2001) and ShipPax (2000) have been used. This aggregation will, however, cause the data set to underestimate the length of the rail haulage, which will be a disadvantage for

[78] In EU statistics, the municipalities are called Local Area Unit 2 (LAU 2) (SCB, 2005a).

combined transport, since it, generally, is favoured by long rail haulage. The demand for different countries that uses the same border crossing will be aggregated, but the demand will not be included in the domestic goods to the same border area. This is because international and domestic goods might use different lorries. The exception is goods to Norway via Göteborg that also is separated from other export/import goods due to that it is sent by land (i.e. potential combined transport goods that uses different lorries) and not by sea as the other goods sent via Göteborg. Also, goods to Finland via Stockholm are separated from other export gods via Stockholm, since different lorries are used. See chapter 9.5.

9.2.2 The National Commodity Flow Survey

The official national transport statistics in Sweden are collected by SCB (Statistics Sweden) by assignment from SIKA (The Swedish Institute for Transport and Communications Analysis). The commodity flow survey (Varuflödesundersökningen, VFU) is a part of that national transport statistics. The survey is sent to 12 000 local units[79] and concerns their arriving and departing shipments (including import and export). The VFU separates itself from previous statistics by its focus on the individual shipment. The previous national transport statistical studies were mode specific and targeted the individual lorry etc. The VFU focuses on individual shipments and maps the shipments origin, destination, weight, value, load unit, the sequence of transport modes used during the entire transport chain, commodity class, etc. Import and export data is included in the survey. The geographical level of detail is very high with each shipment being recorded at a five digit zip code level. Not all lines of businesses are included in VFU, since it focuses on manufacturing and wholesale industry with added data from mining, agriculture and forestry from other sources. The first VFU study was carried out in 2001 and the survey is scheduled to be repeated every third year. Microdata, i.e. raw data, from the survey is availably free of charge for researchers. For more information see SIKA (2001a, 2003a). SIKA has made the VFU microdata for 2001 available for this project.

Unfortunately, the uncertainty in VFU is very high when looking at a detailed level. The data consists of 922 913 observations which is too few to have any acceptable quality when looking at a municipality to municipality

[79] A local unit is defined as each address, or building(s), where a company carries out economic activity.

level (298*298 = 88 804 transport relations[80]). However, aggregate data have acceptable uncertainties. The aggregation of all goods sent from a county[81] (län) has an uncertainty of about 10-20%[82] for a county.

9.2.3 Forwarder Data

The best source of transport flow data is of course the transport providers themselves. The three largest transport companies have, therefore, been contacted and kindly agreed to share flow data with this research project. Flow data has been collected from the large forwarders (Schenker, Danzas[83] and Fraktarna[84]). Unfortunately, not everyone could give data for the same year. Schenker and Fraktarna returned data for year 1999 and Danzas for 2002. The data consisted of all domestic transport flows during the entire year aggregated into a yearly total, i.e. the sum of all transports between two destinations during the year. Danzas' data was also divided per month. Schenker and Fraktarna's data was aggregated into primary areas (primärorter) which is a geographical division of Sweden into about 500 regions created by the transport industry for their planning, pricing, etc. Danzas data was divided into a more detailed division with about 3 000 regions. The data consisted of weight and volumetric weight[85] and number of shipments. The total transported weight in the collected data is 16.3 million tons and represents 7.8 million shipments.

Some weight in Schenker's data is counted double if it is handled at terminals. The forwarders collect small shipments in a region (normally less than one tonne) with smaller lorries and transports them to a terminal, where the shipments are reloaded, e.g. to long-haul lorries, and shipments to the same area are aggregated together for the long-haul transport. They are then

[80] Including export/import destinations.
[81] Sweden is divided into 21 counties. See Appendix 8 for a map.
[82] The lowest being Norrbottens län with 3.9% and the highest Blekinge län with 38.4%. 13 of the 21 counties have an uncertainty less then 20%. Goods from these counties represent 74.6% of the total goods flow. 4 counties have an uncertainty less then 10%., representing 38.3% of the goods flow. 2 counties have an uncertainty greater then 30%, representing 4.3% of the goods flows. A confidence interval of 95% was used (SIKA, 2001a).
[83] Now called DHL.
[84] Now called DSV.
[85] "Fraktdragande vikt" in Swedish. The weight of low density goods is converted to a chargeable weight based on the volume of the goods. A formula converts the actual weight of the shipment to a new "imagined" weight for charging freight in accordance to how much capacity the shipments occupies on the lorry. Also known as cubic weight or dimensional weight.

transported to a terminal in the receiving areas. At this terminal, the shipments are again reloaded, e.g. to distribution lorries, and aggregated with shipments from other areas that are also sent to the same destination. Finally, the shipments are transported to their end destinations. Variations also occur, e.g. that the long-haul lorry is sent directly to the end destination without passing a second terminal, if the volumes are large enough. Each step of the transport chain is then represented once in the data, due to the computer system used at Schenker. Also, some, but not all, of the shipments sent via terminals by Fraktarna are split in parts in the data. Larger shipments are sent direct and correctly represented in the data. All Danzas data represents the full origin to destination flow. In general, the number of shipments handled at terminals is fairly high (70%), but the total weight is only about 10% (Jensen, 1990).

A study, in which this author participated, was initiated by SIKA and The Swedish International Freight Association[86] into regularly collecting flow data from all large transport companies (not only DHL, Schenker, etc.) and modes in Sweden and regularly compile them into a common database. This would result in very high quality data that could be used in the model in future studies. The study shows a possibility for such a database, however, many obstacles remains before such a database becomes a reality (Andersson, et al., 2005).

9.2.4 The Survey Goods Transport in the Swedish Industry

A third data source is the transport survey by Saxin, Lammgård and Flodén conducted in this research project. See chapter 3.4.1. The survey colleted data on the total sent weight, weight sent by each type of transport provider (forwarder, own account transport, etc.), number of lorries, rail cars, etc. sent, sent weight distribution across the day and across the week, weight sent domestically and to different countries, and length of the outgoing transports (percent sent less than 150 km, 150-300 km, 300-600 km and longer than 600 km) from manufacturing and wholesale companies in Sweden. Since the survey covered all large and medium manufacturing and large wholesale companies in Sweden and a selection of the smaller companies, it represents a large part of the total transported weight.

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[86] Sveriges Transportindustriförbund.

Table 7 shows the goods volumes sent by the participating companies in the survey, which is a total of 40.8 million tonne equivalent weight. The data can be compared with Statistic Sweden's commodity flow survey (SIKA, 2003c) where the total volumes from the Swedish manufacturing and wholesale industry is estimated to 143.9 million tonnes[87]. This indicates that the survey would represent about 28% of the total goods volume. Note, however, that the commodity flow survey includes all companies, while the survey only consider companies with outbound transports exceeding 150 kilometres, which is most interesting for combined transport. This indicates that in the selected target population, the survey would represent more than 28% of the goods volumes.

Company	All volume weighted in million tonne equivalents	% of tonne equivalents
Small manufacturing (n=53)	0.4	1.0
Small wholesale (n=42)	0.1	0.2
Medium manufacturing (n=173)	6.2	15.3
Medium wholesale (n=50)	0.4	1.0
Large manufacturing (n=126)	25.3	61.9
Large wholesale (n=86)	8.4	20.6
Total all strata (n=530)	40.8	100%

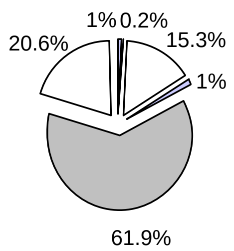

Table 7 Million tonne equivalents transported from local units divided by strata and percentage of total weight transported.

9.2.5 Combining the Data

The three data sources can be combined to create a transport database that can be used in the data set. The VFU data has good overall accuracy for the long-distance transport flows (county to county), but cannot be used on a more detailed level. The data from the forwarders has a good accuracy on a very detail level, but lacks the overall scope to represent the entire transport system. A combination can, therefore, be used where the overall transport patterns comes from VFU and the detailed distribution from the forwarder

[87] Wholesale is 44 088 000 tones and manufacturing is 99 839 000 tonnes.

data and the survey by Saxin, Lammgård and Flodén. All the following calculations from the VFU are made from the raw data supplied by SIKA.

The total transport demand according to VFU is 307 million tons of which 61 million tons is import and 61 million tons is export. Some of this can be excluded as not potential goods to transfer to combined transport. Pulp wood and round timber (53.6 million tons) is excluded, since this is difficult, and unnecessary, to load in ITUs. The goods is easier handled by claw clutch. Also, petroleum products and solid mineral fuels[88] (53.7 million tons) is not included, although there are no technical or legal obstacles for sending it with combined transport. However, petrol products are distributed in a special system where the products are brought in bulk (mainly by ship) to about 40 oil depots in Sweden, from which they are picked up by tank lorries for the final distribution (SPI, 2004). It is not realistic for combined transport to compete for the bulk transports to the oil depots, since large bulk transports are more efficiently performed by other modes. This leaves 200.3 million tonnes.

The remaining goods that is sent by direct rail (no reloading, i.e. rail as the only mode of transport[89]) is also excluded (16.1 million tons), the iron ore transport in Lapland (13.3 million tonnes) and also the remaining goods sent by direct ship as bulk goods[90] (15.0 million tons). Both direct rail and direct ship offers a lower unit cost and, in most cases, a lower environmental impact than both combined transport and direct road transport. This leaves a total goods demand to transport of 155.9 million tons. Of this, 51.6 million tons is export or import, leaving 104.3 million tons domestic.

The base for the common database is the accurate domestic data from the three large forwarders, which represents 15.6% (16.3 million tons of 104.3 million tons) of the relevant domestic transports with very high accuracy. In the survey by Saxin, Lammgård and Flodén, 10% of the goods was sent by own account transport[91], 89% by forwarders and hauliers[92] and 1% in other ways. This is well in line with other studies that also shows that about 10% of the goods is sent by own account transport (SIKA, 2005b). The data from the forwarders are blown up the represent the remaining 73.4% sent by

[88] Mainly oil and petrol. Note that this does not include chemicals.
[89] Rail ferry is considered as rail transport.
[90] Goods declared as liquid or solid bulk goods by the respondent.
[91] Vehicles owned by the sending company.
[92] 33% is sent by forwarder/haulier, but the transport is planned by the sending company and 53% is both sent and planned by the forwarder/haulier.

forwarders and hauliers and 1% sent in other ways. This is made individually for each county to compensate for that the market shares of the three forwarders are different in different parts of the country. The geographical distribution of the forwarder data is, thus, used for 74.4% of the outgoing weight for each county according to VFU. The geographical distribution is, thus, mainly based on the forwarder data. All three forwarders have full national coverage of their transport networks and are very dominant in the market. Since the data represents a total survey of all their shipments during a full year and a total of 7.8 million observations it can be assumed that the distribution well complies with the total distribution for all hauliers. Although the data is not the result from a statistical survey, the 7.8 million domestic observations can be compared with the 900 000 observations used by the VFU to map both the domestic and global transport flows to and from Sweden.

The survey by Saxin, Lammgård and Flodén is then used to determine the domestic own account transports. The goods flows are aggregated into municipalities and all municipalities with outgoing own account transport greater than 100 000 tons[93] is selected. The weight from each respondent is distributed according to the distance intervals provided by the respondent in the survey (<150km, 150-300km, 300-600km, >600 km). This gives a total weight of 1.2 million tonnes or 11% of the domestic own account transports. Within each distance interval, the distribution is made according to the distribution in the forwarder data, e.g. to distribute the weight from municipality A in the interval 300-600km, the distribution in the forwarder data of goods from A to all municipalities within 300-600km is used. The survey data, thus, gives the region the shipments are sent to, but the exact destination municipality is determined by the distribution from the forwarders. This gives very high accuracy of the departure location but lower for the destination. Although own account transport has fairly low goods volumes, it is important to consider them separately, since they represent some large individual goods flow (the ten largest own account shippers in the survey send about 3.0 million tonnes and are mainly companies with an evenly spread distribution, e.g. distribution for the large food chains). It can be expected that the survey data covers most large own account flows, since the survey covers all large companies in Sweden. The own account flows in the survey cannot be blown up to represent all own

[93] A cut of limit is used since this requires some manual work, which is unnecessary if the volumes are very small. 100 000 tons represents about 0.1% of the total gods flow or 1% of the own account gods flows. Seven municipalities have volumes greater than 100 000 tons.

account transport due the concentration into a few large flows. The remaining 89% own account transport is, therefore, considered to follow the distribution from the forwarders and is treated the same way as the forwarder sent volumes above.

The export/import goods flows (51.6 million tons) are estimated using the VFU data and excluding the same commodity groups as for the domestic goods. The accuracy will be lower for this data, but considering that the demand is aggregated at the border crossing, this is still acceptable. Survey data is not used in determining own account export/import goods, since the amount of international own account transport in the survey is too small to be useful. Due to the low accuracy in the VFU data, all export/import goods will be aggregated to the road transport terminals (see below) and blown up to represent the total demand. It is assumed that no road haulage is required to / from the terminal at the border crossing destination.

This gives a total data base on a municipality to municipality level with 10.4% of the demand with very high accuracy (forwarder data), 49.8% with good accuracy (blown up forwarder data), 0.8% with very high accuracy in sending destination and fairly good accuracy in receiving destination (own account from survey), 5.9 % with fairly good accuracy (own account according to forwarder distribution) and 33.1% with acceptable accuracy (import and export goods). Note also, that the total accuracy is higher on the domestic flows that are the focus of the data set. 15.6% of the domestic flows are with very high accuracy (forwarder data), 74.4% with good accuracy (blown up forwarder data), 1.1% with very high accuracy in sending destination and fairly good accuracy in receiving destination (own account from survey) and 8.9% with fairly good accuracy (own account according to forwarder distribution). See Table 8. In total, this gives a good database well suited for the data set.

Source	**Domestic goods**	**Total**
Forwarder data	15.6 %	10.4 %
Blown up forwarder data	74.4 %	49.8 %
Survey data	1.1 %	0.8 %
Own account with forwarder distribution	8.9 %	5.9 %
VFU export / import	-	33.1 %
Sum	100 %	100 %

Table 8 Demand sources

The inherent errors in the database is, apart from the approximations made above, that the forwarder data is from different years and contains some flows that are split in parts when reloaded at terminals. However, this is not expected to have any significant effect on the database when used on a strategic level.

The database represents the total yearly flows between all Swedish municipalities and international destination. To be used in the model, the database is, then, converted to average goods flows per day (total weight / number of days). All days will thus be assigned the same transport demand. Since the data set is designed to represent to transport system on an aggregate and strategic level it can be assumed that the total demand is fairly stable. The intention is to suggest and evaluate the transport system on a strategic level. Note, however, that the HIT-model can be run with varying demand and does not, in any way, require a fixed average demand. A further aggregation of the domestic flows in the database is then made to avoid the large number of very small goods flows between some municipalities. Two small municipalities might only have a few yearly transports between them, which make the average daily transport demand unrealistically small. Goods flows with less than one lorry per day (40 tons) is, therefore, aggregated to the forwarders closest road terminal and included in the transport demand for that municipality[94]. This is also the way these goods flows are handled in reality. Small goods flows are transported by haulier, who consolidates the goods at their terminals. The total number of domestic transport links drops from 76 225[95] to 1 830[96] after the aggregation. The aggregation is made according to Schenker's terminals[97]. The number of terminals and location among the hauliers are similar, although not identical. Note that a transport link might have a demand for transport in one direction, but have been aggregated to terminals in the other direction. Another aggregation is also made for goods to and from the island of Gotland in the Baltic sea. The potential combined transports are forced to use a road ferry transport to the main land which is difficult to model correctly. The goods are, therefore,

[94] Even after the aggregation a few links remain with very small goods volumes.

[95] This is less then the theoretical maximum of 83 521 relations (289*289) since there are no transport demand between all municipalities.

[96] The total number of transport links used, including international goods, is 2 127.

[97] Schenker's terminals are located in Borlänge, Borås, Gävle, Göteborg, Halmstad, Helsingborg, Hudiksvall, Hultsfred, Jönköping, Karlshamn, Karlstad, Kristianstad, Linköping, Luleå, Malmö, Nybro, Skara, Skellefteå, Stockholm, Sundsvall, Umeå, Visby, Vänersborg, Värnamo, Västerås, Växjö, Örebro, Örnsköldsvik and Östersund.

aggregated to the main land ferry terminals in Oskarshamn or Nynäshamn (depending on the direction of transport). The transport from the mainland to Gotland is the same irrespectively if road transport or combined transport is selected since Gotland do not have any rail network.

9.3 Time

Time is an important competitive factor for the transport industry. The main competition in the transport sector is on over-night transport. It is, therefore, important that the data set represents the demand distribution across the day, to accurately model pick-up and delivery times, e.g. to model that the pick-up, in many cases, must be made in time to catch the last train of the day. It is also important to help determine which train loops and, thus, departure times, that are most appropriate.

In the survey by Saxin, Lammgård and Flodén, the respondents were asked to distribute their outgoing goods across five time periods (00-06, 06-10, 10-14, 14-18, 18-00)[98]. The results show that most goods where sent during the middle of the day. See Figure 44.

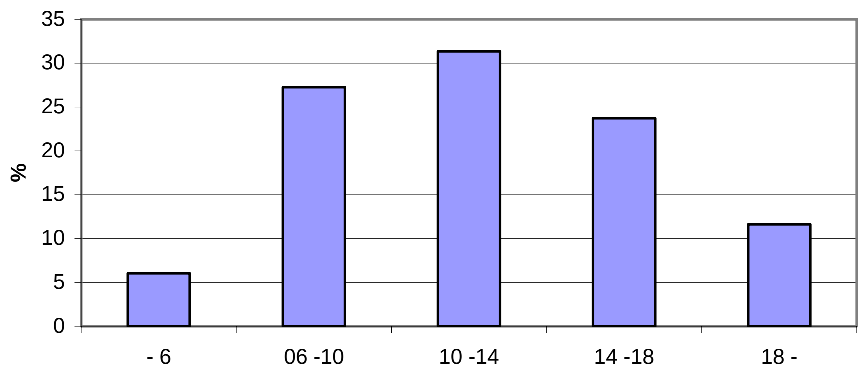

Figure 44 Distribution of outgoing shipments in tons during an average day

The transport demand will be distributed across the day according to this data, however, the earliest time period (00-06) will be merged with the next time period (06-10) due to the small volumes. The demand will be

[98] A 24 hour clock is used for simplicity, i.e. 14 = 2 p.m.

aggregated into one demand occurrence in each time period, positioned in the middle of the time period. Demand occurrences will, thus, occur at 08, 12, 16 and 20. Note that the demand in late time periods are not positioned exactly in the middle of the time period, but more realistically closer to daytime.

The time windows for deliveries and departures will follow the common delivery options on the Swedish freight market where the customer can choose between delivery before 10 a.m. (at a higher price) or during the day. It will be assumed that shipments arriving at the destination terminal in the evening cannot be delivered until the companies open in the morning, since most companies are closed at night. Only two time periods[99], 10-18 and 18-10, will, therefore, be used[100]. A comparative time gap of one hour will be used in the direct comparison with road transport for both departure and delivery. See chapter 6.8. Results from the survey by Saxin, Lammgård and Flodén also shows that the delivery requirements are fairly relaxed. 71% of the goods are to be delivered over night or later[101]. See Table 9.

Time window for delivery	**% of goods weight**
The same day	29 %
Before 10 a.m. the next day	10 %
Sometime the next day	24 %
In two days	9 %
In three days	7 %
Longer	21 %
Sum	100 %

Table 9 Distribution of delivery time windows

[99] This will put several demand occurrences in the same time period. However, they are not merged to make it possible to use other time periods during the sensitivity analysis.
[100] The exact time periods used are 18.1-10 and 10-18.1, i.e. slightly after 18. The reason for this is that it should not be possible for the demand at 08 to be pushed back to catch the evening departure at 18 the day before.
[101] It should be noted that the exact delivery time often has a shorter time window. Results from the survey, for example, show that 32% or the over-night goods weight should be delivered within 30 minutes of the agreed time. This is often caused by planning and capacity constrains at the receiver, where the important aspect is the on-time delivery and not the transport time. It is, thus, important to know exactly when the goods will arrive, but less important if it is e.g. in the morning or in the afternoon.

9.4 Distance Data

Rail distance data is collected from the internet homepage tydal.nu and have been validated against general national GIS databases. The homepage data was found to be very accurate. The homepage tydal.nu has also been recommended by the Swedish National Rail Administration[102]. The shortest distance between the terminals has been selected.

Road distance is collected using the route optimisation software LogiX from DPS[103]. The software determines the shortest route between any two points with a very high accuracy. The software is the leading fleet optimisation software in Sweden today and is used by the large forwarders. The centre of the town where the local government for the municipality is located has been used as the geographical location for the municipality.

9.5 Lorries, Terminals and Trains

The road transport lorries are represented by three types of lorries. The large 25.25 m lorries, standard semi-trailer lorries and ISO 40 foot container trailer lorries. The first two types represents two very common types used for long distance road haulage in Sweden. It is assumed that both 25.25 m lorries and semi-trailer lorries are allowed for all domestic flows and export and import flows to Finland. For other destinations outside Sweden, only trailers are allowed due to legal requirements. Semi-trailer lorries are used for all international destinations apart from goods flows that can be assumed to be sent by sea transport, which are assumed to use container trailer lorries. Sea transport goods are considered to be all international goods using Göteborg or Stockholm as a border crossing, apart from goods to Norway and Finland. See chapter 9.2.

The 25.25 m lorry is considered to consist of a lorry with three axles and a trailer with four axles. Loading capacity is 40 tons and the average speed is 80 km per hour. It should be noted that this is the maximum speed allowed, but a large study by the Swedish National Road Administration also shows that this is in fact the actual average speed for articulated lorries (Vägverket, 2005). The semi-trailer lorry consists of a lorry with two axles and a semi-

[102] The Swedish National Rail Administrations was asked to share rail distance data with this project but denied.
[103] http://www.dps-int.com/

trailer with three axles. Loading capacity is 25 tons and the average speed is 80 km per hour. The 40 foot container lorry is a two axle lorry with a three axle container chassis semi-trailer capable of carrying a 40 foot container. Loading capacity is 26 tons (Lumsden, 1998, Woxenius, et al., 1995) and the average speed is 80 km/h.

The combined transport lorries are represented by four types of lorries. The 25.25 m lorry, the standard semi-trailer adapted for combined transport, a lorry with swap bodies only, and the ISO 40 foot container lorry. The lorries uses 13.6m semi-trailer and/or 7.82 m swap bodies, which has been identified by EU directive 96/53/EC on the length of road vehicles in the EU as most suitable for intermodal transport. The 25.25 m lorry is assumed to consist of a lorry with three axles, a 7.82 m swap body, a two axle dolly and a 13.6 m semi-trailer for combined transport (Sveriges Åkeriföretag, 2004). Loading capacity is 37 tons. The semi-trailer lorry is a two axle lorry with a three axle semi-trailer. Loading capacity is 24 tons (Woxenius, et al., 1995). The average speed is 80 km/h.

The swap body lorry consists of a three axle lorry with a 7.82 m swap body and a two axle trailer with a 7.82 m swap body. Loading capacity is 25 tons and the average speed is 80 km/h. All combined transport lorries are allowed for all destinations, except for international flows from Göteborg and Stockholm. See below. The 25.25 m lorry is not allowed outside Sweden, but the parts of the lorry (the swap body and semi-trailer) are allowed. Since a reloading already takes place at the receiving terminal it is assumed that they are loaded on allowed lorries in that country.

The standard ISO 40 foot container lorry is used for goods flows sent by sea as in the case with all-road lorries, above, and has the same characteristics as the all-road container lorry.

The trains used in the combined transport system are operated with standard electric engines type RC, which are the most common engines in Sweden. Shunting is assumed to be conducted by diesel engines type T44. The maximum train lengths are 650 meters[104]. The average speed of a combined transport train is 70 km/h (CargoNet, 2006). The rail cars used are considered to be 34.2 meter six axle Sdggmrss articulated double pocket wagons, capable of carrying two 40 foot containers or two trailers or four

[104] This is input in the model as 615 m available rail car length, after the length of the engine has been deducted and the rail cars rounded to integer. 18 Sdggmrss rail cars are used.

swap bodies (or one trailer/container and two swap bodies) (AAE, 2005). The train length allocated for one semi-trailer or container is thus 17.1 meters and the length allocated for one swap-body is 8.55 meters. Sdggmrss is the wagon used by CargoNet today for 13.6 m trailers and is starting to replace older wagon types, as a multipurpose wagon (Bark, 2005, CargoNet, 2005b).

The terminals included are the terminals in Borlänge, Gävle, Göteborg, Hallsberg, Helsingborg, Jönköping, Luleå, Malmö, Norrköping, Stockholm, Sundsvall, Trelleborg, Umeå and Älmhult. See Appendix 10 for a map (Banverket, 2005b). Note that both Stockholm and Göteborg actually have two terminals, since there are terminals at the ports also. However, in this data set, they are considered as joint terminals.

9.6 Train Loops

A set of possible train loops have been constructed for all train links. Each train loop has only been allowed to operate on one train route to make it possible to use train route optimisation. The ambition has been to have one possible departure in the evening around 6 pm, one at lunch around 12 and one in the morning around 8 am. This fits well with the current timetable used by Cargo Net where smaller destinations have a departure in the evening and larger destinations have departures in the morning, lunch and evening. Naturally, the departure times have been adjusted to creating working train loops. A list of the possible train loops used are available in Appendix 7. The loops have been set to allow an unlimited number of trains on each loop to represent the possibility to add another departure shortly after if the demand is big enough. Note that the input train loops only represent train loops that are possible for the model to choose to insert capacity on and use and not a given departure. The model has been run several times with different combinations of train loops to determine the best combination. It is not recommended to run the model with all possible train loops at the same time, since the train loops “compete” with each other. See chapter 7.2. From a marketing perspective it is also favourable if the train departure times do not vary between different days.

9.7 Business economic costs

To make all cost calculations comparable in the data set, a common set of calculation principles have been used. All equipment is considered to be bought new and used for its entire service life. The costs are written of using a linear depreciation during the service life, i.e. the same amount is written of each year. If the equipment costs SEK 1 000 and has a service life of 10 years, then SEK 100 is written of each year. A cost of capital of 7% is used based on the average tied-up capital during the service life. 7% is the business economic cost of capital recommended by SIKA (2005c). No profit margin is included in the calculations. All detailed cost calculations can be found in the appendixes. All costs are calculated in the Swedish currency Krona, abbreviated SEK.

9.7.1 Lorry Costs

In general, an exact estimation of the costs to operate a train or a lorry is very hard. Larger hauliers, for example, get better deals on new lorries, fuel, maintenance, loans, etc. than smaller hauliers. The skill of the driver also affects the fuel consumption and wear and tear on the lorry. Similarly, the topology also greatly affects fuel consumption. Added to this is the difference in administration costs, garage, etc. The main cost difference, however, lies between trailer lorries and the bigger 24 - 25.25 m lorries, mainly because of the weight difference. The 18 m lorry with two swap bodies has similar costs as trailer lorry, mainly due to similar weigh and equal number of axles. To differentiate between different types of trailers and between 24 m lorries and 25.25 m lorries and different types of load units is not meaningful, since the normal cost variations among these vehicles are to large (Sveriges Åkeriföretag, 2005). The data set will, therefore, use cost data for only two types of lorries. All trailer lorries and the swab body lorry will be given the same costs and all 25.25 m lorries will be given the same costs. This will affect the selection of the best lorry type to use in combined transport, since both semi-trailer and 40 foot container will be given the same cost (The swap body lorry will not have the same total cost, since the two swap bodies on the lorry will generate a higher terminal cost. See chapter 9.7). The 40 foot container has a slightly greater loading capacity in tonnes, but has the drawback that the volume is smaller[105] and it is less suitable for goods on standard European loading

[105] Approximately 67 m^3 compared to 85 m^3.

pallets. The model will, therefore, be set to use semi-trailer lorries unless the extra loading capacity is needed.

The cost calculations are based on the cost estimations made by Enarsson (1998) for 24 m lorries and trailer after contact with several haulers and hauler associations. A overview of different cost estimates shows that Enarsson's calculations are well in line with other estimates (SIKA, 1999b). Salary and maintenance costs are based on a lorry running 120 000 km per year and used for 3 600 hours.

The cost estimates have been adjusted for this data set, converted to distance dependent costs[106] and time dependent cost[107] and has also been adjusted to 2001 year price level using the Swedish Haulier Associations (Sveriges åkeriföretag) price index for road haulage, kindly provided by the haulier association. The price index shows the cost change for important cost factors in the haulage industry. To make all cost calculations in the data set comparable, the cost estimates have been calculated according to the common calculations principles in the beginning of this chapter. See Table 10. The finished cost calculation has been validated against cost calculations made by SIKA (SIKA, 2002b) for year 2001 and found to be similar. The total yearly cost for a 24 m lorry is, for example, estimated by SIKA to SEK 1 675 959 and in the current calculation to SEK 1 655 017. The complete calculations are available in Appendix 4.

Lorry type	**Time dependent SEK/hour**	**Distance dependent SEK/km**
Trailer or swap body	302	2.97
25.25 m	321	4.17

Table 10 Lorry costs

9.7.2 Train Costs

Railroad costs have been calculated using input data from several sources. Data have been collected for the RC and T44 locomotives used in the Swedish combined transport system. However, since the locomotive types

[106] Distance dependent costs are tyres, fuel and maintenance.
[107] Time dependent costs are depreciation, interest charges, vehicle taxes, insurance, garage, general administration and salary cost. The total cost for a year is divided by the number of hours the vehicle is in use.

are fairly old and are not manufactured any more[108], the purchase price has been substituted for the purchase prise for similar locomotives today[109]. Salary costs are determined using salary statistics from Statistics Sweden (SCB, 2005b). Energy consumption and electricity price is determined using the National Rail Administrations electricity charges for combined transport trains (Banverket, 2005b). Since the Swedish rail transport market is deregulated and the infrastructure provider is separate from the rail operators, all rail operators must pay the cost for their electricity consumption to the rail administration. It is assumed that the energy consumption is linear to the train weight. The gross weight is, therefore, used to determine the energy consumption for each added rail car and ITU. This is, of course, a simplification, but is satisfactory for strategic modelling, in particular compared to other factors affecting energy consumption, such as terrain and drivers skills. The energy saving by changed driver behaviour can, for example, be considerable (Lukaszewicz, 2001)[110].

Track charges are also paid to the rail administration for the use of the rail network. These are different for freight trains and passenger trains, and might also differ depending on the engine type. The track charges used in this data set can be found in Table 11.

Track fee	0.0028 SEK per gross tonne kilometre hauled
Accident fee	0.55 SEK per train kilometre
Diesel charge, full	0.31 SEK per litre consumed diesel in line traffic

Table 11 Track charges for freight (Banverket, 2005b)

The annual running distance of a locomotive is determined using statistics on the number of electric and diesel freight locomotives and the total freight train kilometres transported by these locomotives (SIKA and Banverket, 2004). Diesel engines often are used for shunting which gives a lower annual running distance. Note the same locomotives are used both for combined transport trains and other freight trains. Total yearly running time is calculated using the average speed of a domestic freight train (50 km/h) (Nelldal and Wajsman, 2003) for electric engines, where the running times of diesel engines is estimated to half that of the electric engines.

[108] T44 manufactured between 1968 and 1987. RC manufactured between 1967 and 1988 (Diehl and Nilsson, 2003).
[109] Electric locomotive cost from Nelldal, Troche and Wajsman (2000) and diesel locomotive cost via e-mail from General Electric Locomotive (Sweeley, 2005).
[110] Green Cargo saved 20% fuel consumption on the T44 locomotives in a test project simply by training the drivers in economic driving and installing flowmeters (Rallaren, 2006).

Maintenance costs have been collected from Enarsson (2001, 2003). Data for the Sdggmrss wagon has been collected via e-mail from the wagon rental company AAE, Ahaus Alstätter Eisenbahn, in Switzerland (Oehrstroem, 2005). The train cost calculations are available in Appendix 4 and Table 12. The maximum train length allowed is 18 Sdggmrss wagons and one locomotive.

	Time dependent SEK/hour	**Distance dependent SEK/km**
New train (locomotive)	900	4.55
New rail car	59.79	0.52
Using rail car	-	0.66
Diesel shunting	1 759	-

Table 12 Train costs

9.7.3 Terminal Costs

Terminal handling costs per ITU can vary between different terminals depending on available handling equipment, number of employees and number of ITUs handled at the terminal. The costs per minute to operate an individual fork-lift truck, reach stacker or gantry crane are well known. However, it is not enough the just multiply the cost per minute with the handling time for an ITU. It is necessary to look at the complete operations at a terminal during a period of time. The terminal operations are characterised by a number of peaks when trains arrive and depart. Naturally, peak time operations are more expensive. Some equipment might only be used during peak-times and each employee may perform different tasks or operate different equipment at different times of the day. The cost per ITU is, therefore, best estimated by calculating the total costs of a terminal for a period of time and then dividing the cost by the number of ITUs handled. This will underestimate the cost of peak time ITUs and overestimate the cost of of-peak time ITU, but will give an accurate average cost. It is not possible to directly determine the costs to handle each different type of ITUs, e.g. a trailer or a swap body, at a terminal, since the handling equipment used for an ITU might vary depending on the equipment currently in use and the capacity needed at the terminal. For example, a gantry crane is more expensive to run than a reach stacker but has a greater capacity (lifts per hour). A terminal with both reach stackers and gantry crane, therefore, tries to only use the gantry crane when the extra capacity is needed. Another example would be that a terminal with only one truck in operations must choose a truck powerful (and expensive) enough to handle the largest occurring ITU. Approximate handling costs have been calculated for six different size terminals. Data for the terminal characteristics have been collected from Woxenius, et al. (2003), Woxenius (2003) and Olsson and Särkimäki (2004). The price, maintenance costs and fuel consumption for the handling equipment have been determined using data from Bark (2005) and converted to year 2001. Salary costs have been determined using salary statistics (SCB, 2005b). The handling times to lift an ITU have been studied in detail for different types of handling equipment by Bark, et al. (1990). The handling time by gantry crane was estimated to 2.5 minutes and to 3 minutes by truck. However, these estimates do not include movement of the handling equipment itself, e.g. the time it takes for a truck to drive the distance to get to the location to pick up the next ITU. Jensen (1990) also studied terminal handling times at several terminals and found that they varied between 5 to 10 minutes per ITU depending on terminal, handling equipment and if the ITU was picked up or put down on the ground or on a lorry. The handling times were shorter by gantry crane than by truck. It also needs to be considered that some ITUs are lifted several times if they first are put down on the ground and then later lifted on a train or lorry when it arrives to pick up the ITU. The terminal in Göteborg, for example, handles 52 000 ITUs but performs about 78 000 lifts (Woxenius, 2003). By combining the sources, an average handling time per ITU of 6.5 minutes by truck and 5.5 minutes by gantry crane have been determined.

Shunting of the train must also be performed before the train can be unloaded, as a part of the terminal handling process. The shunting process have been studied by Jensen (1990) at a number of terminals and different train lengths. The average use of shunting personnel, locomotives and driver for a train arriving at and later leaving the terminal can be determined to approximately 2 hours. This includes shunting of the train when it arrives and when it leaves, coupling and decupling of the RC line haul locomotive, relevant break tests and the transfer of the shunting locomotive to and from its depot. Note that the estimated time is for both the arriving and departing train, i.e. two shuntings of the same train at two different times[111]. It is assumed that the shunting is performed by a T44 diesel locomotive. The fuel consumption is estimated at 0.9167 litre per minute when shunting (Jensen, 1990). All costs for the shunting locomotive are considered as time

[111] A study at the Umeå terminal determined that the time consumption for shunting and break test of a combined transport train before departure (departure only) was 1 -1.5 hours (Länstyrelsen, 1999).

dependent. The costs have been calculated according to the same principles as for the RC locomotive and using the same sources.

The calculated direct handling costs (handling equipment, personnel costs and shunting) varies between approximately SEK 150-250 for each handled ITU at the studied terminals. The uncertainties in the calculations make it futile to try to determine the exact costs for each individual terminal. That is also an unnecessary high level of detail for a strategic purpose. An average cost of SEK 230 per handled (loading or unloading) ITU will, therefore, be used as a general cost for all terminals. The handling cost calculations are available in Appendix 4.

A common shared terminal costs has also been calculated since the model uses two types of terminal costs, a direct handling cost and a shared terminal cost. See chapter 6.4. The shared terminal cost consists of general administration, building and land costs. It is very difficult to determine any general shared costs since the size, layout and number of personnel employed varies greatly. There is, for example, no correlation between number of ITUs handled and the size of the terminal area (Sjögren, 1996). Investment costs for a traditional terminal can range from SEK 50-100 million (Nelldal and Wajsman, 2003). Calculations have been made on a number of existing and suggested terminals using data from Woxenius, et al. (2003) and Olsson and Särkimäki (2004). The annual shared cost of a terminal is estimated to between 4 and 7 million SEK, including administrative personnel[112]. However, these costs could be substantially lower if existing terminals and infrastructure (e.g. a road terminal with a rail siding) could be used. The largest cost, SEK 7 million, is assigned to the five largest terminals which separates themselves as handling noticeably more ITUs than the other terminals (42 000 – 75 000 ITU). The terminals are Stockholm (Årsta), Göteborg (Kruthusgatan), Hallsberg, Helsingborg, and Malmö. These are also terminals that are open weekends[113] and have longer opening hours during the weekdays, which give a higher salary cost. The remaining terminals handle fever ITUs (5 000 – 23 000) and are closed during the weekends[114]. These terminals are assigned a fixed cost of SEK 4 million. The fixed costs are in the data set equally divided between all train

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[112] 30 year service life.
[113] Except Helsingborg.
[114] Except Luleå that are open Sundays.

routes serving the terminal[115]. The model does not assign these costs to individual ITUs, however, it could be of general interest to note that the fixed cost per average ITU for the large terminals is approximately SEK 125 per ITU and SEK 260 per ITU for the smaller terminals. The total handling and fixed cost for an ITU at a large terminal is, then, roughly SEK 355 and roughly SEK 490 at a small terminal.

9.8 Environmental Data

The environmental effects will be based on NTM-data. NTM (Nätverket för Godstransporter och Miljö - The network for transport and environment) is a non-profit organisation consisting of transport companies, transport buyers and universities/research institutes working together on how the environmental issues of the transport sector are to be managed in order to reach a sustainable transport system. All large transport companies in Sweden are members. NTM has determined the most important environmental effects from goods transport and made an inventory of existing information and methods for describing the emissions that cause these environmental effects. From this, NTM has created a common compilation of methods and information that describes the environmental performance of the current freight transport in Sweden. The purpose is for the transport industry to have common methods and data to compare different transport systems. The data and a free on-line emission calculator is available at NTM's homepage, http://www.ntm.a.se/, and is continuously updated. The NTM data has become a standard in the transport industry and is also used by other actors, such as SIKA. See Appendix 3 or the NTM homepage for the NTM data. However, it should be noted that emission calculations and estimations are complicated and effected by many factors. As such, the data should be interpreted with caution, although the data represents the best data available today. The economic valuation of the emissions has also been calculated. See chapter 9.9.

The lorries are assumed to use Euro 3 class engines, which is the current legal requirement for all new lorries since year 2000. This gives a low estimation of the pollution, since many older lorries also are used. The fuel

[115] Note that the model allows the fixed costs to be divided freely between train routes. It should be noted, that if no combined transport at all is selected for a train route in the output data, then the shared fixed terminals costs assigned to that train route must be reallocated to the other train routes. See chapter 6.4.

used is Swedish environmental class one (Miljöklass 1). The environmental data is calculated at a load factor of 90%. The HIT-model is expected to result in a high load factor, since it does not use any more lorries than necessary. However, it is not expected to reach 100% since the amount of goods to transport seldom will be exactly a multiple of the lorry capacity. A load factor of 90% have, therefore, been used. The emission calculations are made in the on-line emission calculator. The emissions are the direct fuel emissions from the lorry and do not include a life cycle assessment of the fuel. See Table 13.

Emission in grams	**Trailer lorry, 1 km**	**25.25m lorry, 1 km**
CO_2	890	1 200
NO_x	5.6	7.8
HC	0.45	0.64
CO	0.81	1.1
PM	0.091	0.13
SO_2	0.0011	0.0016
Energy consumption, MJ	12	16
Economic valuation of emissions in SEK	1.71	2.33

Table 13 Lorry emissions in grams

The electric trains are assumed to use electricity produced according to the mix purchased by the National Rail Administration[116]. See Appendix 3. The emissions from the production of the electricity are used and do not include any life cycle assessment of the production. The diesel trains are assumed to use diesel of environmental class one (Miljöklass 1). It should be noted that the diesel locomotives used (type T44)[117] are old locomotives build between 1968 and 1987 (Diehl and Nilsson, 2003). The average locomotive is thus close to the end of its service life. A modern diesel locomotive have, for example, almost half the emissions of NO_x, HC and PM compared with the T44 (Banverket and SIKA, 2002)[118]. All emissions are calculated using

[116] Green Cargo only purchases electricity that is produced by renewable sources. However, the total mix of production sources for electricity used in rail transport is used in this data set to represent the general conditions in the rail sector 2001. Today, the railway sector only uses renewable power (99.6% hydropower and 0.4% wind power (year 2004) (Banverket, 2006).
[117] The diesel engine is a V12 EMD 645 2-stroke engine, which is a common engine for diesel locomotives (Ahlvik, 1996).
[118] Green Cargo recently ordered a modernisation of their T44 engines which is expected to cut fuel consumption by 20%, CO_2 by 20%, NO_x by 66%, CO by 75%, HC by 13% and

emission data from NTM[119] and running times, etc. from the business economic calculations. The power loss in the electricity transfer is estimated to 20%[120] (Banverket, 2005b). See Table 14 and Appendix 3.

Emission in grams	**Electric train**				**Diesel shunting per hour**
	per gross tonne-km	**new train per km**	**new rail car per km**	**using rail car per km**	
CO_2	0.623	49.252	21.696	41.147	2 368
NO_x	0.00158	0.12500	0.05506	0.10443	52.30
HC	0.00001	0.00102	0.00045	0.00086	2.092
CO	0.00020	0.01616	0.00712	0.01350	3.362
PM	0.00008	0.00589	0.00259	0.00492	1.345
SO_2	0.00150	0.11818	0.05206	0.09874	0.374
Energy consumption, MJ	0.0738	5.8302	2.5682	4.8708	1940
Economic valuation of emissions in SEK	0.00118	0.08689	0.03773	0.07155	2 243

Table 14 Train emissions in grams

The environmental effects of the terminal handling have been calculated using data from Persson and Kindbom (1999)[121] for an average truck. To this, the environmental effects of the diesel shunting have been added. The effects are calculated for a full train of 18 Sdggmrss rail cars and 58 ITU (40% trailer and 60% swap bodies (Banverket, 2005a)) where it is assumed that the diesel locomotive is used for active shunting for 30 minutes. A full train is used since it is expected that the model will try to add full trains. See Table 15.

particles by 60%. The modernisation is planned to take place during 2009-2013 (Green Cargo, 2007a).

[119] Note that the on-line emission calculator is not used since NTM uses some given settings in their on-line calculator that is not suitable for this scenario. Most noticeably, NTM uses a net weight calculation based on a “typical” combined transport freight train.

[120] The rail administration includes the power loss in the price. The estimated power consumption is, thus, without the power loss (Johansson, 2005).

[121] Persson and Kindbom used adjusted data from the Corinair database.

Emission in gram for an average handled ITU from terminal activities	
CO_2	5 893.63
NO_x	111.12
HC	14.14
CO	51.96
PM	5.416
SO_2	0.20810
Energy consumption MJ	76.99
Economic valuation of emissions in SEK	4.54

Table 15 Emissions from terminal handling

9.9 Social cost

The estimation of the social costs takes its starting point in the business economic costs. These are then adjusted for tax effects and external costs are added.

A tax effect occurs when the resources spent on a service or product has an alternative use, i.e. the customer can spend his money on something else. A valuation of the product is then made when the customer decides to spend his resources (money) on that product. The taxes he has to pay are then, of course, included. However, in an alternative use of the resources, the taxes might be different, e.g. different fuel taxes or VAT. Since it is impossible to know what alternative usage the resources would have, a general tax factor (skattefaktor I) have been decided by SIKA to be used in all public societal calculations in Sweden[122]. The indirect taxes paid are then subtracted from the cost estimates and replaced by a general tax factor of 1.23 (23%) that is to represent the “average” tax (SAMPLAN, 1995, SIKA, 2005c). The use of a tax factor varies between different countries and it is not used in all countries. See Trafikministeriet (2002) and Møller and Jensen (2004) for a review. However, the tax factor will be included in this data set, since it is recommended by SIKA for national planning in Sweden. In this data set, tax effects occur only on fuel taxes. Note that rail traffic does not pay diesel or

[122] A second tax factor (skattefaktor II) is sometimes also used to represent the dead weight loss for projects that are financed by taxes.

electricity taxes. No VAT is included in the data set since all actors are companies who can deduct ingoing VAT against outgoing VAT.

The most important external factor is the environmental consequence of transport. The effects occur on three levels: local, regional and global. Local effects are health effects, contamination (dirt) and corrosion. Regional effects are damage to the environment and health effects. Global effects are the green house effect and reduction of the ozone layer (SIKA, 2002c). The data set will be based on the valuations of these effects recommended by SIKA (2005c) for the Swedish national transport planning. Note that not all emission factors have a cost estimate for each level. The cost estimates are at year 2001 price level in SEK. The data is available in Appendix 5 and the calculations in Appendix 6.

9.9.1 Local effects

The local effects are very much dependent on where the emissions occur. The costs are determined according to "exposure units". An exposure unit is the exposure of one person to 1 microgram/m^3 of the emission during one year and converted to a cost per kg according to a special formula[123]. The costs of a 1 kg emission can, thus, vary greatly. Cost estimates for particles, for example, range from 9 500 SEK/kg for downtown Stockholm to 924 SEK/kg for the small town of Laholm (SIKA, 2002c). Long-haul transports mainly occur outside cities which motivates a fairly low valuation of these effects. The effects must be calculated to represent an average transport, since the HIT-model does not include different cost estimates for different areas. SIKA (2004) calculated the population density along six selected transport links in Sweden, and found that about 80-90% of the transport occurred in rural areas. For calculation of the local effects for this data set, it will be assumed that the average transport is 80% rural transport. The emissions in the rural part of the transport will be assigned no local effect. The remaining 20% will be considered to run in an average sized Swedish population centre[124] of 3 856 inhabitants (SCB, 2002). From this, a total cost for a typical transport is calculated and divided into a cost per km to use in the data set. The higher estimation, 20%, of the part of the transport that is in populated areas is used, since the use of a relatively small average

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[123] Value/kg = 0.029 * ventilation factor * sqrt(population) * value/exposure unit. The ventilation factor is between 1.0-1.6 for Sweden (SIKA, 2002c). 1.0 is used in this scenario.
[124] Coherent settlement with maximum 200 meters between the houses and at least 200 inhabitants (SCB, 2002).

sized population centre underestimates the costs in highly populated areas. The same division is used both for road transport and rail transport. All shunting is considered to take place in an average sized population centre.

The emissions are based on the engine emissions. Particles also result from wear on tyres, road paving, brakes, etc. However, these are not included in the data set due high uncertainties in existing estimates and difficulties in attributing the emissions to individual vehicle types.

The noise from transport also causes external effects. As with other local effects, the effect varies depending on the location. SIKA uses a cost estimate according to how many people that are subjected to a certain dBA indoors and outdoors. These valuations are very difficult to convert to the effect of a single lorry or train. Banverket (Banverket and SIKA, 2002) has studied the external effect of noise from trains and found that it varied greatly between different types of trains and region. The geographical differences are great with, for example, more than half of the total costs of noise (SEK 202 million of SEK 387 million) being generated on the line between Stockholm and Malmö. Freight trains are also about three times as disturbing as passenger trains. It is calculated that freight trains are responsible for almost half of the total costs of noise from Swedish trains (SEK 185 million). Using railway statistics (SIKA and Banverket, 2004) of the total freight train kilometres, it can be determined that the average freight train in Sweden causes an external cost of SEK 0.21 per train kilometre.

The noise from road traffic has similar variations. The total cost from road traffic noise in Sweden is estimated by the road administration to about SEK 3.2 billion. The average cost per truck in rural traffic is estimated to SEK 0.048 per vehicle kilometre and SEK 0.613 per vehicle kilometre within a city (Vägverket, 2000). As before, a division of 80% rural traffic and 20% city traffic is used in this data set, resulting in a cost per vehicle kilometre of SEK 0.161.

Accident cost is another external effect from transport. An accident results in costs in the form of medical care, loss of income, etc. SIKA values accidents according to a given estimate for each fatality, severely injured, lightly injured and material damage. The estimates are based on both the direct material damage and a risk valuation representing the monetary value of avoiding the accident risk (i.e. the value of a "statistical life"). See SIKA (2002d, 2005c). Naturally, these kinds of valuations are very uncertain. The total number of accidents involving heavy lorries in Sweden 2001 were 924, resulting in 121 fatalities, 311 severely injured and 1 332 slightly injured (SIKA, 2001b, Trivector, 2003). The total societal cost can, thus, be estimated to SEK 3.3 billion. The total distance operated by heavy lorries in Sweden are 4 000 million kilometres (SIKA, 2003b) which gives an average accident cost of SEK 0.83 per lorry kilometre.

The accident risk in rail transport is directly represented by the accident fee of SEK 0.55 per train km, included in the railway charges. This fee is set to the average accident cost (Banverket and SIKA, 2002). The accident cost in rail transport is, therefore, not explicitly included.

9.9.2 Regional effects

The regional effects are estimated according to the values recommended by SIKA (see Appendix 5). The effects are costs per emission and are calculated from the emission data.

9.9.3 Global effects

The global effect mainly consists of carbon dioxide and its influence on global warming. However, an accurate costs estimate of the green house effect is extremely difficult to make. SIKA recommends a CO_2 cost of 1.50 SEK/kg, although the estimate is mainly based on political ambitions and is under revision (SIKA, 2002a, 2005a, 2005c). The value recommended by SIKA is used in this data set.

9.9.4 Total cost estimates

The cost estimates above can be summarised into the cost estimates in Table 16 and Table 17 for the different vehicle and train types in the data set. The estimates are based on the emission data determined in chapter 9.8. Note that SIKA assigns no cost to CO emissions. This does not mean that there are no negative effects from these emissions, but that no cost estimate can be asserted. No CO cost will, therefore, be included in the data set.

Lorry type	Time dependent SEK/hour	Distance dependent SEK/km
Trailer or swap body	302	4.85
25.25 m	321	6.34

Table 16 Societal road cost estimates

	Time dependent SEK/hour	Distance dependent SEK/km
New train (locomotive)	900	4.85
New rail car	59.79	0.56
Using rail car	-	0.73
Diesel shunting	2 242.51	-

Table 17 Societal rail cost estimates

An average cost of 235 per handled (loading or unloading) ITU will be used as a general societal cost for all terminals. The shared fixed terminal costs will be the same as for the business economic calculations, since no environmental effects, etc. are assigned to the fixed terminal activates[125].

Many societal calculations also include a time cost of transport relating to a loss or gain in transport time by, for example, a construction project. However, that is not applicable to this data set since the model only transfers goods between the modes that have an equivalent transport time.

[125] Note that the model can assign environmental effects to the shared fixed terminal activities but it is not used in this data set.

10 Model runs and analysis

The model can be run with an almost unlimited number of different settings and combinations of settings and data sets. It is not the purpose here to use all possible settings, but to determine the potential of combined transport in Sweden and to demonstrate the developed HIT-model. The model runs used the developed data set, which was developed to represent the Swedish transport system on an appropriate level of detail for this purpose. Other data sets with a different level of detail and other assumptions could be developed to further investigate the potential for combined transport in Sweden, but this is an area for future research, see chapter 11.3. In this modelling, it is particularly important to remember that the model focuses on finding the potential of combined transport, given the assumptions in the model. It is also important to remember that the results should only be analysed in a long term strategic perspective and not at a detailed level.

The model has been run with the data set in a number of different implementations. The run time for the model varied between 10 and 25 minutes depending on the data set. The more complex the input data, e.g. number of demand instances, number of possible train departures, etc., the longer the run times. The model was run on an ordinary desk top PC, an HP Compaq dc7600, 3 GHz Intel Pentium 4 processor and 1 GB RAM memory. The modelling period was 60 consecutive working days to reduce any start up effects, and an average daily value was calculated from the output data. The raw output data can be found in Appendix 13. It is very important to notice that the data presented in the appendix is the raw model output and, thus, affected by the assumptions and delimitations made when developing the data set, e.g. that some goods types where excluded from the data set. The raw output data must, therefore, be analysed and put into perspective. The raw output should be regarded as input into a final analysis.

All data is for an average day and the numbers have been rounded. All costs are in Swedish kronor, SEK, and cost estimates for the year 2001. The word optimisation is used here to represent the heuristics calculations in the HIT-model

10.1 Basic Model Runs

The input data set (see chapter 9) was first tested with a number of basic model runs. All four possible train loop systems in the input data set was tested, i.e. morning departures, morning and evening departures, lunch departures and evening departures. Each train loop system were tested in all four optimisation settings, i.e. lowest cost and train route optimisation, lowest cost and system optimisation, maximum transfer and train route optimisation and, finally, maximum transfer and system optimisation. Lowest cost optimisation means that the HIT-model finds the transport system that gives the lowest total cost. Maximum transfer optimisation means the model finds the system that sends the most goods with combined transport without increasing the total system cost compared with an all-road system. Train route optimisation means that each train route is considered separately, e.g. Stockholm-Göteborg and back. System optimisation means that the entire transport system, e.g. all of Sweden, is considered jointly. This allows for cross subsidising between different parts of the system, see chapter 6.16. Optimisation according to business economic estimates was used. This makes a total of 16 tested basic transport systems.

The train route optimisations required several model runs for each tested train system, since the fixed costs in the combined transport system are allocated to train routes already in the input data, see chapter 6.4. The fixed costs allocated to train routes that do not use any combined transport must, thus, be reallocated to other train routes. Since this might affect the modal split, the model needs to be re-run with the new allocation of fixed costs. The new allocation of fixed costs follows the same allocation as before, i.e. the fixed costs for a terminal is equally shared by all train routes using the terminal. Sometimes, this resulted in new train routes being excluded from combined transport, thus, requiring a new reallocation of costs and a new model run. Four of the tested transport systems in train route optimisation required one iteration and four required two iterations. No system required three iterations. These iterations where not necessary for system optimisations, since all costs are considered jointly for the entire system.

Since different train loop systems, i.e. time tables, might be suitable for different train routes, a joint train loops system was also created for each of the four optimisation settings, where the best train loop system for each train loop was combined to one, e.g. if the lunch trains gave the best cost saving on the train route A to B and evening trains gave the best saving on route C to D, then lunch trains were used on A to B and evening trains on B to A[126]. For lowest cost optimisation, the cost saving for each train loop after the first run was used to determine the best system. However, for system optimisation it is, by definition, not possible to directly determine which train loops are profitable, since cross subsidising is allowed. The same joint train loop system as for lowest cost optimisation was, therefore, tested. The results from the model runs are presented in Table 19.

Some data, which is common for all model runs conducted, are presented in Table 18. The fixed terminal costs per day for all scenarios are 190 000 and the number of possible train routes are 91.

Demand	**Tonnes**	**Business economic cost if sent by all-road**	**Social economic cost if sent by all-road**
Total demand	427 194	49 400 000	62 800 000
Of which sending and receiving terminals are the same	67 237	1 200 000	1 400 000

Table 18 Shared data

[126] If several train systems had the same cost saving, then the systems were prioritised by first selecting the evening departure system, followed by evening and morning departures, lunch departures and morning departures. This is based on the structure of the transport system today when evening departures are most common.

	Tonnes in combined transport	Total cost combined transport	Cost train system incl. terminals and handling	Total cost saving
Lowest cost system				
Train route optimisation				
Morning departures	77 600	6 700 000	5 400 000	4 700 000
Lunch departures	180 600	14 700 000	11 600 000	11 500 000
Evening departures	79 500	7 200 000	5 800 000	6 200 000
Morning and evening departures	152 700	13 600 000	11 000 000	10 000 000
Joint timetable	197 900	16 800 000	13 400 000	13 100 000
System optimisation				
Morning departures	78 600	6 800 000	5 500 000	4 900 000
Lunch departures	181 400	14 700 000	11 700 000	11 700 000
Evening departures	80 800	7 300 000	5 900 000	6 400 000
Morning and evening departures	153 100	13 600 000	11 000 000	10 200 000
Joint timetable	197 900	16 800 000	13 400 000	13 100 000
Maximum transfer system				
Train route optimisation				
Morning departures	92 200	8 100 000	6 300 000	4 400 000
Lunch departures	220 600	17 800 000	14 300 000	10 300 000
Evening departures	87 700	8 300 000	6 600 000	5 800 000
Morning and evening departures	176 800	16 900 000	13 400 000	8 800 000
Joint timetable	229 900	20 000 000	15 500 000	12 200 000
System optimisation				
Morning departures	115 600	10 000 000	7 600 000	4 100 000
Lunch departures	245 600	20 500 000	15 200 000	9 800 000
Evening departures	96 400	10 100 000	8 100 000	5 100 000
Morning and evening departures	206 200	19 400 000	15 000 000	8 300 000
Joint timetable	233 200	20 300 000	15 600 000	12 300 000

Table 19 Basic model runs

As can be seen, the joint timetable produces the best result both for lowest cost optimisations and maximum transfer optimisations. As can be expected, the results are better for the system optimisations, than for the train route optimisations. The lowest cost optimisations determine the lowest cost for the transport system. They can be run with two settings, either train route optimisation or system optimisation. However, as discussed in chapter 6.16, the results are almost identical, since only goods with a positive cost saving is sent by combined transport. The difference is how the fixed costs are allocated. In a system optimisation, the costs are considered jointly for the system, while in a train route optimisation, they are considered for each train route. In other words, cross subsiding between train routes for the fixed costs are allowed in a system optimisation. This means that, on some train routes with a low cost saving, this makes the difference between if the total cost saving for the train route is positive or negative. Thus, slightly more goods can be sent by combined transport in a lowest cost system optimisation, than in a lowest cost train route optimisation[127].

The system optimisations try to transfer as much goods as possible to combined transport without increasing the total system cost. Theoretically, this would result in a total cost saving of zero, i.e. no change in cost from a system with only all-road transport. However, in the current dataset, there are not enough goods to send by combined transport to reach zero cost saving. The positive cost saving generated in the beginning of the mode run, must be outweighed by transferring goods with a negative cost saving to combined transport. See the descending cost curve in Figure 19 on page 63. In the system optimisations towards maximum transfer of goods, all goods that do not have the same sending and receiving terminal and that do not violate the time constraint, i.e. can match the delivery times offered by all-road transport, have been sent by combined transport. This can also be defined as the operational potential of the tested system. The operational potential represents the maximum amount of goods that, irrespective of costs, can be transported by combined transport while offering competitive pick-up and delivery times compared to all-road transport[128].

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[127] The joint timetable system produces identical results in both settings, since the system optimisation uses the same train system as for the train route optimisation. The train routes with a low cost saving have then already been excluded from combined transport in the joint timetable.

[128] In this case, the maximum transfer total system optimisations resulted in the operational potential. However, with another data set, it is possible that the total cost saving would reach zero and not transfer all goods possible, thus, not represent the operational potential. The operational potential can also be calculated by running a data set where the costs for

Note that the joint time table contains some train routes where combined transport is not allowed, since the time table is based on the train route optimisation, where some train routes had a negative cost saving. A special joint time table was, therefore, constructed with allowed combined transport on all routes to determine the operational potential for this train loop system. Lunch departures were used for the train route that did not have any allowed combined transport, since this is the most common departure used. This resulted in 261 600 tonnes being sent by combined transport, which is the highest operational potential reached in the combined transport system.

In the train route optimisations, most train routes reached their operational potential by transferring all possible goods to combined transport, but a few train routes had goods that theoretically could have been sent by combined transport, but where the economic constraint forced them to use all-road transport. They, thus, reached almost zero cost saving[129].

However, in a real world situation, it is not likely that a combined transport system developed according to a total system optimisation principle and/or a maximum transfer of goods principle will ever be implemented, since it is very unlikely that any combined transport operator would be interested in running transport services that generate a loss. The results of these systems are of general interest to determine the potential of the combined transport system, but to unrealistic to develop in detail. The following analysis and model runs will, therefore, focus only on a train route optimisation with a lowest cost focus and business economic cost estimates. The output data is also presented in more detail in Appendix 13.

As can be seen, the best train system for lowest cost and train route optimisation is the train system with a joint time table. This system will, therefore, be analysed in more detail. Of the 91 possible train routes in the system, 10 routes had no profitable trains, 2 routes used evening departures only, 33 used evening and morning departures, 46 used lunch departures and none used morning departures only. An unexpected high number of train

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combined transport (including the road haulage part) are set to zero and the all-road system costs are set any higher cost. This will result in that all goods, that are possible, is be sent by combined transport.

[129] The cost saving never reaches exactly zero, since costs and cost savings are added stepwise, e.g. per lorry and/or train. Most train routes stopped transferring goods to combined transport when a new train was needed on the train route. To add a new train represent a large cost, which would have pushed the total cost saving passed zero to a negative value.

routes used lunch departures only, which is caused by the time periods used in the data set. The largest demand occurrence for each day is placed at noon, according to the demand distribution collected in the survey. Since the model allows for certain flexibility in pick up time, this demand occurrence's pick up time is pushed back a few hours by the model to catch the lunch train departure, since this is more favourable. This assumes flexibility from the shipper's perspective that is realistic in a long term perspective.

10.2 Potential

The potential for combined transport can be measured in a number of ways. It is here defined as the reduced resource consumption from using combined transport compared with all-road transport. This is expressed as the reduced cost by transferring goods from an all-road system to a combined transport system. This measurement has the advantage of being independent of the surrounding system, e.g. demand outside the data set does not affect the potential[130]. However, another interesting measurement is the relative measurement of modal split, i.e. % of the total demand sent by combined transport. This measurement has the advantage of being commonly used when comparing different modes and is also easy to understand. However, it is relative in that it is dependent of what is regarded as the total demand. The modal split presented in the raw output data is limited in that the total demand in the data set only represents a selection of the total demand in Sweden. It could be argued that this modal split shows the potential modal split correctly, since it is the modal split of the potential demand. However, this model split will not be used since it is not directly comparable to national statistics and other research. The modal split will, therefore, be determined according to the long-haul transport demand (excl. the iron ore rail traffic) measured in transport performance (i.e. tonnekm), since it is the most common measurement used. Although combined transport consists of two modes working together, national statistics reports only the transport performance in the rail system part. This will, therefore, also be done here. Total yearly long-haul transport 2001 (over 100 km) in Sweden is 79.1 billion tonnekm total and 75.5 billion tonnekm excl. iron ore transport (SIKA and Banverket, 2004, Wajsman, 2005). This can be compared with combined transport of 40.3 billion tonnekm in the rail part (44.1 total) from

[130] Naturally assuming that all relevant parts of the transport system have been included in the data set.

the HIT-model, which gives combined transport a potential of 53.4% of the total long haul transport excluding iron ore. Combined transport (rail part) transported, in 2001, 2.4 billion tonnekm, which is 6% of the determined potential. The results can further be divided into domestic and international transport. Of the 2.4 billion tonnekm in the transport system, 2.2 billion was domestic and 0.3 was international. The corresponding numbers from the HIT-model are 24.0 billion tonnekm domestic and 16.3 billion tonnekm international[131]. The realised potential is, thus, 9% domestic and 2% international. The lower number for international transport indicates that combined transport today has a lower market share for international transport. This is particularly true, since the data set used in the model concentrates all international demand at the border crossing, thus disregarding the transport distance outside Sweden. This is expected to have reduced the international potential for combined transport in the model, since combined transport, in general, is favoured by longer transport distances. The weight transported in combined transport measured in tonnes is 72.2 million tonnes yearly, of which 41.7 million tonnes are domestic and 30.5 million tonnes are international.

It should be noted that distance transported, and thus the tonnekm, is different for different modes. Combined transport is, generally, transported a longer distance, since it has to be transported via terminals. The difference in total tonnekm between an all-road system[132] and the modelled transport system[133] is 5.5 billion tonnekm or 8%. Comparing with the rail part of combined transport only in the modelled system[134], the difference is 1.7 billion tonnekm or 3%. This must be kept in mind when looking at the potential, and, thus, slightly reduce the potential of combined transport measured in comparison with all-road transport.

This potential might seem very high, but it should be remembered that the purpose of the HIT-model is to show the theoretical maximum potential in combined transport. Only transport cost and delivery times are considered in the modal choice. It is important to underline that this is the theoretical

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[131] Note that the figures only refer to the part of the international transport that is carried out in Sweden.

[132] Assuming shortest path direct road transport from origin to destination in the demand database. However, note that some demand in the input database has been aggregated to terminals, see chapter 9.2.

[133] Total tonnekm in the transport system according to the determined modal split, i.e. the all-road transports of the system and both the road part and rail part of combined transport.

[134] The all-road transports of the system and only the rail part of combined transport.

potential, given the assumptions for the model. The HIT-model makes a number of assumptions that affects the realisable market share. First, it is assumed that the transport mode with the lowest costs (and equal transport quality, etc.) is always selected, which, naturally is, a simplification. The model also assumes that all demand can be aggregated together on the same lorries with a high load factor, which also would not be possible in reality for a large number of reasons, e.g. unwillingness to cooperate, unwillingness to share transport with competitors, goods characteristics (e.g. food or temperature sensitive), different transport companies, perceived lack of control, transport routes or lack of coordination. Further, there is also a difference between the weight in tonnes used in this dataset to determine loading capacity and the volume required for the goods. In many cases, the goods volume can be the limiting factor. The actual realisable market share will not be further discussed here

What is interesting from these results is not just the theoretical maximum potential, but information on the circumstances under which combined transport has the potential to be successful. An interesting aspect is to look at distances where combined transport is competitive. The share of transport demand that used combined transport in the model can be compared with the distance between the terminals in Figure 45 and Table 20.

Distance	**Share <50%**	**Share 50-75%**	**Share >75%**	**Total**
< 250 km	15 (79%)	4 (21%)	0 (0%)	19 (100%)
250-500 km	7 (23%)	17 (57%)	6 (20%)	30 (100%)
> 500 km	6 (14%)	14 (33%)	22 (52%)	42 (100%)
Sum	28 (31%)	35 (38%)	28 (31%)	91 (100%)

Table 20 Number of train routes and share of combined transport by distance

Note that share of combined transport in the graph is compared with the demand in the input data set and, thus, not the potential defined above. The share of combined transport is also affected by other factors, such as unbalanced flows and total goods volume. Further, the size of the potential collection area around the terminal will affect the share[135].

[135] Assume that transport demand on train route A to B is 100 and 10 is sent by combined transport, i.e. a 10% share. Most likely, the areas close to the terminal will have the largest share, while the areas very far from the terminal will have a share close to zero. Now, assume that the areas furthest away would be assigned to another terminal (i.e. train route), e.g. by the

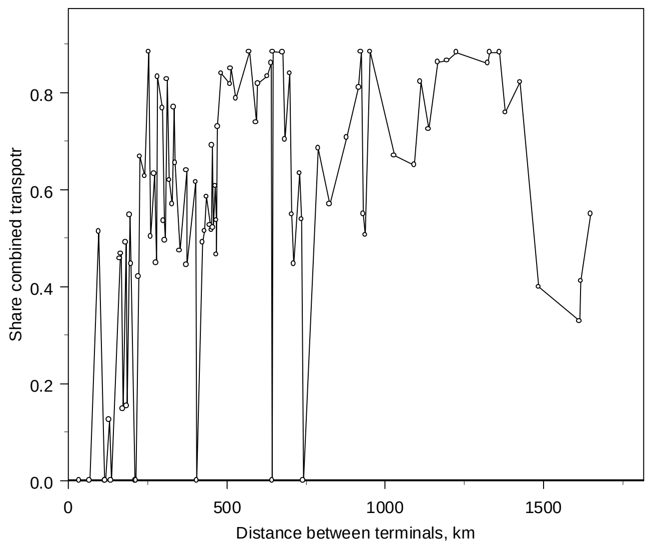

Figure 45 Distance between terminals and share of combined transport

However, it can be seen that train routes shorter than 250 km have none or very low potential for combined transport. Between 250 and 500 km, the potential is higher and above 500 km almost all train routes show a very good potential. Thus, it can be concluded that combined transport is not competitive on distances shorter than 250 km, can be competitive on distances between 250 and 500 km if the conditions are right, and almost always competitive on distances longer than 500 km. The reason why the four longest train routes are less competitive is that a large part of the demand here fails the time constraint, i.e. cannot match the delivery time by all-road transport. The short train routes with a high share of combined transport are routes with a short road transport distance to and from the terminal. This distance is between 10 and 25 km, which can be compared with an average distance of approximately 50 km for other demand sent by combined transport. They mainly represent train routes with a high share of international goods, since this goods have been aggregated to the border crossing terminal, without any collection/distribution haulage by road to the border terminal.

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building of a new terminal. The demand sent by combined transport on route A to B would still be 10, but, since the total transport demand on the route has decreased, the share of combined transport has increased. Thus, the combined transport system around the terminal has not changed, but the share has changed.

The competitive distances are also in line with previous research. E.g. Nelldal, et al. (2000) calculated the break-even distance between combined transport and all-road transport. The calculations compared the cost per ton for trailer in combined transport with 150 km road haulage in both ends with all-road transport. The break-even distances per ton were, approximately, 350 km for a 40 ton lorry (standard European trailer lorry) and 850 km for a 60 ton 25.25m lorry. Nelldal's calculations are reasonable in comparison with the distances determined by the HIT-model, considering that Nelldal's calculations are made with longer collection distances to the terminals than in the current model, which is less favourable for combined transport. The current system (both all-road and combine transport) also uses a large portion of trailer and container lorries (78%) but rather few 25.25m lorries (22%) (see chapter 9.5).

Looking at different train routes, it is difficult to determine the potential in percent of the transport demand, since there are no statistics available about the total long-haul transport demand on such a detailed level as individual train routes. However, what is interesting from a marketing perspective is the potential volumes.

Terminals (both directions)		**Potential tonnekm per day**
Luleå	Trelleborg	6 500 000
Göteborg	Luleå	6 800 000
Luleå	Stockholm	5 500 000
Sundsvall	Trelleborg	5 400 000
Helsingborg	Stockholm	5 000 000
Göteborg	Stockholm	4 700 000
Stockholm	Trelleborg	3 500 000
Göteborg	Umeå	3 300 000
Borlänge	Trelleborg	3 000 000
Hallsberg	Luleå	3 000 000
Malmö	Stockholm	2 900 000
Jönköping	Luleå	2 700 000
Göteborg	Trelleborg	2 600 000
Göteborg	Sundsvall	2 600 000
Stockholm	Älmhult	2 800 000

Table 21 Potential tonnekm per train route

Table 21 shows the 15 train routes[136] with the highest potential transport in tonnekm per day in the rail transport part. The train routes represent routes with a long transport distance and also routes involving the largest cities in Sweden (Stockholm, Göteborg and Malmö) and border crossings (e.g. Trelleborg).

The reason for the modal choice can be subdivided into economic constraints and time constraints. Of the demand (in tonnes) sent by all-road transport[137] 32% violated the economic constraint and 53% the time constraint. A further 15% are on train routes where no combined transport at all is used, which is caused by a combination of these factors[138]. In 26 of the train routes, only the time constraint is the restricting factor. The main challenge for combined transport is, thus, not the cost but the pick-up and delivery times. This can be further validated by using an input data set with shorter time windows. A data set was run with comparative time gaps of one hour only and no time windows, i.e. combined transport must deliver and depart within one hour of all-road transport (i.e. the direct transport time by road) or faster. This reduced the share of combined transport drastically. Only 3.6 billion tonnekm was sent by combined transport, or 4.8% of the long haul transport demand. In the current data set, it is very difficult for combined transport to match the all-road transport times under those circumstances, since lorry and train speeds are similar, and the all-road transports travels directly to the destination the shortest path without passing any terminals. A more relaxed test was to require delivery and departure within 4 hours of direct road transport, i.e. a 4 hour time gap. This resulted in 29.4 billion tonnekm being sent by combined transport, or 38.9% of the total long haul demand.

The importance of time is also shown by calculating the operational potential for combined transport by looking at the special joint time table used for the maximum transfer total system optimisation, see chapter 10.1. This sends all goods that, do not violate the time constrains and do not have the same sending and receiving terminal, with combined transport. The operational potential is 46.3 billion tonnekm (rail part) or 61.3% of the total long-haul

[136] Train routes with more than 2% each of the total tonnekm in the rail transport part of combined transport.

[137] Excluding demand where the sending and the receiving terminal are the same.

[138] It cannot be determined exactly what factors cause the decision not to use combined transport on the train routes, since the routes have been tested with several different train systems. The reasons can be determined for each of the tested train systems, but naturally, the percent of the demand that fails the delivery times or the economic constraints is different for each of the tested systems.

demand excluding iron ore. The difference compared with the theoretical potential determined above is, thus, only 7.9% of the total demand. A very large part of the operational potential has already been reached in the theoretical potential. This further confirms that the main challenge for combined transport is not costs, but achieving competitive delivery times. A further discussion on time can be found in chapter 10.6.

The potential of combined transport is also affected by the international goods transported in the domestic combined transport system. A test was conducted with removing all international goods flows from the data set. This caused the model to send 24.9 billion tonnekm by combined transport. Comparing the results with the long-haul domestic demand of only 35.0 billion tonnekm excluding iron ore[139], the potential of combined transport is 71.2%, i.e. an increase of 15.7% compared to the original data set. The potential for international combined transport, measured in percent of the total transport demand, is, thus, less than the potential for domestic goods. Most likely, this is caused by the goods characteristics where large international goods flow, such as bulk shipping and timber export/import, where excluded from combined transport already when the demand database was designed (see chapter 9.2). Looking at the domestic combined transport, it is interesting to note that the amount of domestic combined transport in the original data set also was 24.9 billion tonnekm, i.e. removing the international goods did not have any significant effect on the domestic goods volume. This result is surprising, since it could be expected that larger volumes in the rail system would cause scale effects, thus giving a more competitive rail system. However, the HIT-model does not include scale effects, other than in the rail system when the high initial cost of new train capacity is considered. When, e.g. a new train has been inserted on a train route, the train can be used by subsequent goods at a marginal cost, e.g. the cost of rail cars. The effect of the step wise cost curve used in the rail system appears to even out between the different train loops. Some train loops have an increase in domestic combined transport goods while some have a decrease.

[139] Calculated using a percentage distribution of types of long haul transport for 2004 from Wajsman (2005).

10.3 Costs

The focus in the cost analyses has been on the business economic costs. The HIT-model always calculates both business economic costs and social economic costs, although the optimisation only considers one of them. The data below comes from business economic optimisations, unless otherwise stated.

10.3.1 Business economic costs

Looking at costs, the total cost savings from using the suggested combined transport system are SEK 13 100 000 or approximately 27% of the cost of an all-road system. However, the cost savings can also be compared with the all-road cost only for the demand that is sent by combined transport. The cost savings are then 44%. This can be translated into an average cost per tonnekm combined transport of SEK 0.14. The cost in the rail part of combined transport (including terminal handling) is SEK 0.12. The cost per tonnekm for all-road is SEK 0.32 and for the road part of combined transport SEK 0.33.

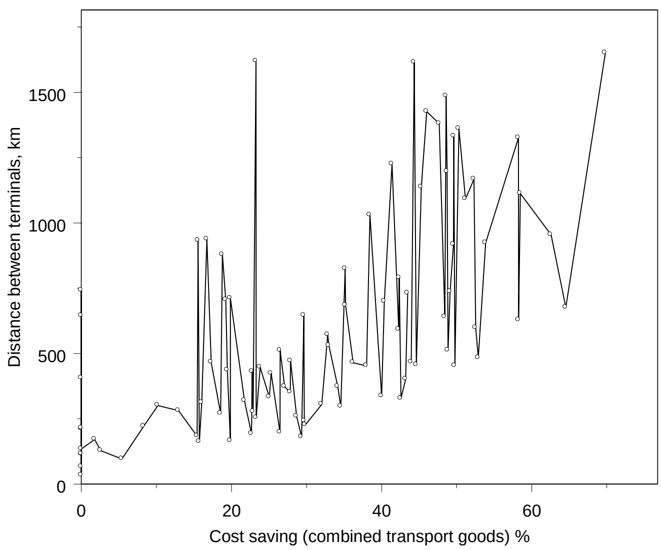

Figure 46 Cost savings and distance between terminals

The cost savings can also be compared with the transport distance. As can be seen in Figure 46, the cost savings increases with the distance between terminals. The figure shows the cost savings in percent for the goods sent by combined transport compared with if the goods had been sent by all-road transport. The results can be expected, since combined transport has a lower transport cost per tonnekm, and this confirms the assumption that combined transport increases its competitiveness with the length of the rail haulage.

Similar results are shown by examining the cost per tonnekm in combined transport and the distance between terminals as in Figure 47. It can be seen that the shorter train routes have a higher cost per tonnekm than the longer routes. This is caused by the fixed terminal costs, which are independent of the transport distance.

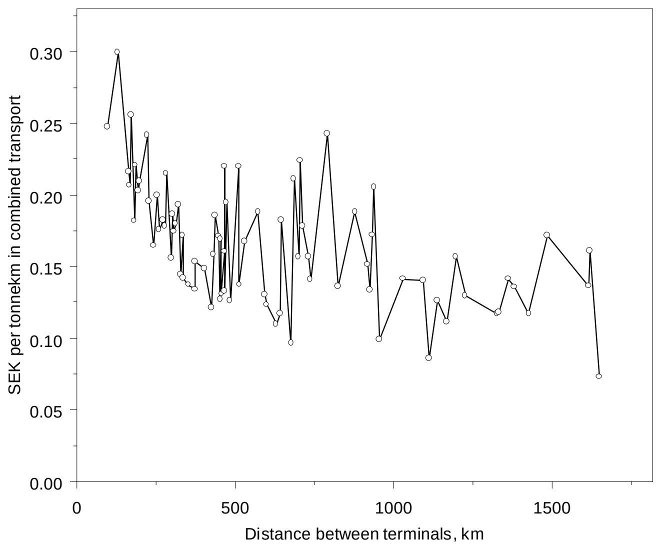

Figure 47 Cost per tonnekm in combined transport and distance between terminals

The output cost can also be compared with CargoNet’s price list for combined transport. Although price and cost are different the comparison is interesting. Most hauliers are also offered discounts on the price list. The rail and terminal cost for an average ITU between Sweden’s two largest cities Stockholm and Göteborg, according to the HIT-model, is SEK 1 070. This can be compared with CargoNet’s price list (including terminal handling) for

2005 of 2 185 for a trailer, 1 092 for a swap body and 2 404 for a 40 foot container (CargoNet, 2005a)[140]. The HIT-model uses very few swap bodies on the selected route (only 14 of 424 ITUs per day), which makes the calculate cost more comparable to the trailer and container prices. The all-road cost, according to the HIT-model, for a 25.25m lorry (1 trailer and 1 swap body) is 3 797 which can be compared with 3 277 for the same transport in combined transport, according to CargoNet's price list. A similar comparison between Sweden's largest and third largest cities, Stockholm and Malmö, shows that the cost according to the HIT-model, is 1 410 while the price from CargoNet is 2 706 for a trailer, 1 353 for a swap body and 2 977 for a container. Here the HIT-model also uses very few swap bodies (6 of 218). The all-road cost is 4 885 for a 25.25m lorry in comparison with 4 059 for combined transport. The costs in the HIT-model are thus about half of CargoNet's price. However, it must be considered that the costs/prices are for different years, the need for a profit margin for CargoNet and that discounts are often offered. The HIT-model also transports more demand in the combined transport system than CargoNet's real world system and using only direct trains, which also is expected to give a lower unit cost. CargoNet's prices seem to correspond well with the cost for all-road transport. The Swedish Haulier Association's price index for road transport lorries (see chapter 9.7) increased by approximately 20% between 2001 and 2005. By adjusting the road transport costs with the index to the 2005 level, it can be found that the cost difference between all-road cost and CargoNet's prices is about 30% in both cases. This cost difference would correspond to a road collection and distribution of about 80-100 km in both ends.

It is also interesting to look at the cost structure for combined transport. The largest cost factor is the train haulage followed by the terminal costs, see Table 22. The table shows the distribution of the total system cost. Train haulage is, not surprisingly, the largest cost, but also the variable terminal costs represent a fairly large share of the combined transport costs. Terminal operations are an area that is the subject for much research and where the costs also can vary greatly between different terminals. It is, therefore, interesting to see the effects of reduced terminal costs. A data set was run in the HIT-model with the variable terminal costs, i.e. handling costs, reduced by 50%. All other data were the same. This resulted in 218 100 tonnes daily

[140] The prices are, in essence, dependent on the length of the ITU, i.e. the price of a trailer occupying a full rail car is twice that of a shorter swap body occupying only half a rail car. This is easy for the customer to understand, but does not consider the number of lifts needed at the terminal.

being sent by combined transport, or 42.4 billion tonnekm yearly. The potential for combined transport, thus, increased to 56.2%.

Transport part	% of combined transport costs
Road haulage	20.5%
Variable terminal costs	25.1%
Fixed terminal costs	1.1%
Train haulage	53.3%
Total	100%

Table 22 Cost structure of combined transport

10.3.2 Social costs

The social cost savings for the modelled system, with a business economic cost optimisation, are 19 900 000 or 33% of the cost of an all-road system and 52% of the all-road costs for the demand sent by combined transport. The cost per tonnekm combined transport is SEK 0.15. The cost in the rail part of combined transport (including terminal handling) is SEK 0.13. The cost per tonnekm for all-road is SEK 0.41 and the road part of combined transport is SEK 0.43. The social cost is approximately 18% higher than the business economic cost for the total system and 8% for the demand sent by combined transport. The difference in the road transport part is 27%. This shows the low societal costs involved in rail transport in comparison with road transport.

A model run with social cost optimisation was also done for a lowest cost system with train route optimisation. The model run used the same joint time table as for the business economic calculations[141]. This resulted in 215 400 tonnes daily being sent by combined transport, which can be compared with 197 900 tonnes for the same train system in a business economic optimisation. In tonnekm, the social cost optimisation sent 42.3 billion tonnekm yearly with combined transport, representing a potential of 56.0% of the total long haul transport demand excluding iron ore. Only 11.0% of the weight sent by all-road transport could not be sent by combined transport for economic reasons, compared with 31.7% for the business economic

[141] It should be noted that the joint train time table is designed for the business economic optimisations and, thus, not necessarily the best joint train time table for social economic optimisations.

optimisation[142]. Not surprisingly, the social cost optimisation used more combined transport than the business economic optimisation. The same joint time table system, thus, sent 17 500 tonnes (8.8% increase), or 2 billion tonnekm (5.0% increase), more with combined transport. Again, this shows that combined transport is more favourable from a social economic perspective.

10.4 Environment

Combined transport also gives a substantial reduction in emissions harmful to the environmental. The environmental savings from using the suggested combined transport system compared with an all-road transport system are shown in Table 23[142]. Table 24 shows the average emission per tonnekm for the two parts of the modelled transport system.

CO_2	CO	SO_2	NO_x	PM	HC	Energy	Monetary estimation of emissions
53%	49%	-5 225%	53%	48%	53%	31%	53%

Table 23 Environmental savings compared with an all-road system

	CO_2 grams	CO grams	SO_2 grams	NO_x grams	PM grams	HC grams	Energy MJ	Monetary estimation of emissions
Combined transport part	5.57	0.007	0.0037	0.035	0.0009	0.0028	0.24	0.010
All-road part	44.55	0.041	0.000057	0.28	0.0046	0.023	0.60	0.086
Total system	17.88	0.018	0.0026	0.11	0.0021	0.0092	0.35	0.034

Table 24 Emission per tonnekm for the modelled system

As can be seen, the environmental effects of using combined transport are substantially lower than those of all-road transport. The only exception is SO_2 where combined transport causes much higher emissions. This is caused by the electricity mix used in this data set. Only 2.43% of the electricity purchased by the rail administration in 2001 was produced by coal but this is enough to cause this large effect compared with the very low sulphur

[142] Excluding demand where both the sending and the receiving terminal are the same.

emissions from road transport. Still, the sulphur emissions from rail transport are very low. An interesting comparison can be made to diesel fuel with Swedish Environmental class 3 (Miljöklass 3) which is the minimum EU requirement. This fuel causes about 100 times greater SO_2 emissions than the Environmental class 1 fuel (Sveriges åkeriföretag, 2007) used in these calculations, which would cause all-road transport to have more SO_2 emissions than combined transport. It should also be noted that the rail administration today only purchases electricity from renewable energy sources with no sulphur emissions.

The CO_2 emissions are of particular importance considering the greenhouse effect and climate change. The total Swedish CO_2 emissions from heavy traffic (trucks and busses) are 4.2 million tonnes per year (SCB, 2000). The reduced emissions in the suggested transport system are 1.3 million tonnes per year compared with an all-road system, or 31% of the total CO_2 emissions from heavy traffic. Although some goods already are sent by combined transport, this shows that combined transport could contribute significantly to reducing CO_2 emissions. A model run was also conducted with an environmental optimisation towards the system with the lowest CO_2 emissions. The HIT-model, thus, calculated the transport system giving the lowest CO_2 emissions[143]. This optimisation resulted in 45.0 billion tonnekm being sent by combined transport, which is 4.7 billon tonnekm more than in the original system. This is also more than in the socio-economic optimisation. This further shows that combined transport can contribute greatly to reduced CO_2 emissions.

10.5 Equipment utilisation

The HIT-model also selects the number and types of lorries that are to be used. In the combined transport system, an average of 9 188 ITUs are dispatched every day. These are carried on 8 839 lorries distributed among 55% 40-foot container lorries, 41% trailer lorries and 4% 25.25m lorries. In the all-road transport system, an average of 9 570 lorries was used, distributed among 12% 40-foot container lorries, 50% trailers and 38% 25.25 meter lorries. A total of 32% 40-foot container lorries, 46% trailers and 22% 25.25 meter lorries was used in the two systems.

[143] See chapter 6.5.

	Combined transport				All-road transport			
	40-foot lorry	**Trailer lorry**	**25.25 m lorry**	**Total number**	**40-foot lorry**	**Trailer lorry**	**25.25 m lorry**	**Total number**
%	55%	41%	4%	9 188	12%	50%	38%	9 570
Load factor	94%	77%	87%	87%	87%	68%	84%	76%

Table 25 Number of lorries and load factor

A surprisingly large share of 40-foot container lorries is used. Partly, this is explained by the export/import demand that has to be sent by container (24% of all container lorries in combined transport and 87% of all container lorries in all-road transport) but the main reason is the input data used. Both trailer lorry and 40-foot container lorry are given the same cost, but the container has a greater loading capacity in tonnes, which makes it more attractive. Even though the HIT-model is set to use container lorries only if the extra capacity is needed, this causes a large number of container lorries to be used, see chapter 9.7. In reality, however, containers are seldom used for domestic road transport, since their loading capacity measured in volume and in number of standard European loading pallets (which is in many cases are the limiting factors) is lower than that of an ordinary trailer. A data set was, therefore, tested where containers were banned from all-land transport. The cost savings for this system, compared with the all-road cost for the demand sent by combined transport, where 43%, i.e. 1% lower than the original system. 39.9 billion tonnekm were sent by combined transport, i.e. a potential of 52.8% or 0.6% less than the original system. The transport system, thus, got slightly more expensive and transported slightly less goods by combined transport, but removing the container lorries did not cause any major changes.

25.25m lorries are only competitive in combined transport if they have a high load factor. This can be explained by the higher terminal handling cost for these lorries since they consist of two load carriers. The terminal cost, thus, increases by 100% and the rail cost increases by 50% (requiring 1.5 rail cars compared with only 1 rail car). Although a 24.24m lorry can carry 54% more goods, this requires a high load factor (e.g. that one full 25.25m lorry can replace two less full trailer lorries) and long rail transport distances to be competitive. 25.25m lorries are more competitive in all-road transport, where the cost difference is much smaller since the costs are not in the same way directly dependent on the number and length of the ITUs. Still, a high load factor is required, i.e. that the extra loading capacity is used, to be competitive. An interesting comparison can be made with the current pricing strategy used by CargoNet (CargoNet, 2005a), which is, in essence, based on the length of the ITU, while the HIT-model also considers the number of lifts performed at the terminal, i.e. the number of ITUs. The disadvantage of having several ITUs on a lorry is, therefore, reduced with CargoNet's current pricing.

There has been a lot of discussion about the 25.25 meter lorries within the European Union. Currently, they are only allowed in Sweden and Finland, but strong forces want this larger type of lorry also to be allowed within the rest of the EU. Most likely, this would increase the competitiveness of all-road transport compared with other transport modes. An interesting alternative would be to only the 25.25m lorries for combined transport, but not for all-road transport. This would promote combined and intermodal transport and compensate road haulers for the higher purchasing cost and reduced loading capacity with load carriers and lorries adapted for combined transport. This was tested in a model run, where 25.25m lorries were allowed only for combined transport. 42.2 billon tonnekm was then sent by combined transport, which is an increase of 1.9 billion tonnekm. Interestingly, the model did not choose to use more than 5% 25.25m lorries of all lorries used for combined transport, which is a decrease from the 8% used in the old system. Although the actual number of 25.25m lorries used increased, their share of the total number of lorries was reduced. However, the consequences of the reduced competitive pressure from all-road transport when the 25.25.m lorries was removed, was enough to increase the potential in combined transport.

No swap body lorries were used in the system. This is also caused by the input data where the cost for a trailer lorry and a swap body lorry is the same. Although the loading capacity is slightly higher in the swap body lorry, the fact that there are two individual ITUs on the lorry doubles the terminal handling cost, which makes the trailer lorry a better alternative. However, to have several ITUs on a lorry can sometimes be an advantage worth the extra costs, e.g. when the two ITUs should be delivered to different customers. An advantage of using detachable load carriers is that one load carrier it can be dropped of at the shipper/receiver for loading and/or unloading while the lorry continues with the other load carrier to its destination.

The load factors are high, which can be expected, since the HIT-model does not use more lorries than necessary. In reality, the load factors would be lower. A test was, therefore, carried out with an input data set where the loading capacity on all lorries was cut by 50%. All characteristics about the lorries where the same as before, apart from that their loading capacity was reduced to half of the original. This resulted in a potential of 54.0% combined transport (0.6% reduction) and cost savings of 45% (1% reduction. Costs compared with the all-road cost for the demand sent by combined transport). The potential and the cost savings are thus almost the same. However, the total cost has increased. The cost per tonnekm has increased to 0.24 for combined transport (0.21 for the rail transport and 0.57 for the road transport) and to 0.51 for all-road transport. The fact that the potential remained the same is natural, since both the competing modes where given the same reduction in loading capacity. Not surprisingly, the costs have increased. However, the increase is only about 75% for combined transport and 55% for all-road transport. The fact that the cost increase being less than 100%, which could have been expected, can be explained by that the load factor has increased on the lorries. If a demand instance previously required a half lorry (50% load factor) it now still only uses one lorry but with a 100% load factor. The average load factor is now 95% for combined transport and 88% for all-road compared with 87% and 76% previously.

A total number of 520 trains were used in the system on 324 train loops. 114 of the train loops used more than one train. The average length of a train (excluding engine) was 516 meters (15 Sdggmrss rail cars), which is 83.8% of the maximum length allowed. 439 of the trains were of maximum length[144]. On 13 train routes, all trains were of maximum length. Not all rail cars were used on all departures. The average empty capacity on a departing train was 102 m (19.6% of the average train length) or 3 Sdggmrss rail cars. 65.0% of the departing trains used all of the rail cars on the train.

10.6 Time

The model made some adjustments in departure and delivery times compared with all-road transport. All adjustments were made within the allowed time windows and time gaps. The delivery times, in mot cases, were

[144] Note that a departure in the model can consist of several physical trains, e.g. a departure at 6 p.m. can consist of two trains. The figures showed here refer to the number of physical trains.

adjusted forward in time, see Figure 48. The only occurrences where the delivery time was adjusted backwards in time (14.3%), i.e. earlier delivery compared with all-road, are when the departure times also were moved earlier. No demand has both later departure time and earlier delivery time. As can be seen, 58.7% of the goods weight in combined transport are delivered no later than fiver hours after all-road transport and 28.8% are delivered no later than two hours after all-road.

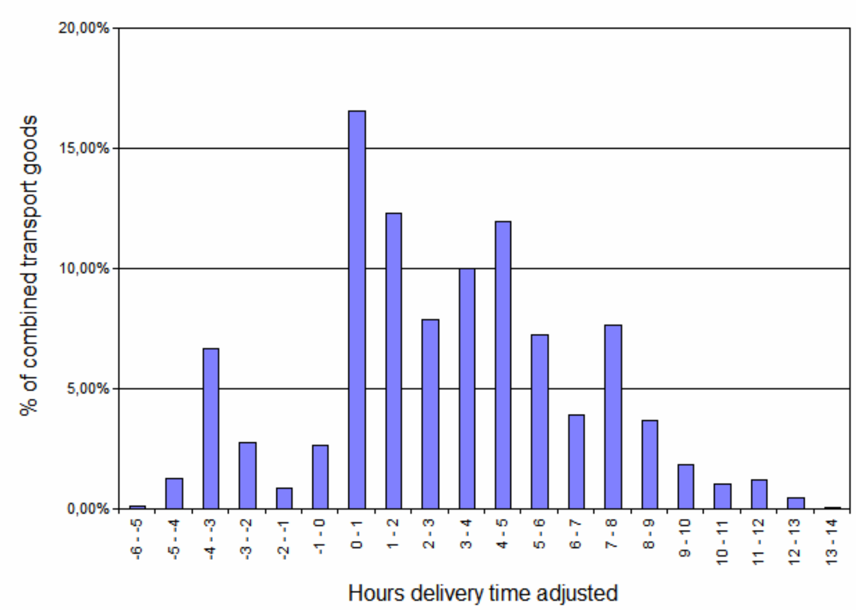

Figure 48 Adjusted delivery times and share of goods weight in combined transport

The departure times were also adjusted. A majority of the demand was adjusted forward in time, i.e. later departure, with only 30.5% of the weight in combined transport being sent earlier, see Figure 49. This can be explained by the use of over night transport, where a large portion of the all-road demand would be delivered during the night. This makes it possible for combined transport to use later departure times and still deliver in the same time period. Figure 50 shows the delivery times by combined transport and if the same demand would have been sent by all-road transport[145]. All-road transport has many deliveries late in the evening (41.1% compared with 5.3% for combined transport between 18-00), while combined transport has

[145] Time is in the figures showed using a 24-hour time scale, e.g. 2 p.m. equals 14.

more deliveries during the night (35.5% compared with 11.0% between 00-08). However, both are in the same time period (18-08) and, thus, considered equal.

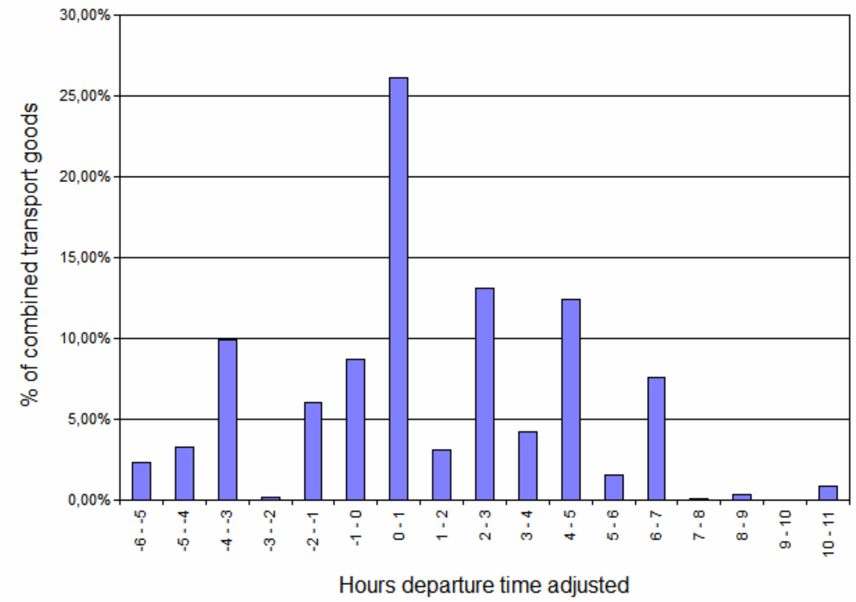

Figure 49 Adjusted departure times and share of goods weight in combined transport

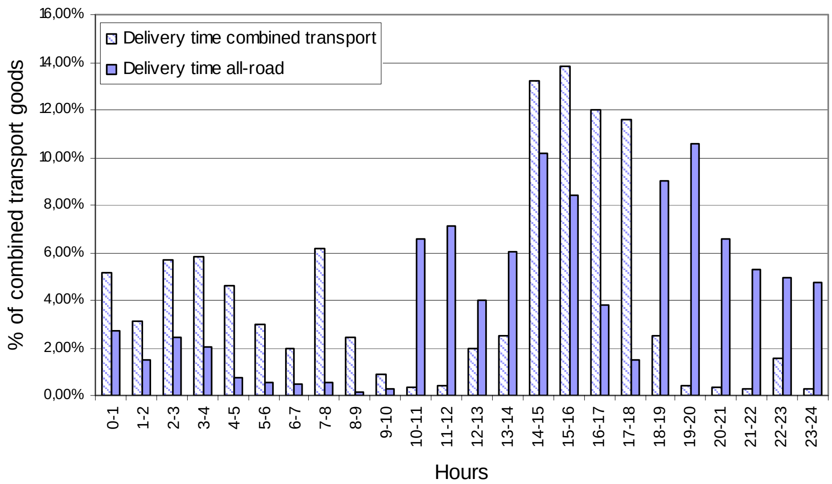

Figure 50 Delivery times compared between the modes

It is interesting to note, that none of the demand in the evening demand at 8 p.m. is sent by combined transport. Figure 51 shows the departure times in combined transport and the departure time in road transport if the same demand would have been sent by all-road transport, i.e. the input time used in the data set for the demand. The demand occurrences in the input data is set at 8 a.m., noon, 4 p.m. or 8 p.m. but none of the demand at 8 p.m. is sent by combined transport. The time periods used do not allow this demand to use the evening departure at 6 p.m. and the morning departure at 8 a.m. is too late to match all-road transport.

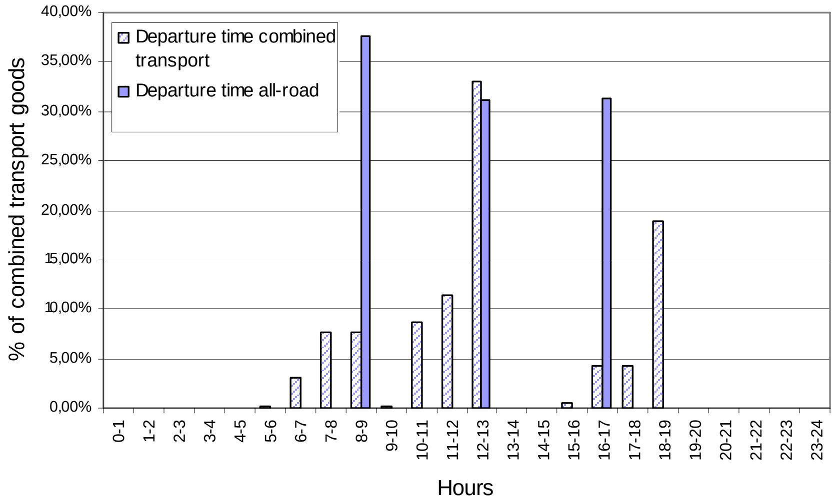

Figure 51 Departure times compared between the modes

The total time adjustments are fairly moderate. Figure 52 shows the total time adjustment by the model. Only earlier departure time and later delivery compared with all-road transport was considered[146], since later pick-up and earlier deliveries are not expected to cause any problems[147]. It can be seen that 49.3% of the combined transport goods in tonnes required an adjustment

[146] The time difference between delivery and departure times for all-road and combined transport was summed up. E.g. combined transport departing one hour before all-road and being delivered one hour later is calculated as 1+1=2. However, combined transport departing after all-road and/or being delivered before all-road is regarded as 0. Thus, if combined transport departs one hour after all road and is delivered one hour after all-road, the calculation is 0+1=1.

[147] Pick-up and/or delivery times could always be arranged to match all-road simply by delaying the goods at the terminal.

of less than four hours and 70.6% require an adjustment of less than five hours. 26.0% required an adjustment of less than one hour. The large portion of goods with an adjustment of 4-5 hours is caused by the frequent use of lunch train departures, where the morning demand at 8 a.m. is being adjusted forwards to catch the lunch departure at noon and the afternoon demand at 4 p.m. is being adjusted backwards to catch the lunch departure.

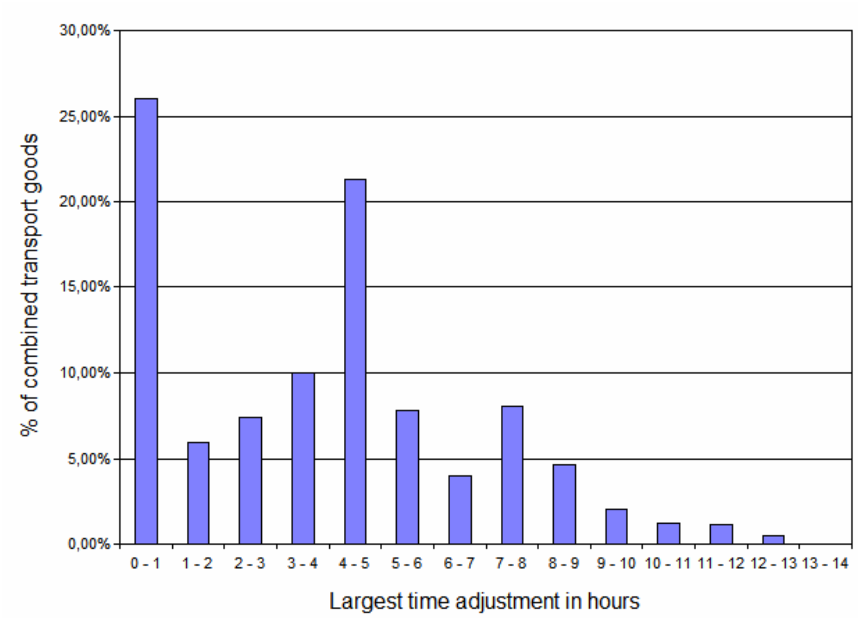

Figure 52 Hours departure/arrival times adjusted by the model

Time has been identified as an important are for combined transport. The main challenge for combined transport is to achieve competitive pick-up and delivery times compared with all-road transport. Basically, there are three ways of achieving this. Convincing the shipper and/or receiver to accept more generous time windows, increasing the speed of combined transport and/or reducing the speed of all-road transport. The effects of changed time windows have been investigated in chapter 10.2. Increasing the speed of combined transport can be achieved by more efficient terminal operations, faster trains (better equipment and infrastructure) and better time tables (e.g. access to better time slots on the tracks). Green Cargo recently ordered new swap body rail cars to be used in post trains, than is intended to run in 160 km/h, in cooperation with the Swedish Post (Green Cargo, 2007b). A data set has been run where this has been taken as an example of a faster combined transport service. An average train speed of 160 km/h has been used[148]. All other data has remained the same. This new system increased the amount of goods in combined transport to 47.0 billion tonnekm or a potential of 62.3%. This is higher than the operational potential in the old system. The amount of goods violating the time constraint has been reduced to 23% of the demand in tonnes sent by all-road transport[149], compared with 53% in the old system. 13% violates the economic constraints.

To test the effects of slower all-road transport, a data set was run with the speed of road transport lorries, including the road transport lorries in the combined transport system, reduced. This is to represent increased congestion, and also better respect for speed limits. The current dataset has a road transport speed of 80 km/h, since this is the actual average speed on the roads today. See Vägverket (2005) and chapter 9.5. However, this is also the maximum speed allowed for articulated lorries. Obviously, a large number of lorries breaks the speed limit, since it is the average speed. A recent study by NTF (The National Society for Road Safety) outside Stockholm showed that 79% of all articulated lorries where speeding (NTF and Vägverket, 2006). The tested data set used a lorry speed of 50 km/h. All other data remained the same as in the old system. This data set sent 46.2 billion tonnekm with combined transport. The amount of goods violating the time constraint was also 23%, as in the previous data set. The result was, thus, very similar to the data set with faster trains. The two data set can also be combined into one, i.e. both faster trains and slower lorries. The result of running this combined data set was that 49.8 billon tonnekm was sent by combined transport, or a potential of 66.0%. It is clear that faster train and/or slower lorries greatly can contribute to increasing the potential of combined transport. This has increased the potential of combined transport more than any other parameter settings used in the HIT-model.

10.7 Collection area

The collection area is the area around a terminal where combined transport is a competitive alternative. The average transport distance (per transported ton) to or from a terminal is 26 km, i.e. a total road transport of 52 km. The

[148] Naturally, the average speed of the post train is not 160 km/h, but this have been used to also represent the potential of other improvements that is not included in the model, e.g. terminal operations and better time slots, and as an indication of the effects of faster combined transports.
[149] Excluding demand where both the sending and the receiving terminal are the same.

weight distribution can be seen in Figure 53, which shows the share of combined transport goods distributed by the total road transport distance at both ends (i.e. collection distance plus distribution distance). As can be seen, 50% of the goods (in tonnes) have a total collection and distribution distance of less than 40km. 95% have a road transport distance of less than 140km. This confirms the general belief that the road transport part should be kept as short as possible. The profitable distances, thus, only represent the closest surroundings of the terminal. The large share of goods with a distance less than 10 km is caused by international goods that are aggregated at the border crossing (and at the road transport terminals in the other end) and by domestic goods located in the same municipality as a terminal, thus, with a very short collection distance. As terminals are located in most large cities (i.e. with a large demand for transport) there is a large share of the demand that has a short distance to a terminal. Of the total input demand, 31% are located less than 10 km total (collection distance + distribution distance) from terminals.

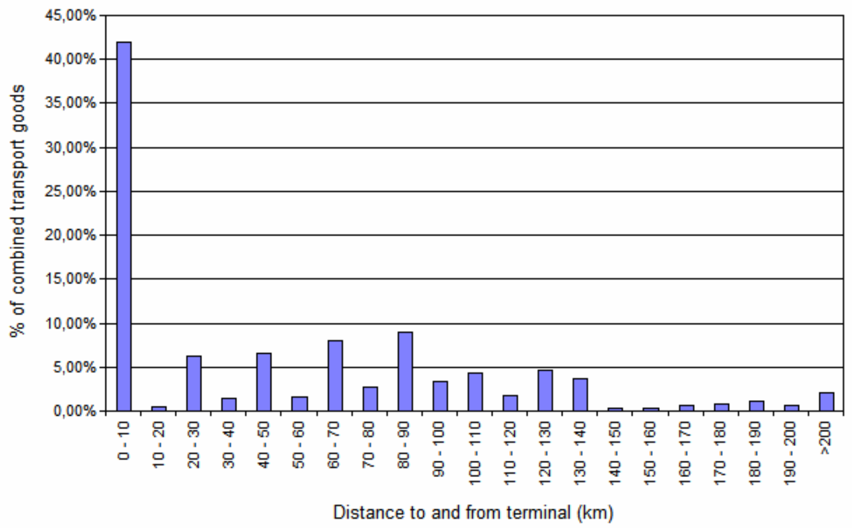

Figure 53 Collection and distribution distance by share of goods weight in combined transport

There might be a need for new terminals for long-haul transport. Apart from capacity constraints in the terminals, which are not considered in the HIT-model, there might also be geographical reasons. Figure 54 shows the number of tonnes in the input demand and the total road transport distance in the combined transport system, if they should be send by combined transport (i.e. to the sending terminal and from the receiving terminal). Demand with a direct all-road transport distance (i.e. direct from demand point to demand point) of less than 100 km was excluded from the graph, since the database is not designed for short distances, and it is not likely to be of interest as combined transport goods. Of the demand of 128.4 million tonnes, 57.7% have a total road transport distance to and from combined transport terminals longer than the average distance (i.e. 52 km). Only 12.5% of the input demand has a distance longer than 140 km, which can be compared with the fact that 5% of the goods sent by combined transport had a distance to and from terminals longer than 140 km. In general, most demand seems to be within a competitive distance from a terminal. However, 19.5% are in the range between 100km and 140 km, which is among the longest collection distances used. This range should be examined further to determine if any new terminals are needed.

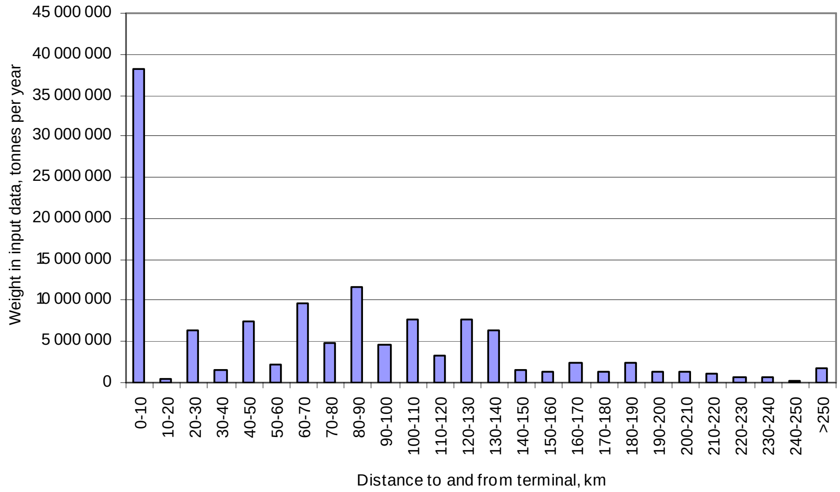

Figure 54 Weight in input data by distance to and from terminal, excluding short-haul demand

For the collection and distribution transports to/from the terminals, it can be seen that 45% of the goods weight is less than 10km from the closest sending terminal and 57% has its destination is less than 10km from a receiving terminal.

As can be seen in Table 18, 15.7% of the total demand have the same sending and receiving terminal and are, thus, always assigned to all-road transport. This share is interesting because it cannot be sent by combined transport without new terminals. However, this should be interpreted with caution, since the demand database used in the data set is not designed for very short distances. Some data from the forwarders were, for example, divided into three parts (to terminal, long-haul and from terminal). This makes the data set not fully representative on very short distances. Also, the fact that there is a potential train route to use does not necessarily mean that the train route can be made profitable. However, a careful geographical analysis can be made by looking at the share of the total transport demand for a region[150], where sending and receiving terminals is the same. This share is highest in the areas around the two largest cities Stockholm and Göteborg, followed by the areas in northern Sweden (north of Sundsvall). A notable exception is the area around Jönköping, which also has higher than average share. The high share for the largest cities can be explained with that they have a large population and are large consumption centres. It can be noted that the third largest city, Malmö, has a relatively low share, most likely because there are several terminals in the area. Similarly, the high share in northern Sweden can be explained by few terminals in the area. The high share for the cities is accompanied by large transport volumes, in contrast to the large areas in northern Sweden, where the volumes are small.

10.8 Balance

As with most transport flows, there is a certain unbalance. Figure 55 shows the unbalance for the different train routes. 100% means that the system is balanced, i.e. equal amount of goods in both directions. 200% means that the amount of goods in one direction is double that of the other direction. The average unbalance is 223% and the median unbalance is 159%.

[150] Calculations were made both for each county and for each terminal area (i.e. the area defined in the input data as the potential collection/distribution area for a terminal).

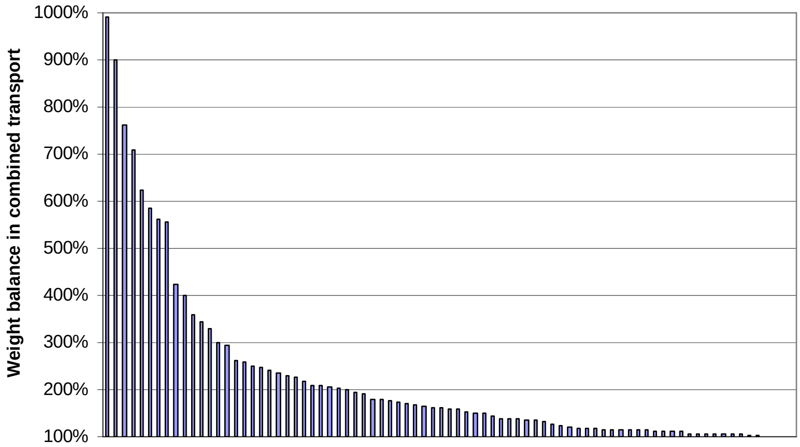

Figure 55 Balance in combined transport flows per train route

The unbalance also exists in the input demand data. Figure 56 compares the unbalance in the input data with the unbalance in the combined transport system, e.g. 200% means that the difference between the unbalance in the input data and combined transport system is 200%[151]. A positive value means that the unbalance is higher in input data and a negative value means that the unbalance is higher in the combined transport system. The unbalance is greater in the input data than in combined transport. 52 train routes have a greater unbalance in the input data and 28 in combined transport. The greater unbalance of combined transport is also rather small, with the exception for four train routes with very high unbalances. These train routes are the same routes that have the highest unbalance in the combined transport flows. The unbalances in these routes are caused by the time constraint which restricts almost all reaming demand to be sent by combined transport on these routes. The lower unbalance in combined transport can be explained by that the "more profitable" direction subsidises the "less profitable" direction, since the HIT-model considers the full train loop.

[151] For example, the input unbalance is 500% and the combined transport unbalance is 300%, i.e. input unbalance – combined transport unbalance (500-300 = 200).

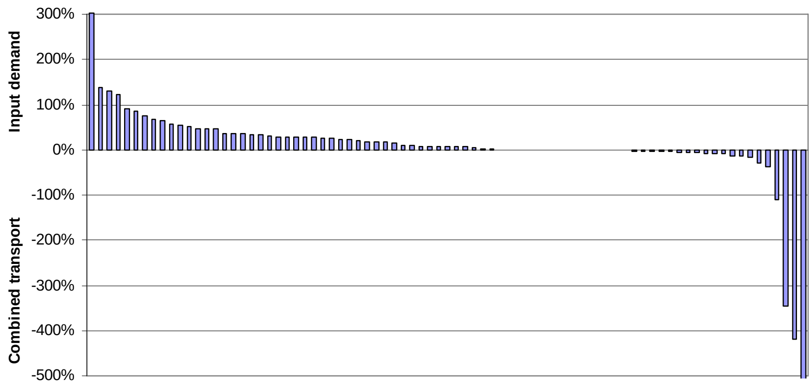

Figure 56 Balance in combined transport compared with balance in input data per train route

One train route was excluded from both graphs, since combined transport only exists in one direction[152]. This makes it impossible to calculate a balance.

[152] This is caused by a large industry that has a very large outgoing transport flow to a specific destination, as identified by the VFU-survey. The transport flow is known but cannot be identified here due to respondent confidentiality.

11 Conclusions

The conclusions are separated in two parts. First, the conclusions for the HIT-model itself are given, followed by the conclusions from the model runs of the current Swedish transport system. Finally, suggestions for future research are given.

11.1 The HIT-model

The Heuristics Intermodal Transport Model (HIT-model) was developed for decision support concerning combined transport Sweden. As shown when determining the potential for combined transport in Sweden, see chapter 10, the model is well adapted for its purpose.

One of the aims was to build a flexible model. The model structure does not limit the size or geographical area (e.g. other countries) of the model. Input and output data can easily be changed, processed and analysed using the Microsoft Access database, without requiring any advanced computer skills from the user. Not only large size data sets (e.g. the national Swedish transport system used in this thesis) can be run, but the Hit model can also be used with small data sets, e.g. for an individual train route or an individual combined transport operator. The HIT-model could also be extended to include other modes of transport. In particular, shipping would be interesting to add to the model. From a modelling perspective, the principal modelling is the same. A long-haul transport mode is simply a representation of loading capacity, costs and transport times, which could just as well represent a ship or an aircraft as a train. The HIT-model is, thus, very flexible and versatile and can be used in a large number of different situations.

The HIT-model can be used by politicians and decision makers to evaluate and examine the potential for intermodal transport and also to test the effect of changes to the system, e.g. taxes, cost changes, new technology, new infrastructure, etc. The transport industry can use the model to develop new transport systems and improve existing systems. The model can also be used as a calculation tool to calculate the performance, costs and environmental impact of a given transport system.

The use of C++ programming gave great freedom in designing the heuristics. By designing an independent software, the model could be tailored to the specific research question. The combination with a Microsoft Access database as a user friendly interface was very successful. In particular for practical reasons, since the input data files can get rather large. For example, the input demand data file in the current data set amounts to more than 500 000 lines. This would not have been possible to manage without a database. This, also, reduced the risk of errors in the input data. The database was also crucial in analysing the output data. The HIT-model output summarised data in a text-file, but all major analysis were performed in Access. The output file for the demand transported with combined transport is, for example, more than 200 000 lines. This could not have been analysed without a database. The run time of the model is fairly short, which simplifies the use of the model. Also, considering the rapid developments in computer technology, it is likely that the run time will further decrease in the future when new and faster computers become available.

The analysis and model runs performed with the HIT-model when determining the potential of combined transport in the current Swedish transport system highlighted the importance of being familiar with the model and the assumptions made during the model runs and analysis. Several parts of the output data could be explained by how the model heuristics works. This shows that a model user must be very well acquainted with a model before attempting to use it. This gives the user the ability to separate the effects of the model technology from the effects of system studied.

11.2 The Potential of Combined Transport

The HIT-model has shown that there is a great potential for combined transport in Sweden. See chapter 10 for the detailed results. Both business economic costs and environmental effects can be lowered by using more combined transport. It can also be seen that combined transport, almost always, is economically competitive if the transport distance is long enough. Thus, the main challenge for combined transport is not cost, but achieving competitive pick-up and delivery times compared with all-road transport.

There are two main strategies for achieving this: creating a speed advantage for combined transport or influencing the attitude of the transport customer to allow later deliveries and/or earlier pick-up. Both strategies take time to implement, but, already now, it is possible to start influencing the transport customer, since each individual transport customer will contribute towards reaching the potential. More relaxed delivery and pick-up times drastically increase the potential for combined transport. This does not imply that the delivery/pick-up times should be any more uncertain than they are with all-road transport, but that the flexibility in setting the agreed times should be greater. A possible way of convincing the transport customer is to use the cost reduction gained by using combined transport to reduce the price of transport. The speed advantage can be reached by either improving the speed of combined transport or reducing the speed of all road transport. Increasing road congestion points at that we are likely to see a reduction in road transport speeds. At the same time, technical development in the rail sector indicates that the speed of combined transport will increase. Also, a more market oriented rail transport sector with the, potential, entry of new actors, is likely to put pressure on the combined transport actors to streamline their operations. The transport sector is, therefore, likely to move towards the use of more combined transport, however, actions are necessary to ensure this development. In particular, the attitude of the transport customer is a key factor in increasing the share of combined transport.

The potential gain for society from using more combined transport is also substantial. In particular, the environmental impact of transport can be reduced by an increase of combined transport. Specifically, reduced CO_2 emissions are a major concern for society today, considering the climate change and greenhouse effect. It is important for the society to retain its high interest in intermodal transport to support and facilitate a modal shift to achieve a sustainable society. Also, the rail industry must continue to use electric power from renewable energy sources to maintain its environmental advantage.

The transport industry, also, can gain an advantage from utilising the cost advantage in using combined transport. Competition in the transport industry is fierce and the cost savings resulting from using combined transport can be used as a competitive advantage. Large transport operators could operate their own trains to fully utilise the cost advantage.

11.3 Ongoing and suggested future research

Several new ideas emerged during the work on the model and input data set. Some was incorporated in the current research, but others have been left for future research. Some research projects on how to further extend and develop the model have also already been funded and initiated.

11.3.1 The HIT-model

The HIT-model could be further improved and developed. Of particular importance is adding the possibility to include other modes of transport in the model. The most interesting mode would be shipping. Also, some more control possibilities can be added to the model. Among the possibilities identified as interesting is allowing different time windows and gaps to be used for arrival and departure, to allow the demand to choose among several terminals, to expand the possibilities for direct environmental optimisation, to expand the possibilities to allow train loops to operate between several terminals (e.g. from terminal A to B to C to D to A…), to add a time delay at terminals and to allow the model to determine the handling capacity at terminals. None of these extensions are expected to cause any significant difficulties in adding to the HIT-model.

The user friendliness of the HIT-model could also be further improved, e.g. by extending the Microsoft Access database interface and developing user manuals. This will allow for others to use the model, for example at government agencies and in businesses. However, it is important to remember the need for a through understanding of the model and heuristics to properly analyse the output data. A careful trade-off between user friendless and model understanding must, therefore, be made.

The inclusion of geographical information systems (GIS) could also further improve the user friendliness and analytical capabilities of the HIT-model. This would allow the input and output data to be displayed graphically on a map, which would facilitate the perception of the data, since most data has a geographical connection.

Random input data and some random disturbances can be used in the HIT-model. However, this could be further extended to better investigate the sensitivity of the suggested transport system. Dr. Lars Brigelius at the School of Business, Economics and Law has developed a simulation model of the combined transport system, which can be used in cooperation with the HIT-model to further extend the analyses. The two models could be used together in a two-step evaluation process where the output data will be connected to the simulation model where a more advanced sensitivity analysis can be made, see Jensen and Brigelius (2000), Jensen, Brigelius and Flodén (2001a, 2001b, 2006) and Figure 57. This iterative procedure would be repeated until reaching a satisfactory analysis and result.

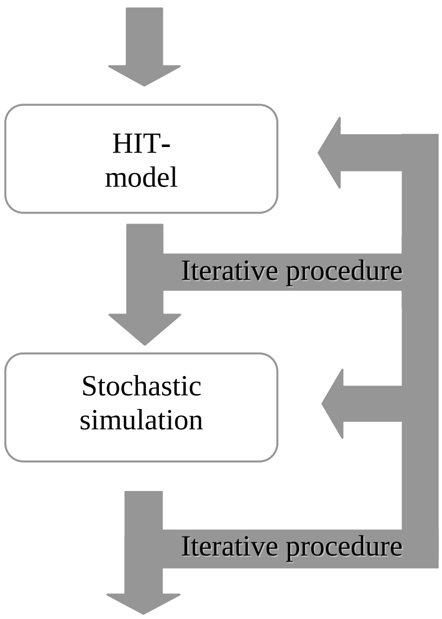

Figure 57 A two-step model

11.3.2 Modelling and input data

Some improvements in the input data and further analyses can be made. More extensive and detailed databases for the transport demand and cost structure should be developed. There is, in particular, a need for further development in the demand database. Creating a more detailed demand database is a very difficult and large project, but it is of great interest to many actors, e.g. other researchers and government agencies. A wide cooperative project with several parties involved could be a recommended strategy to develop the data base, see for example Andersson, et al (2005). This could include studies into specific transport flows that perhaps should, or should not, be regarded as potential combined transport goods, e.g. large existing and well managed transport flows in some industries.

The cost estimates for the rail transport could also be made more detailed. The HIT-model outputs a suggested rail transport system that could be further analysed to benefit from scale effects, e.g. more efficient train loops by using engines and rail cars on several train routes and shunting between trains. This new cost estimate could be returned to the HIT-model to improve the cost estimates in the model and the input data set could be re-run with the new cost estimates.

The level of detail in the modelling of the international transport could also be extended. The international flows were largely simplified in the current data set. To improve the level of detail outside Sweden could be fruitful, however, it would require new data sources.

As shown in chapter 2.1, there are also several interesting questions that could be answered using the HIT-model, e.g. the effect of new taxes. Model runs can be made to test different measures to promote intermodal transport. Of particular interest are future scenarios for the combined transport system, because of the expected great increase in transport demand.

Time was identified as the most important factor for a successful combined transport system. However, many other factors also affect success, such as direction of transport to the terminal, total goods volume on the train route, distance between terminals, balance in the goods flows, etc. The HIT-model can be used to further investigate these factors and how they interact.

The model output already presented in this thesis can be used for decision support on how to further develop the Swedish combined transport system. The data, available in chapter 10 and Appendix 13, can be further analysed for specific train routes and issues. In particular, the capacity needed in terminals and in the rail infrastructure could be analysed. It is clear that the full potential of combined transport would require significant capacity increase in terminals, and most likely, also in rail infrastructure. This can be determined from the model output.

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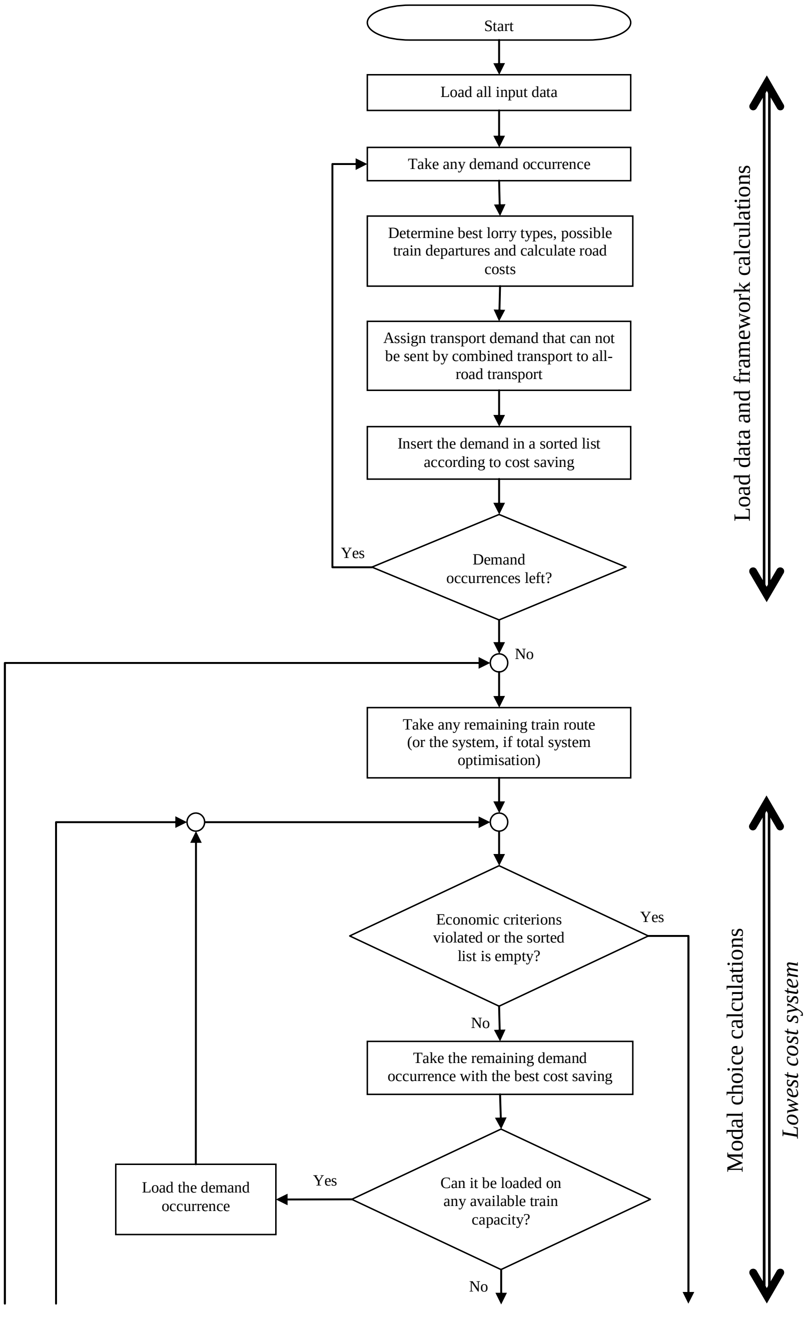
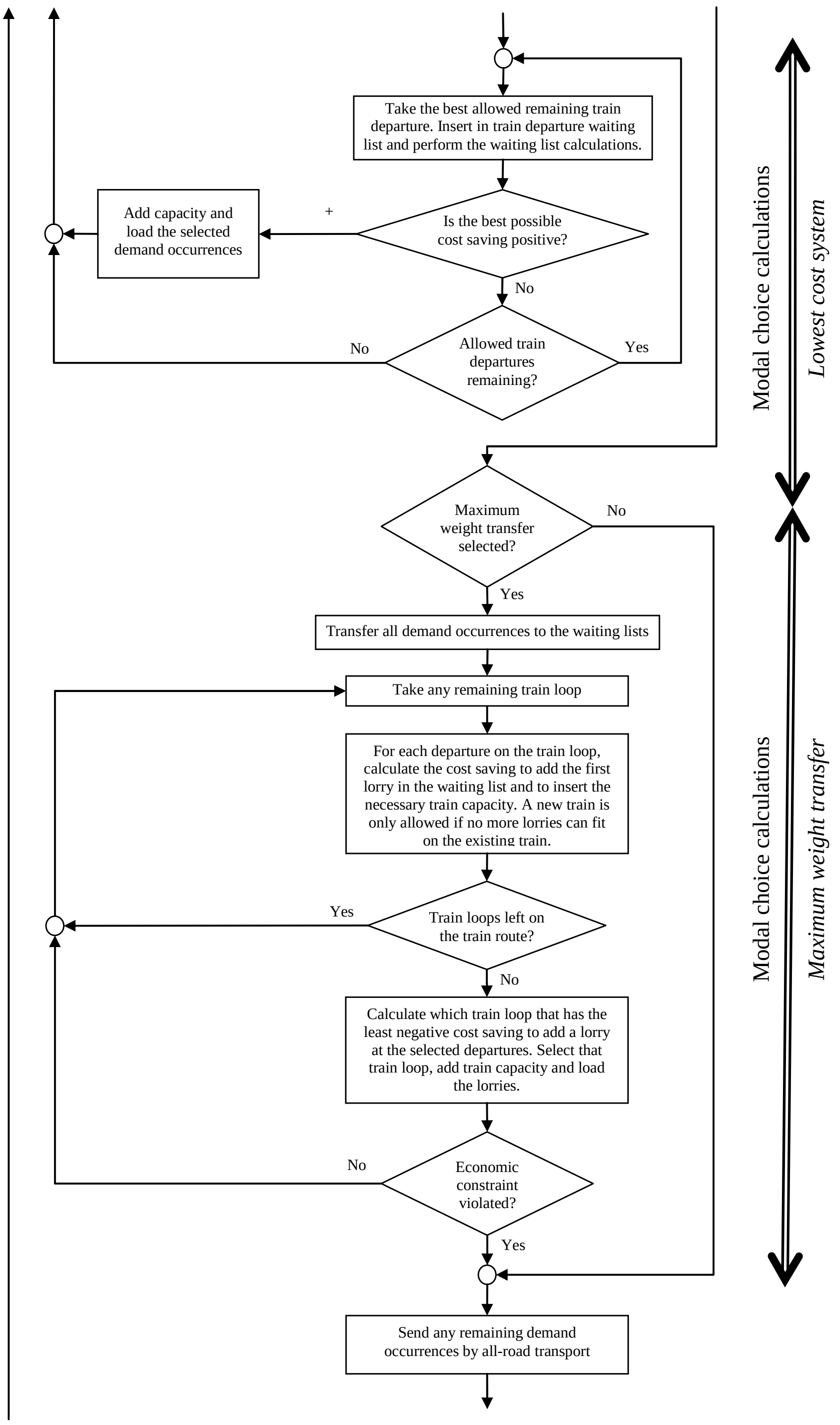
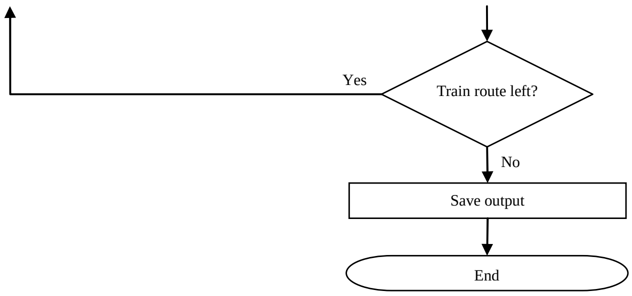
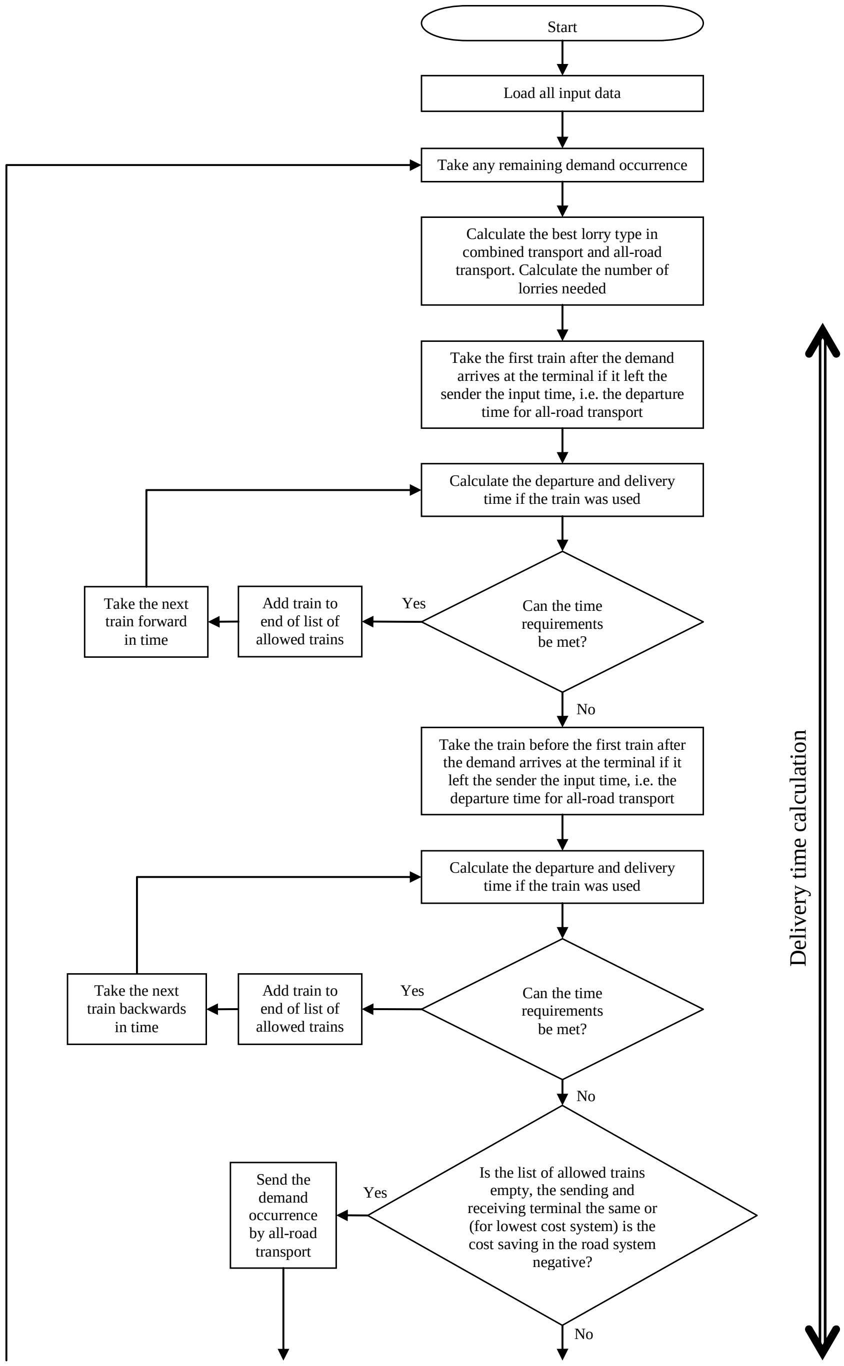
Appendix 1 Simplified Flow Chart

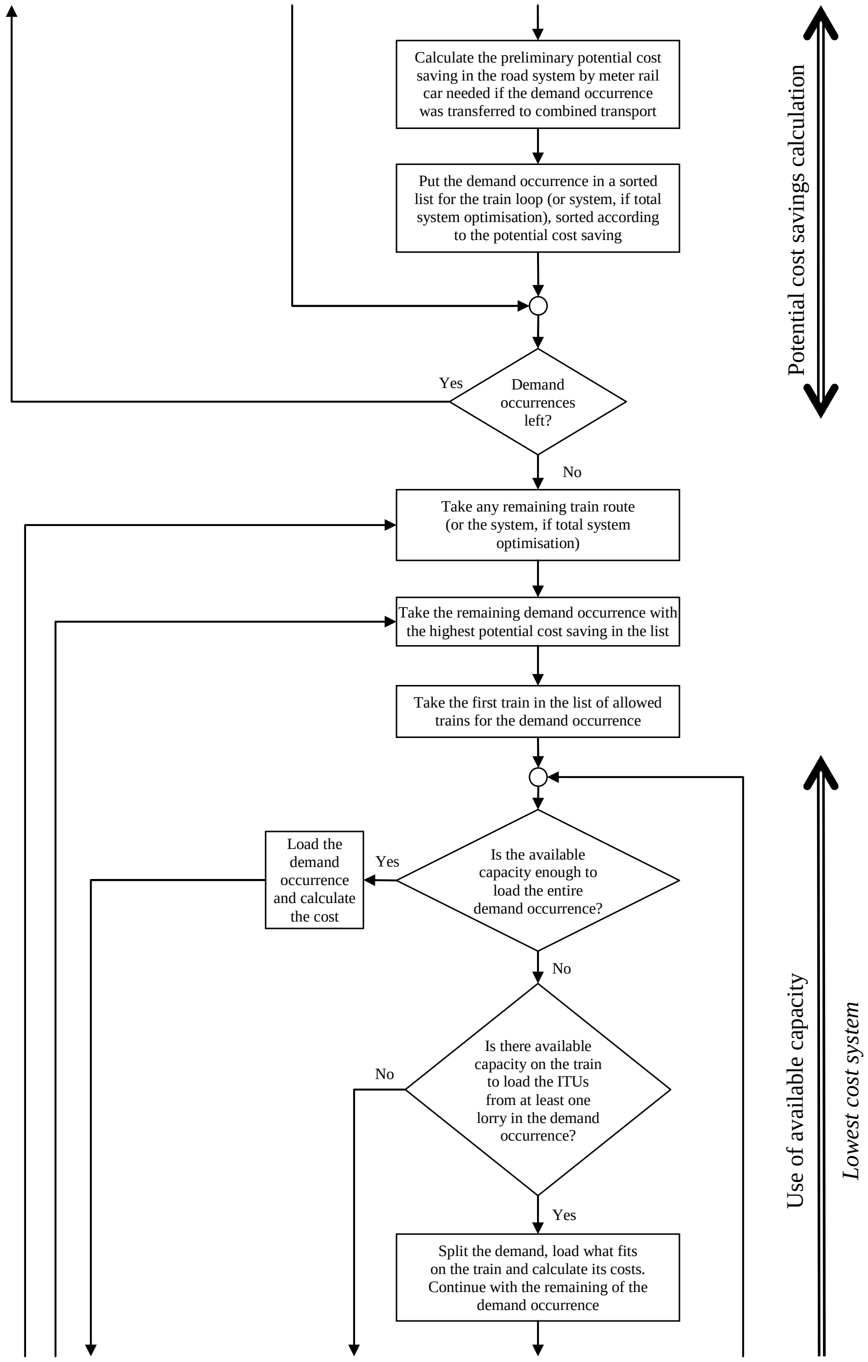


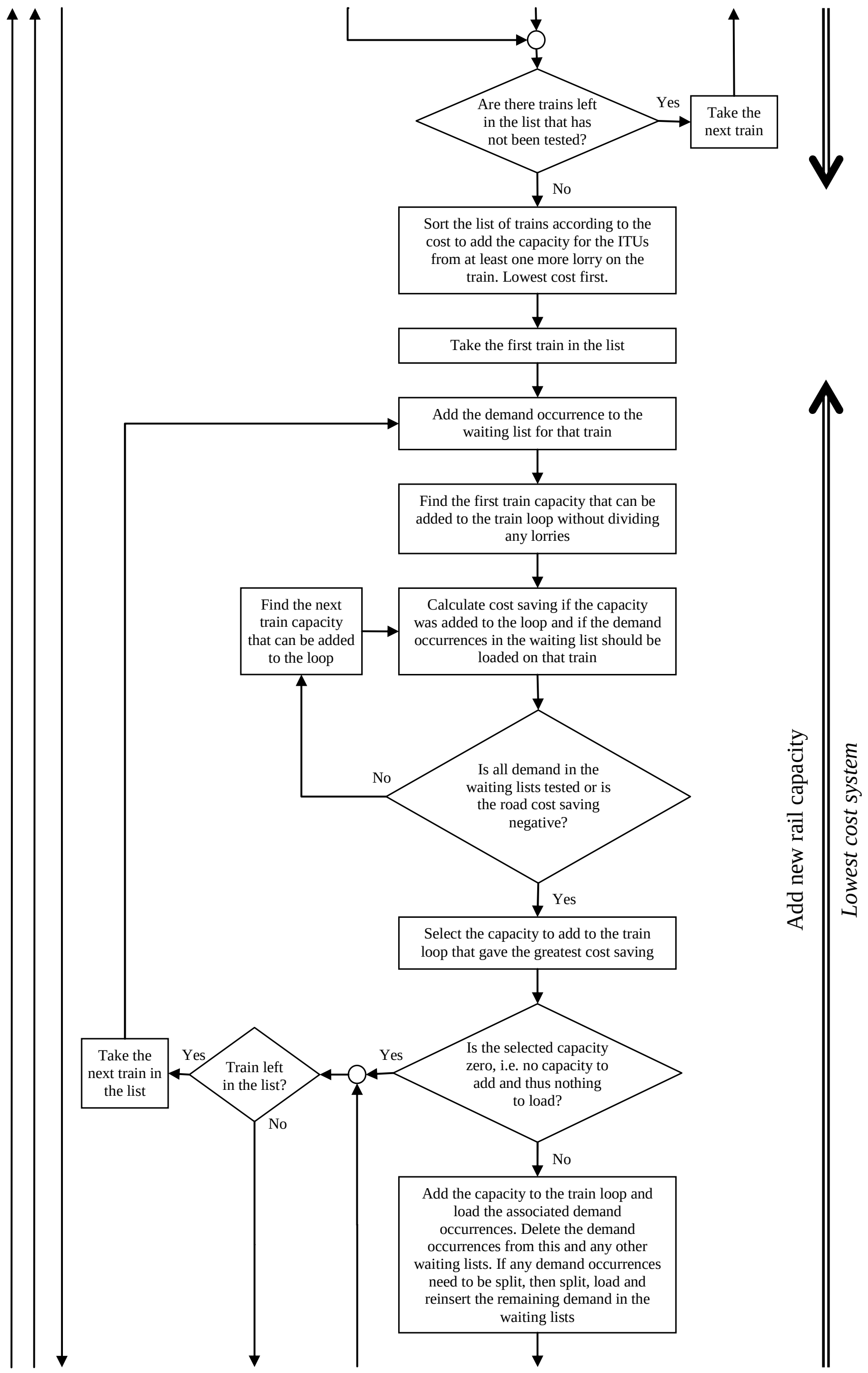

Take the best allowed remaining train departure. Insert in train departure waiting list and perform the waiting list calculations.
Is the best possible cost saving positive?
+
Add capacity and load the selected demand occurrences
No
Allowed train departures remaining?
No
Yes
Maximum weight transfer selected?
No
Yes
Transfer all demand occurrences to the waiting lists
Take any remaining train loop
For each departure on the train loop, calculate the cost saving to add the first lorry in the waiting list and to insert the necessary train capacity. A new train is only allowed if no more lorries can fit on the existing train.
Train loops left on the train route?
Yes
No
Calculate which train loop that has the least negative cost saving to add a lorry at the selected departures. Select that train loop, add train capacity and load the lorries.
Economic constraint violated?
No
Yes
Send any remaining demand occurrences by all-road transport
Modal choice calculations
Lowest cost system
Modal choice calculations
Maximum weight transfer

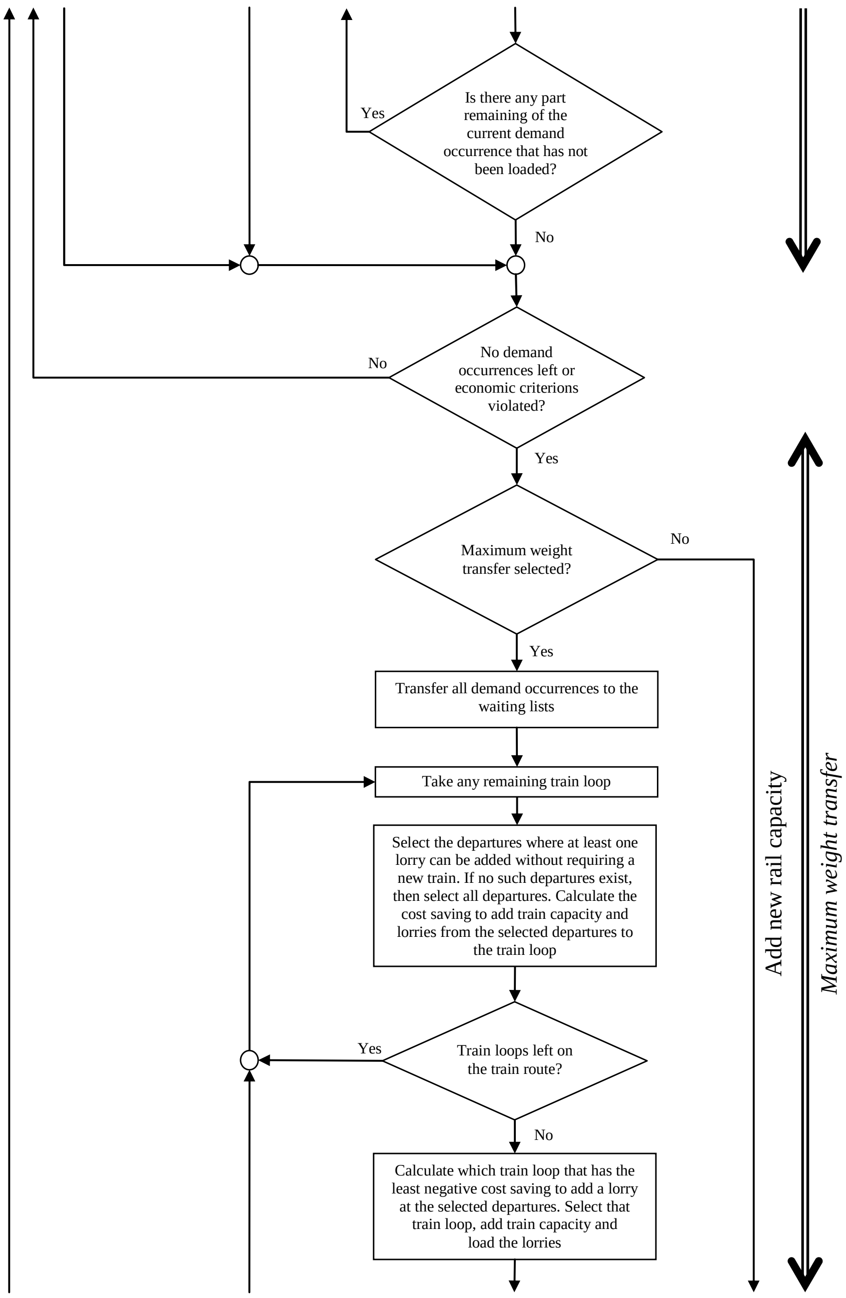

Yes
Train route left?
No
Save output
End

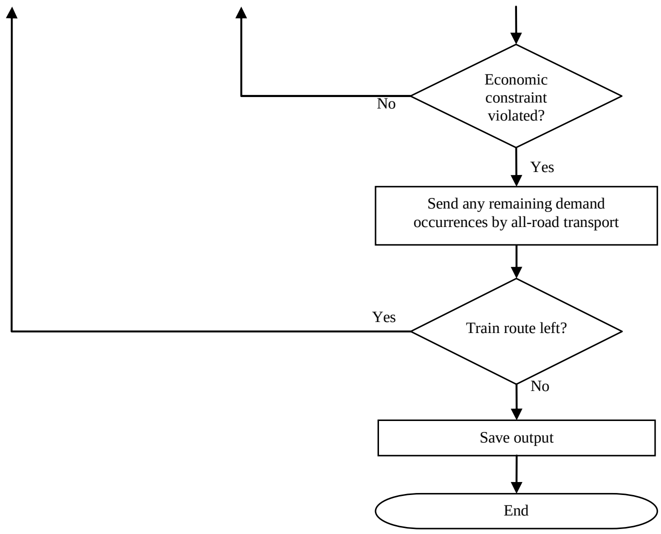
Appendix 2 Detailed Flow Chart




Calculate the preliminary potential cost saving in the road system by meter rail car needed if the demand occurrence was transferred to combined transport
Put the demand occurrence in a sorted list for the train loop (or system, if total system optimisation), sorted according to the potential cost saving
Demand occurrences left?
Yes
No
Potential cost savings calculation
Take any remaining train route (or the system, if total system optimisation)
Take the remaining demand occurrence with the highest potential cost saving in the list
Take the first train in the list of allowed trains for the demand occurrence
Is the available capacity enough to load the entire demand occurrence?
Yes
Load the demand occurrence and calculate the cost
No
Is there available capacity on the train to load the ITUs from at least one lorry in the demand occurrence?
No
Yes
Split the demand, load what fits on the train and calculate its costs. Continue with the remaining of the demand occurrence
Use of available capacity
Lowest cost system


Are there trains left in the list that has not been tested?
Yes
Take the next train
No
Sort the list of trains according to the cost to add the capacity for the ITUs from at least one more lorry on the train. Lowest cost first.
Take the first train in the list
Add the demand occurrence to the waiting list for that train
Find the first train capacity that can be added to the train loop without dividing any lorries
Calculate cost saving if the capacity was added to the loop and if the demand occurrences in the waiting list should be loaded on that train
Find the next train capacity that can be added to the loop
Is all demand in the waiting lists tested or is the road cost saving negative?
No
Yes
Select the capacity to add to the train loop that gave the greatest cost saving
Is the selected capacity zero, i.e. no capacity to add and thus nothing to load?
Yes
Train left in the list?
Yes
Take the next train in the list
No
No
Add the capacity to the train loop and load the associated demand occurrences. Delete the demand occurrences from this and any other waiting lists. If any demand occurrences need to be split, then split, load and reinsert the remaining demand in the waiting lists
Add new rail capacity
Lowest cost system


Is there any part remaining of the current demand occurrence that has not been loaded?
Yes
No
No demand occurrences left or economic criterions violated?
No
Yes
Maximum weight transfer selected?
No
Yes
Transfer all demand occurrences to the waiting lists
Take any remaining train loop
Select the departures where at least one lorry can be added without requiring a new train. If no such departures exist, then select all departures. Calculate the cost saving to add train capacity and lorries from the selected departures to the train loop
Train loops left on the train route?
Yes
No
Calculate which train loop that has the least negative cost saving to add a lorry at the selected departures. Select that train loop, add train capacity and load the lorries
Add new rail capacity
Maximum weight transfer



Economic constraint violated?
No
Yes
Send any remaining demand occurrences by all-road transport
Train route left?
Yes
No
Save output
End

Appendix 3 Environmental data

The data is from NTM, unless otherwise stated.
http://www.ntm.a.se/
Access date September 5, 2005.

	Lorry with trailer, long-haul Euro 3	**24 m Lorry, long-haul Euro 3**	**Type T44, diesel train engine**		
	kWh/tonnekm	kWh/tonnekm			
Energy	0.19	0.17			
	gram/tonnekm	gram/tonnekm	g/kg fuel	g/litre fuel	g/kWh
CO_2	50	46	3170	2583.55	751
NO_x	0.31	0.28	70	57.05	16.5
HC	0.025	0.023	2.8	2.282	0.7
PM	0.0050	0.0046	1.8	1.467	0.51
CO	0.044	0.040	4.5	3.6675	1.1
SO_2	0.000062	0.000057	0.5	0.4075	0.1
Total weight	40	60			
Load factor	70%	70%			

Density MK1 diesel: 0.815 kg per litre

Energy content in diesel fuel, Environmental class 1
(source: Svenska Petroleum Institutet, SPI, http://www.spi.se)
9 800 kWh/m^3, 1 kWh = 3.6 MJ

National Rail Administration (Banverket) electricity mix 2001 (source: Banverket and NTM)	
Hydro power	85.10%
Nuclear power	7.50%
Wind power	1.50%
Coal	2.17%
Oil	0.17%
Combined power and heating plant - coal	0.26%
Combined power and heating plant - oil	0.08%
Combined power and heating plant - natural gas	0.68%
Combined power and heating plant – bio fuel	2.03%
Combined power and heating plant - peat	0.29%
Gas turbine	0.20%

Emission from production of electricity in g/kWh

	CO_2	NO_x	SO_2	CO	PM	HC
Hydro	0.0677000	0.0002630	0.0001090	0.0018000	0.0000295	0.0002470
Nuclear	0.0720000	0.0002200	0.0002110	0.0000336	0.0000258	0.0000521
Wind power	0.0607000	0.0001390	0.0001520	0.0000325	0.0000330	0.0000164
Coal	858.0000000	2.2200000	2.4600000	0.0005410	0.1030000	0.0044700
Oil	682.0000000	0.4610000	0.4610000	0.1380000	0.1010000	0.0370000
Combined plant - coal	548.0000000	1.4200000	1.5700000	0.0003450	0.0658000	0.0047700
Combined plant - oil	321.0000000	0.2170000	0.2170000	0.0651000	0.0434000	0.0175000
Combined plant - natural gas	242.0000000	0.0429000	0.0021100	0.0426000	0.0002490	0.0000650
Combined plant – bio fuel	0.0951000	0.1810000	0.0330000	0.1650000	0.0165000	0.0000202
Gas turbine	986.0000000	3.0800000	0.6670000	1.0800000	0.0000419	0.0573000

	Emission in gram per kWh for Banverket electricity mix 2001[153].	**Emission in gram for an average truck per handled ITU[154]**
CO_2	30.4117277	4668.630498
NO_x	0.077185148	84.06828
SO_2	0.072976529	0.01488
HC	0.000633186	13.0572
CO	0.009977335	50.22
PM	0.003635436	4.72068
Energy consumption MJ	-	60.264
Economic valuation of emissions in SEK	0.052883796	3.92

Electricity consumed by a combined transport train (Banverket, 2005b)
0.02050 kWh per gross tonnekm

[153] Calculated from the data above including a 20% transfer loss.
[154] Calculated from data in Persson and Kindbom (1999).

Emissions from rail transport

Calculated from the data above

Combined transport train	Electric locomotive	Diesel shunting
Electricity consumption, kWh per gross tonnekm	0.02050	-
Diesel consumption, litre per minute shunting	-	0.9167
CO2 direct emission gram per gross tonnekm	0.623440	-
NOx direct emission gram per gross tonnekm	0.001582	-
SO2 direct emission gram per gross tonnekm	0.001496	-
HC direct emission gram per gross tonnekm	0.000013	-
CO direct emission gram per gross tonnekm	0.000205	-
PM direct emission gram per gross tonnekm	0.000075	-
Energy consumption MJ per gross tonnekm	0.073800	
Running distance, kilometres per year	136 640	15 470
Number of hours in use per year	2 733	1 366
Locomotive		
Weight, gross ton	79	76
Shunting		
CO2 direct emission gram per minute	-	2 368.340285
NOx direct emission gram per minute	-	52.297735
SO2 direct emission gram per minute	-	0.373555
HC direct emission gram per minute	-	2.091909
CO direct emission gram per minute	-	3.361997
PM direct emission gram per minute	-	1.344799
Energy consumption MJ per minute		32.341
Line haul		
CO2 direct emission gram per km	49.251793	-
NOx direct emission gram per km	0.125001	-
SO2 direct emission gram per km	0.118185	-
HC direct emission gram per km	0.001025	-
CO direct emission gram per km	0.016158	-
PM direct emission gram per km	0.005888	-
Energy consumption MJ per km	5.8302	

Empty Sdggmrss wagon

Weight, gross ton	34.8
CO2 direct emission gram per km	21.695727
NOx direct emission gram per km	0.055064
SO2 direct emission gram per km	0.052061
HC direct emission gram per km	0.000452
CO direct emission gram per km	0.007118
PM direct emission gram per km	0.002594
Energy consumption MJ per km	2.56824

Loaded Sdggmrss wagon, added to the unloaded wagon

Gross weight loaded on wagon, ton	66
CO2 direct emission gram per km	41.147068
NOx direct emission gram per km	0.104432
SO2 direct emission gram per km	0.098737
HC direct emission gram per km	0.000857
CO direct emission gram per km	0.013499
PM direct emission gram per km	0.004919
Energy consumption MJ per km	4.8708

Appendix 4 Business Economic Costs

Year 2001, SEK

24 m lorry

	Lorry	Trailer	Total
Purchase price	918 000	561 000	1 479 000
Service life, years	7	12	
Depreciation	131 143	46 750	177 893
Cost of capital	7%	7%	
Average tied-up capital	459 000	280 500	739 500
Average cost of capital	32 130	19 635	51 765
Vehicle taxes	23 296	17 753	41 049
Insurance	25 386	14 370	39 756
Garage, communication equipment	23 934	2 749	26 684
Total fixed vehicle costs	**235 889**	**101 257**	**337 146**
Salary	230 397		
Salary taxes, etc.	93 334		
Number of drivers	2		
Total salary costs	**647 461**		
General overhead costs	**170 000**		
Running distance, kilometres per year	120 000		
Number of hours in use per year	3 600		
Salary costs per hour in use	180		
Fixed costs per hour in use	94		
Overhead costs per hour in use	47		
Total costs per hour in use, time dependent	**321**		
Fuel cost per litre	6.02		
Fuel consumption, litre per km	0.38	0.11	0.49
Tyre SEK/km	0.23	0.17	0.40
Fuel SEK/km	2.29	0.66	2.95
Repair and maintenance SEK/km	0.60	0.22	0.82
Total variable vehicle costs SEK/km, distance dependent	**3.12**	**1.05**	**4.17**
Total yearly vehicle cost	**1 655 017**		

<u>Trailer lorry</u>

	Lorry	Trailer	Total
Purchase price	867 000	352 454	1 219 454
Service life, years	8	12	
Depreciation	108 375	29 371	137 746
Cost of capital	7%	7%	
Average tied-up capital	433 500	176 227	609 727
Average cost of capital	30 345	12 336	42 681
Vehicle taxes	25 661	10 320	35 981
Insurance	25 483	6 315	31 797
Garage, communication equipment	19 498	2 749	22 248
Total fixed vehicle costs	**209 362**	**61 091**	**270 453**
Salary	230 397		
Salary taxes, etc.	93 334		
Number of drivers	2		
Total salary costs	**647 461**		
General overhead costs	**170 000**		
Running distance, kilometres per year	120 000		
Number of hours in use per year	3 600		
Salary costs per hour in use	180		
Fixed costs per hour in use	75		
Overhead costs per hour in use	47		
Total costs per hour in use, time dependent	**302**		
Fuel cost per litre	6.02		
Fuel consumption, litre per km	0.27	0.08	0.35
Tyre SEK/km	0.15	0.14	0.29
Fuel SEK/km	1.62	0.48	2.11
Repair and maintenance SEK/km	0.43	0.15	0.57
Total variable vehicle costs SEK/km, distance dependent	**2.20**	**0.77**	**2.97**
Total yearly vehicle cost	**1 443 963**		

Year 2001, SEK

Locomotive

	Electric locomotive	Diesel shunting
Purchase price	23 000 000	24 000 000
Service life, years	30	30
Weight, gross ton	79	76
Engine output, kWh max	3 600	1 235
Electricity consumption, kWh per gross tonnekm	0.02050	-
Diesel consumption, litre per minute shunting	-	0.917
Depreciation	766 667	800 000
Cost of capital	7%	7%
Average tied-up capital	11 500 000	12 000 000
Average cost of capital	805 000	840 000
Total fixed vehicle costs	**1 571 667**	**1 640 000**
Salary	262 296	262 296
Salary taxes, etc.	106 256	106 256
Number of drivers	2	-
Total salary costs	**737 104**	**-**
General overhead costs	**150 000**	**150 000**
Running distance, kilometres per year	136 640	15 470
Number of hours in use per year	2 733	1 366
Salary costs per hour in use	270	230
Diesel cost for shunting, per hour in use	-	164
Repair and maintenance for shunting, per hour in use	-	55
Fixed costs per hour in use	575	1 200
Overhead costs per hour in use	55	110
Total costs per hour in use, time dependent	**900**	**1 759**
Fuel cost per litre	-	2.98
Electricity cost per kWh	0.298	-
Electricity consumption (locomotive only) kWh per km	1.62	-
Electricity (locomotive only) SEK/km	0.48	-
Repair and maintenance SEK/km	3.30	4.85
Track charges per km for locomotive	0.77	-

Total variable vehicle costs SEK/km, distance dependent	**4.55**	**-**
Total yearly vehicle cost	**3 080 553**	**2 403 504**

<u>Empty Sdggmrss wagon</u>

	Electric locomotive
Purchase price	1 000 000
Service life, years	30
Weight, gross ton	34.8
Wagon length	34.2
Depreciation	33 333
Cost of capital	7%
Average tied-up capital	500 000
Average cost of capital	35 000
Total fixed vehicle costs	**68 333**
Running distance, kilometres per year	80 000
Number of hours in use per year	1 143
Total costs per hour in use, time dependent	**59.79**
Electricity consumption kWh per km	0.71
Electricity SEK/km	0.21
Repair and maintenance SEK/km	0.21
Track charges per km	0.10
Total variable vehicle costs SEK/km, distance dependent	**0.52**
Total yearly wagon cost	**110 040**

Loaded Sdggmrss wagon, added costs to the unloaded wagon

	Electric locomotive
Gross weight loaded on wagon, ton	66
Total costs per hour loaded, time dependent	**0**
Electricity consumption kWh per km	1.35
Electricity SEK/km	0.40
Repair and maintenance SEK/km	0.07
Track charges per km	0.18
Total variable vehicle costs SEK/km, distance dependent	**0.66**

Year 2001, SEK

Terminal handling costs

	Gantry crane	Reach-stacker	Top-lift truck	Forklift truck	Forklift truck
Purchase price	11 000 000	5 000 000	2 900 000	1 700 000	1 200 000
Service life, years	20	10	10	10	10
Lifting capacity, ton	45	45	32	28	20
Time to load an ITU, hours	0.09	0.11	0.11	0.11	0.11
Depreciation	550 000	500 000	290 000	170 000	120 000
Cost of capital	7%	7%	7%	7%	7%
Average tied-up capital	5 500 000	2 500 000	1 450 000	850 000	600 000
Average cost of capital	385 000	175 000	101 500	59 500	42 000
Total fixed equipment costs per year	**935 000**	**675 000**	**391 500**	**229 500**	**162 000**
Salary per person	220 848				
Salary taxes, etc.	89 466				
Salary cost per year	**310 314**				
Fuel cost per litre	6.02	6.02	6.02	6.02	6.02
Fuel consumption, litre per hour	15	22	18	13	13
Fuel cost per hour	90.24	132.35	108.28	78.20	78.20
Repair and maintenance SEK per hour	260	83	60	39	39

Variable costs per hour, excl. salary	**350.24**	**215.35**	**168.28**	**117.20**	**117.20**
Shunting locomotive T44, cost per hour	1759.00	incl. fuel and maintenance.			
Line haul locomotive RC, cost per hour	899.72	incl. fuel and maintenance.			
Example terminal	Gantry crane	Reach-stacker	Top-lift truck	Forklift truck	Forklift truck
Type of equipment available	0	2	0	0	0
Number of ITUs handled	0	20 000	0	0	0
Time to load an ITU, hours	0.09	0.11	0.11	0.11	0.11
Number of hours in use per year, summary	**0**	**2 167**	**0**	**0**	**0**
Total yearly equipment and running costs	**0**	**1 816 582**	**0**	**0**	**0**
Total yearly fuel consumption, litres	0	47 667	0	0	0
Number of full time operators at terminal	4				
Yearly salary cost	**1 241 254**				
Time for shunting to and from terminal	45	minutes with RC			
Time for shunting to and from terminal	60	minutes with T44			
Shunting cost per train, SEK	2433.80				
Number of trains per week	10				
Yearly shunting costs	**1 265 574**				
Total terminal handling costs	**4 323 410**				
Total number of ITUs handled	20 000				
Total yearly fuel consumption, litres	47 667				
Average cost per ITU	**216.17**				
Fuel consumption per ITU, litres	2.38				

Appendix 5 External Costs of Transport

SIKA (2005c)

	Material costs SEK	Risk valuation SEK	Accident cost SEK
Fatality	1 242 000	16 269 000	17 511 000
Severely injured	621 000	2 503 000	3 124 000
Slightly injured	62 000	113 000	175 000
Material damage	13 000	-	13 000

Local emission	SEK / exposure unit	Cost estimate SEK/kg in a population centre with 3 856 inhabitants	Cost estimate SEK/kg for 20% populated and 80% rural transport
NO_x	1.5	2.70	0.54
HC	2.5	4.50	0.90
Particles	426	767.14	153.43
SO_2	12.5	22.51	4.50

Regional emission, kg	Cost estimate SEK
NO_x	62
HC	31
SO_2	21

Global emission, kg	Cost estimate SEK
CO_2	1.50

Appendix 6 Social Economic Costs of Transport

Year 2001, SEK

24 m lorry

	Lorry	Trailer	Total
Total costs per hour in use, time dependent			**321**
Fuel cost per litre	3.66		
Fuel consumption, litre per km	0.38	0.11	0.49
Tyre SEK/km	0.23	0.17	0.40
Fuel SEK/km	1.39	0.40	1.79
Repair and maintenance SEK/km	0.60	0.22	0.82
Local effects per km			
Societal cost NOx	-	-	0.00421
Societal cost SO2	-	-	0.00001
Societal cost HC	-	-	0.00058
Societal cost PM	-	-	0.01995
Noise	-	-	0.16100
Accident	-	-	0.83253
Regional effects per km			
Societal cost NOx	-	-	0.48360
Societal cost SO2	-	-	0.00003
Societal cost HC	-	-	0.01984
Global effects per km			
Societal cost CO2	-	-	1.80000
Total variable vehicle costs SEK/km, distance dependent	-	-	**6.34**
Total yearly vehicle cost			**1 915 190**
Emission costs per km			2.33

Trailer lorry

	Lorry	Trailer	Total
Total costs per hour in use, time dependent			**302**
Fuel cost per litre	3.66		
Fuel consumption, litre per km	0.27	0.08	0.35
Tyre SEK/km	0.15	0.14	0.29
Fuel SEK/km	0.99	0.29	1.28
Repair and maintenance SEK/km	0.43	0.15	0.57
Local effects			
Societal cost NOx	-	-	0.00303
Societal cost SO2	-	-	0.000005
Societal cost HC	-	-	0.00041
Societal cost PM	-	-	0.01396
Noise	-	-	0.16100
Accident	-	-	0.83253
Regional effects			
Societal cost NOx	-	-	0.34720
Societal cost SO2	-	-	0.00002
Societal cost HC	-	-	0.01395
Global effects			
Societal cost CO2	-	-	1.33500
Total variable vehicle costs SEK/km, distance dependent	-	-	4.85
Total yearly vehicle cost			**1 669 932**
Emission costs per km			**1.71**

Year 2001, SEK

Locomotive

	Electric locomotive	Diesel shunting
Running distance, kilometres per year	136 640	15 470
Number of hours in use per year	2 733	1 366
Salary costs per hour in use	270	230
Diesel cost for shunting, per hour in use	-	164
Repair and maintenance for shunting, per hour in use	-	55
Fixed costs per hour in use	575	1 200
Overhead costs per hour in use	55	110
Local effects per hour	-	
Societal cost NOx	-	8.48
Societal cost SO2	-	0.50
Societal cost HC	-	0.57
Societal cost PM	-	61.90
Noise	-	-
Regional effects per hour		
Societal cost NOx	-	194.55
Societal cost SO2	-	0.47
Societal cost HC	-	3.89
Global effects per hour		
Societal cost CO2	-	213.15
Total costs per hour in use, time dependent	**900**	**2 242.51**
Emission costs per hour in use	-	483.50
Fuel cost per litre	-	2.98
Electricity cost per kWh	0.298	-
Electricity consumption (locomotive only) kWh per km	1.62	-
Electricity / Fuel (locomotive only) SEK/km	0.48	-
Repair and maintenance SEK/km	3.30	-
Track charges per km for locomotive	0.77	-
Local effects per km		
Societal cost NOx	0.00007	-
Societal cost SO2	0.00053	-
Societal cost HC	0.00125	-
Societal cost PM	0.00090	-
Noise	0.21188	-

Regional effects per km		
Societal cost NOx	0.00775	-
Societal cost SO2	0.00248	-
Societal cost HC	0.00003	-
Global effects per km		
Societal cost CO2	0.07388	-
Total variable vehicle costs SEK/km, distance dependent	**4.85**	**-**
Emission costs per km	0.08689	
Total yearly vehicle cost	**3 121 378**	**3 064 1651**

<u>Empty Sdggmrss wagon</u>

	Electric locomotive	
Total costs per hour in use, time dependent	**59.79**	
Electricity consumption kWh per km	0.71	-
Electricity / Fuel SEK/km	0.21	
Repair and maintenance SEK/km	0.21	
Track charges per km	0.10	
Local effects per km		
Societal cost NOx	0.00003	-
Societal cost SO2	0.00023	-
Societal cost HC	0.00000	-
Societal cost PM	0.00040	-
Regional effects per km		
Societal cost NOx	0.00341	-
Societal cost SO2	0.00109	-
Societal cost HC	0.00001	-
Global effects per km		
Societal cost CO2	0.03254	-
Total variable vehicle costs SEK/km, distance	**0.56**	
Emission costs per km	0.03773	
Total yearly wagon cost	**113 058**	

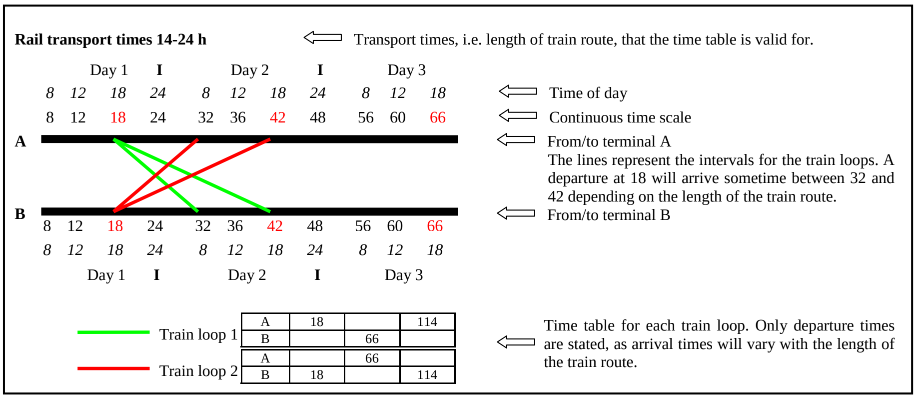
Loaded Sdggmrss wagon, added costs to the unloaded wagon

	Electric locomotive	-
Total costs per hour loaded, time dependent	**0**	
Electricity consumption kWh per km	1.35	
Electricity / Fuel SEK/km	0.40	
Repair and maintenance SEK/km	0.07	
Track charges per km	0.18	
Local effects per km		-
Societal cost NOx	0.00006	-
Societal cost SO2	0.00044	-
Societal cost HC	0.00000	-
Societal cost PM	0.00075	
Regional effects per km		-
Societal cost NOx	0.00647	-
Societal cost SO2	0.00207	-
Societal cost HC	0.00003	
Global effects per km		-
Societal cost CO2	0.06172	
Total variable vehicle costs SEK/km, distance dependent	**0.73**	
Emission costs per km	0.07155	

Appendix 7 Train Loops

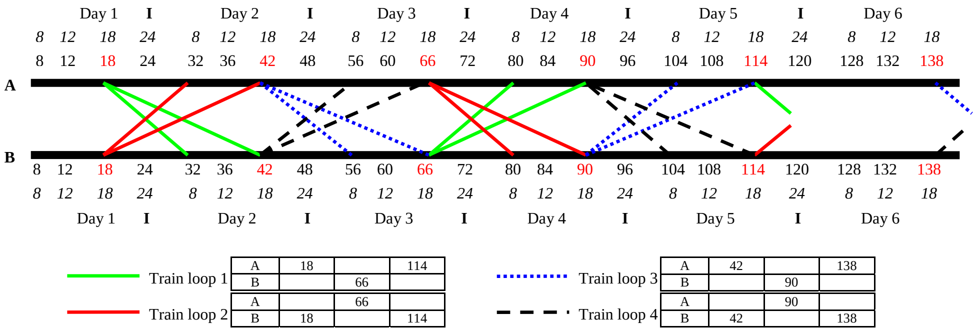
This appendix contains the possible train loops used in the scenario. The train loops are presented in a graphical time table. The time tables are divided into evening departures where all trains depart at 6 p.m., morning departures where all trains depart at 8 a.m., lunch departures where all trains depart at noon. There is also a combination of evening and morning departures where some train loops can be saved by shorter waiting times. The principle used when setting the time table is stated on each page, e.g. that a train must arrive before 8 a.m. to be allowed to leave again at 6 p.m. The principles are based on a reasonable appreciation of loading and unloading time for a train. The rail transport time that the time table is valid for is also stated on each page, i.e. the time table is valid for those train routes that has a rail transport time in that interval. All train loops are designed to be scalable, i.e. there are departures the same time every day and the train loops can be extended forward in time without adjustments.

Example:



Train loop				
Train loop 1	A	18		114
	B		66	
Train loop 2	A		66	
	B	18		114

Evening departures
A train must arrive before 8 AM to be allowed to depart the same evening at 6 PM
Rail transport times 14-24 h

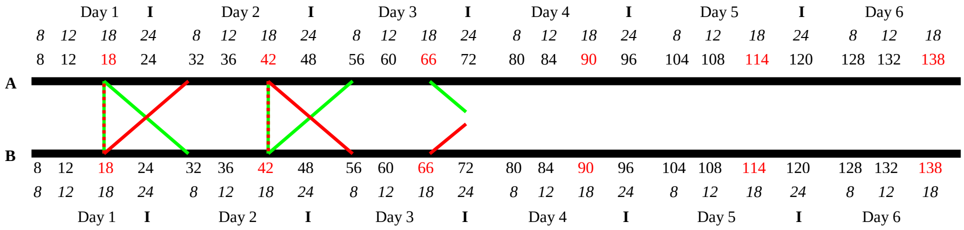


Train loop				
Train loop 1	A	18		114
	B		66	
Train loop 2	A		66	
	B	18		114
Train loop 3	A	42		138
	B		90	
Train loop 4	A		90	
	B	42		138

Evening departures

A train must arrive before 8 AM to be allowed to depart the same evening at 6 PM.

Rail transport times < 14 h

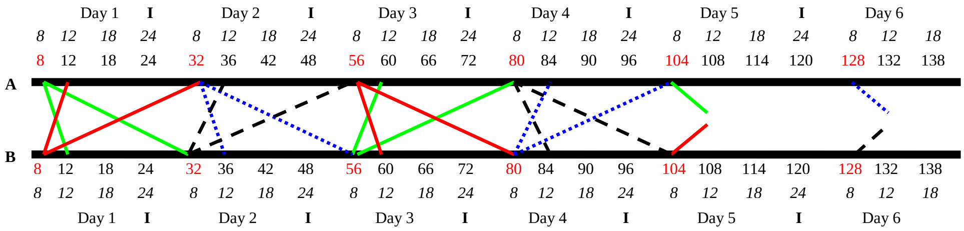


Train loop 1	A	18		66
	B		42	
Train loop 2	A		42	
	B	18		66

Morning departures

A train must arrive before noon to be allowed to depart the next morning at 8 AM.

Rail transport times 4-24 h



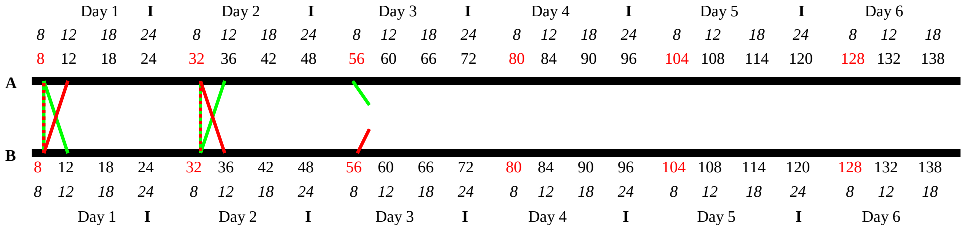
Train loop 1	A	08		104
	B		56	
Train loop 2	A		56	
	B	08		104

Train loop 3	A	32		128
	B		80	
Train loop 4	A		80	
	B	32		128

Morning departures

A train must arrive before noon to be allowed to depart the next morning at 8 AM.

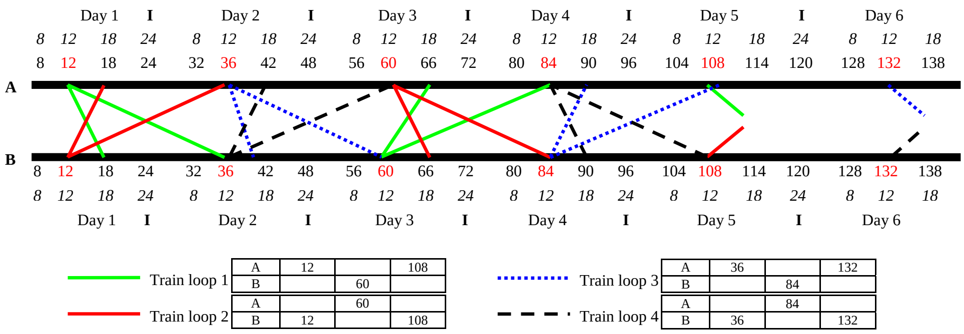
Rail transport times < 4 h



Train loop 1	A	08		56
	B		32	
Train loop 2	A		32	
	B	08		56

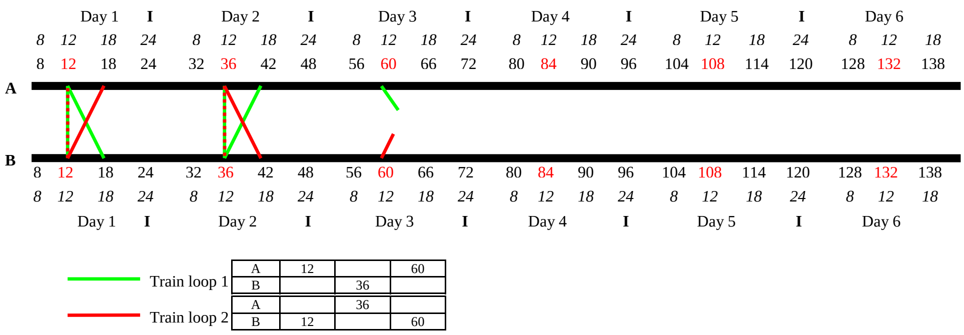
Lunchtågen

If a train arrives between noon and 6 PM, it can earliest depart at noon the following day.
If a train arrives between 6 PM (day one) and noon (day two), it can earliest depart at noon day three.
Rail transport times 6-24 h



Lunch departures

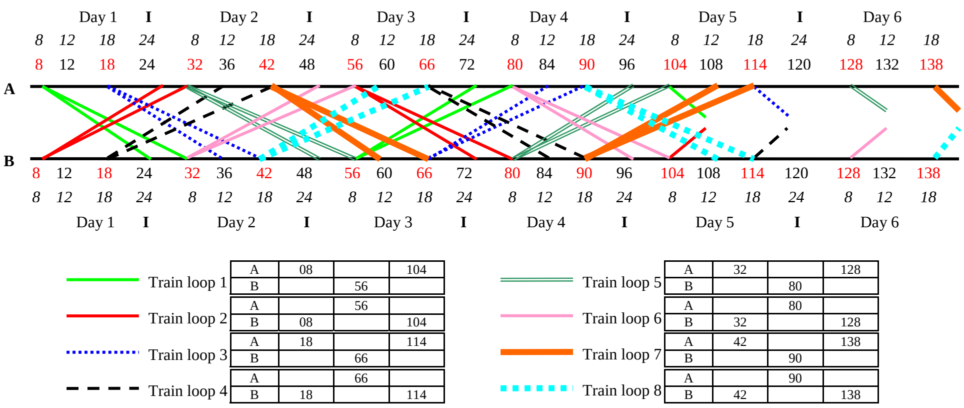
If a train arrives between noon and 6 PM, it can earliest depart at noon the following day.
If a train arrives between 6 PM (day one) and noon (day two), it can earliest depart at noon day three.
Rail transport times < 6 h



Evening/morning departures

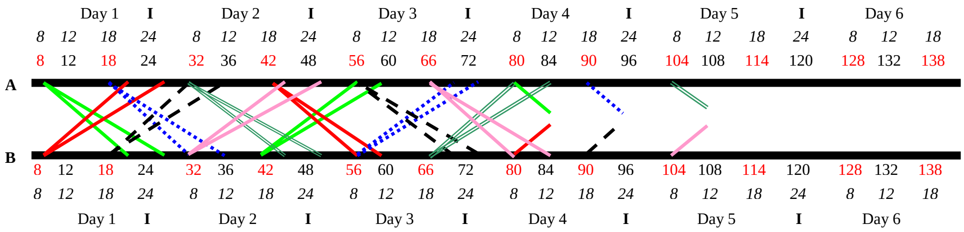
If a train arrives between 8 AM and noon, it can earliest depart at 8 AM the following day.
If a train arrives between noon and 8 AM (day one-two), it can earliest depart at 6 PM day two.
Rail transport times 18-24 h

The train loops are only evening departures or morning departures. Otherwise the loops would not fit together. Some trains thus stay longer than necessary at a terminal.



Evening/morning departures

If a train arrives between 8 AM and noon, it can earliest depart at 8 AM the following day.
If a train arrives between noon and 8 AM (day one-two), it can earliest depart at 6 PM day two.
Rail transport times 14-18 h

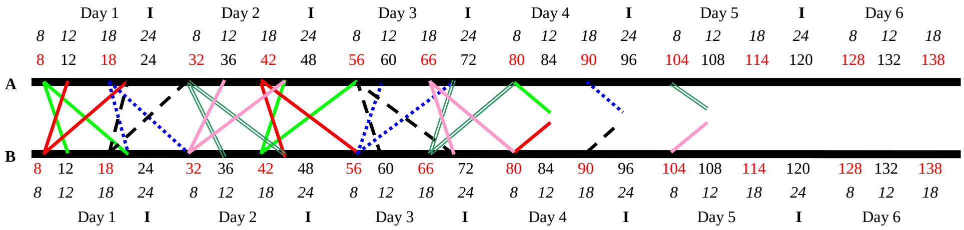


Train loop 1	A	08		80
	B		42	
Train loop 2	A		42	
	B	08		80
Train loop 3	A	18		90
	B		56	
Train loop 4	A		56	
	B	18		90
Train loop 5	A	32		104
	B		66	
Train loop 6	A		66	
	B	32		104

Evening/morning departures

If a train arrives between 8 AM and noon, it can earliest depart at 8 AM the following day.
If a train arrives between noon and 8 AM (day one-two), it can earliest depart at 6 PM day two.
Rail transport times 4-14 h

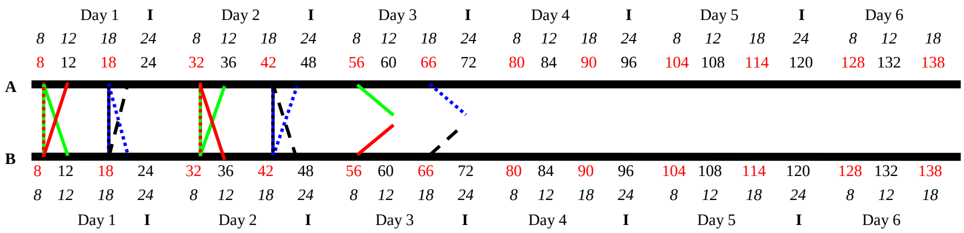
The train loops are adjusted to make them fit together. Some trains thus stay longer than necessary at a terminal.



Train loop 1	A	08		80
	B		42	
Train loop 2	A		42	
	B	08		80
Train loop 3	A	18		90
	B		56	
Train loop 4	A		56	
	B	18		90
Train loop 5	A	32		104
	B		66	
Train loop 6	A		66	
	B	32		104

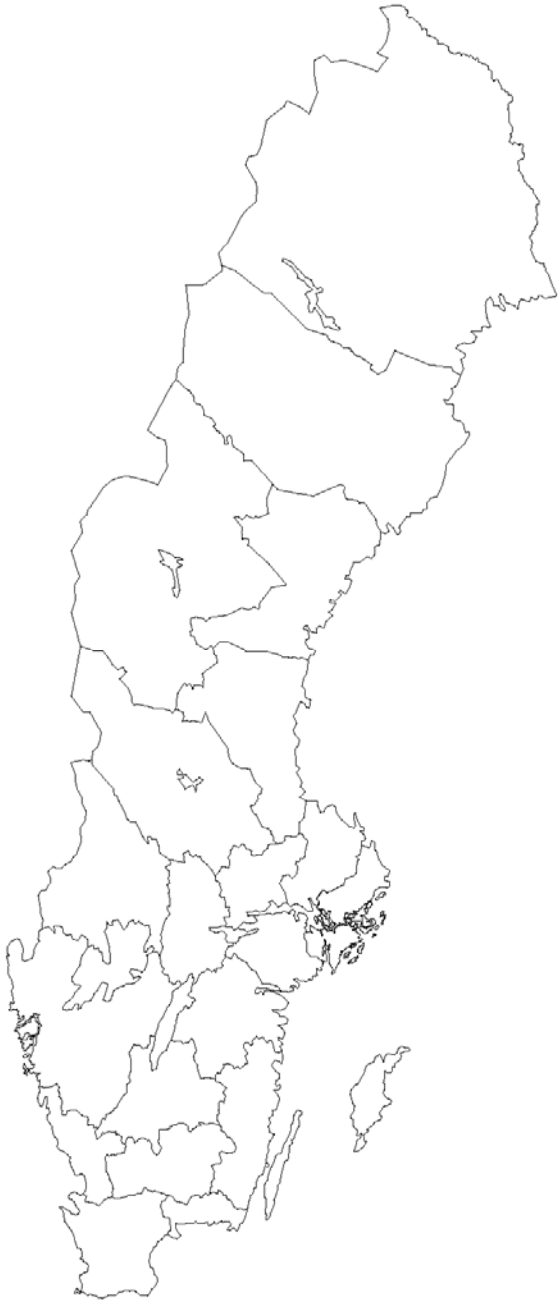
Evening/morning departures

If a train arrives between 8 AM and noon, it can earliest depart at 8 AM the following day.
If a train arrives between noon and 8 AM (day one-two), it can earliest depart at 6 PM day two.
Rail transport times <4 h



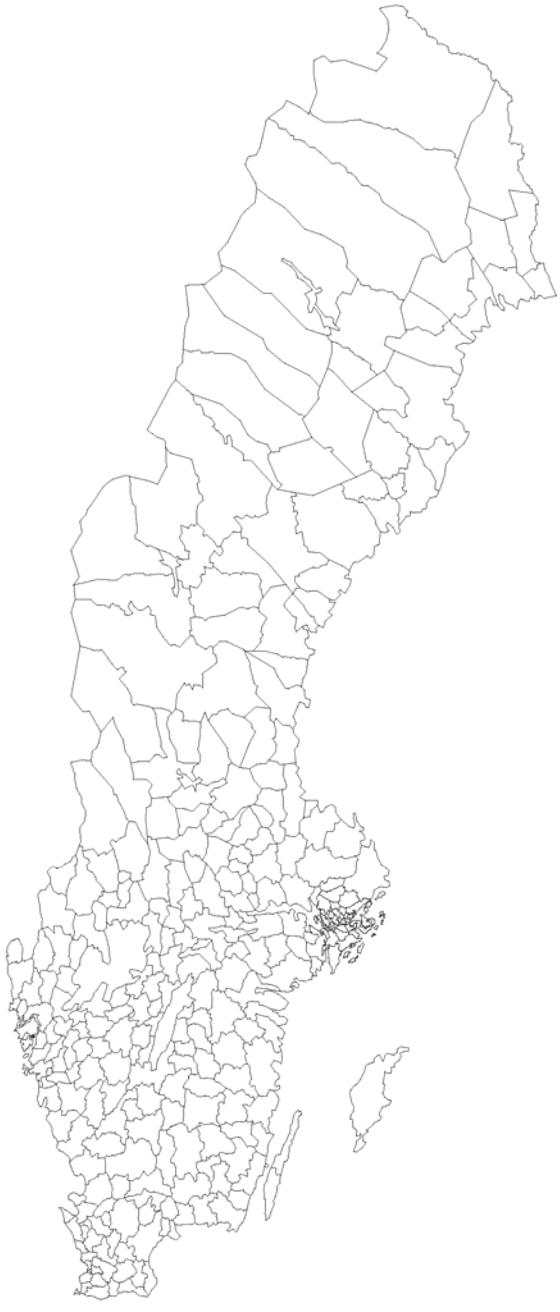
Train loop 1	A	08		56
	B		32	
Train loop 2	A		32	
	B	08		56
Train loop 3	A	18		66
	B		42	
Train loop 4	A		42	
	B	18		66

Appendix 8 Map of Swedish Counties
(SCB, 2006)



Appendix 9 Map of Swedish municipalities

(SCB, 2006)



Appendix 10 Map of Combined Transport Terminals

Including rail network. Adapted from Banverket (2005b, p. 49).

Appendix 11 The Survey Goods Transport in the Swedish Industry

This is the original survey in Swedish that was sent out to the respondents. A cover letter (not shown here) and a post-free envelop for returning the survey was also included.

Handelshögskolan
VID GÖTEBORGS UNIVERSITET

Näringslivets godstransporter
– fakta och önskemål

Denna undersökning avser huvudsakligen Ert arbetsställes utgående godstransporter överstigande 150 km. Om Ert arbetsställe inte har några sådana transporter, ber vi Er fylla i denna sida samt fråga ett och två på nästa sida och därefter skicka in enkäten i det portofria svarskuvertet till oss. Det är mycket viktigt för oss att Ni sänder in enkäten, även om Ni inte har utgående godstransporter.

Vilket ansvarsområde har Ni på Ert arbetsställe?
- ☐ Samtliga godstransporter
- ☐ Vissa godstransporter, nämligen:

………………………………………………

Svaren i enkäten innefattar:
- ☐ Arbetsställets samtliga transporter
- ☐ Endast de transporter som jag ansvarar för

Om Ni inte kan besvara alla frågor i enkäten, var god lämna över den till lämplig person på Ert arbetsställe för kompletterande svarsinformation.

Enkäten besvarad av:

Namn______________________
Befattning:______________________
Arbetsställe:______________________
Postadress:______________________
E-post:______________________
Telefon:______________________

Övriga frågor i enkäten har besvarats av:

Namn______________________
Ansvarsområde:______________________
Befattning:______________________
Arbetsställe:______________________
Postadress:______________________
E-post:______________________
Telefon:______________________

Enkäten är inte tillämplig för oss, därför att:
- ☐ vi inte har några utgående godstransporter
- ☐ vi har utgående godstransporter, men alla är *kortare än* 150 km

Var vänlig ange här vilken enhet som Ni avser att använda när Ni besvarar frågor angående godsmängd.

- ☐ ton
- ☐ fraktdragande vikt (ton)
- ☐ m^3
- ☐ Annan enhet, nämligen:

……………………………………

Om Ni inte använder verklig vikt i ton, var god ange här en ungefärlig omräkningsfaktor:

1 ton fraktdragande vikt ≈ ………..ton (verklig vikt)
1 m^3 ≈ ………..ton (verklig vikt)
Annan enhet:……….. ≈ ………..ton (verklig vikt)

I svaren vill vi helst ha uppgifter gällande år 2002. Om Ni inte kan lämna uppgift för detta år, ange här (eller vid respektive fråga) vilket år som avses. Uppgifter gäller för år: …………..…

Tveka inte att kontakta oss om ni har några frågor eller kommentarer:

Bernt Saxin	telefon 031-773 5133	e-post: Bernt.Saxin@handels.gu.se
Catrin Lammgård	telefon 031-773 5466	e-post: Catrin.Lammgard@handels.gu.se
Jonas Flodén	telefon 031-773 5131	e-post: Jonas.Floden@handels.gu.se

Var god besvara varje fråga i enkäten om inte annat anges!

1.

a) Ungefär hur stor godsmängd skickar Ert arbetsställe årligen? Kryssa för den måttenhet som används.

Cirka……………………………… ☐ ton
☐ fraktdragande vikt, ton
☐ m^3
☐ Annan enhet, nämligen:
……………………………

b) Ansvarar Ert arbetsställe *dessutom* för distribution från lager i annat land, direkt till kunder i Sverige?

☐ Ja, utöver den i fråga 1a angivna volymen distribuerar vi ………………………………………(i samma enhet).
Denna volym distribueras till kunder i Sverige från följande land / länder:
……………………………………………………………
☐ Nej, vi distribuerar ej från annat land

2. **Hur fördelar sig Ert arbetsställes leveranser på nedanstående produktkategorier? Ange en ungefärlig fördelning i procent av den utgående godsmängden.**

Ungefär …….% är lagerförda produkter från
☐ egen tillverkning
☐ andras tillverkning
Ungefär …….% är produkter tillverkade direkt mot order från
☐ egen tillverkning
☐ andras tillverkning

Summa 100 %

3. **Vilken är Ert arbetsställes huvudsakliga verksamhet?**

☐ Tillverkningsindustri
☐ Parti-/grossisthandel
☐ Postorder/ e-handel till industri
☐ Postorder/ e-handel till konsument
☐ Detaljhandel
☐ Internleverantör till annan enhet inom företaget
☐ Annat, nämligen:……………………………………

4. **Ange vilka kundkategorier (inklusive andra arbetsställen inom företaget) Ert arbetsställe levererar till och deras andel av den utgående godsmängden.**

	Andel av utgående godsmängd
Tillverkningsindustri[1]	………….%
Byggindustri / -installatörer	………….%
Partihandel / grossist	………….%
Detaljhandel	………….%
Annat, nämligen:………………	………….%
Summa	*100 %*

[1] Förutom byggindustri / -installatörer

Kommentar:………………………………………………….

5. **Vem utför Ert arbetsställes utgående transporter och till vilken andel av utgående godsmängd?**

	Andel av utgående godsmängd
Vi anlitar speditörer / transportörer[1]	………..%
Egna transporter planeras och utförs i företagets regi	
med inhyrd transporttjänst[2]	………..%
med egna (eller leasade) fordon	………..%
Våra kunder anordnar själva transporterna	………..%
Annat sätt:……………………	………..%
Summa	*100 %*

[1] Även s.k. tredjepartslogistiker
[2] D.v.s. åkeri eller lastbilscentral utför enbart transporten, men samordnar inte transporterna i övrigt

Kommentar:………………………………………………

6. *Denna fråga besvaras om utgående transporter köps in.*
Vem beslutar om valet av transportör?

☐ Företagsledningen / koncernledningen
☐ Ledningen för arbetsstället
☐ Transportchef /-ansvarig
☐ Inköpschef
☐ Vår kund
☐ Annan, nämligen ……………………………
☐ Vet ej

Kommentar………………………………………………………
………………………………………………………………
………………………………………………………………

7. **Vem beslutar om valet av transportslag (lastbil, tåg, fartyg, flyg eller en kombination av dessa)?**

☐ Företagsledningen / koncernledningen
☐ Ledningen för arbetsstället
☐ Transportchef /-ansvarig
☐ Inköpschef
☐ Vår speditör / transportör[1]
☐ Vår kund
☐ Annan, nämligen ……………………………
☐ Vet ej

[1] Även s.k. tredjepartslogistiker

Kommentar:……………………………………………
…………………………………………………………

8. *Denna fråga besvaras om utgående transporter köps in.*
Hur många transportföretag har Ni långsiktiga avtal med (minst ett år) rörande utgående transporter och hur många av dessa innehåller tjänster utöver ren transporttjänst[1]?

Vi har totalt ……………st långsiktiga transportavtal
varav……………st även med annan logistisk tjänst[1]
☐ Vet ej

Var god specificera även de tre största avtalens längd och andel.

Avtal	*Avtalets längd*	*Andel av utgående godsmängd*
Det största	…….år	………%
Det näst största	…….år	………%
Det tredje största	…….år	………%

[1] Lagerhållning, plockning, märkning, prissättning, etc.

9. **Fördela viktsumman 100 procent på nedanstående egenskaper i förhållande till deras betydelse för Ert arbetsställe när Ni väljer transportlösning för Era utgående transporter.**

Egenskap hos transportlösning	*Egenskapens vikt*
Priset	………%
Transporttiden från dörr till dörr	………%
Tidsprecisionen[1] från dörr till dörr	………%
Miljöeffektiviteten (representerad av koldioxidutsläpp)	………%
Summa	*100 %*

[1] Upphämtning och leverans sker inom överenskommet tidsfönster

10. **Vilka lastnings- och lossningsmöjligheter finns vid Ert arbetsställe?**

☐ Industrispår (för tåg)
☐ Kaj (för fartyg)
☐ Lastbrygga (för lastbil)
☐ Terminalyta, t.ex. för uppställning av trailers, containers etc.

Kommentar:………………………………………………………………………………………………………

11. **Ange hur den utgående godsmängden från Ert arbetsställe fördelas på mottagare i nedan angivna geografiska områden och använd gränsstation vid export?**

Mottagare i	*Andel av utgående godsmängd*	*Gränsstation (ort) vid export*
Sverige	Ungefär ………%	
Norge	Ungefär ………%	Gränsstation: ………………………………………
Danmark	Ungefär………%	Gränsstation: ………………………………………
Finland	Ungefär………%	Gränsstation: ………………………………………
Övriga Europa	Ungefär……….%	Gränsstation: ………………………………………
Övriga världen	Ungefär……….%	Gränsstation: ………………………………………
Summa:	*100 %*	

☐ Vet ej

Kommentar:………………………………………………………………………………………………………

12. *Denna fråga avser endast godstransporter till kunder i Sverige.*
Uppskatta ungefär fördelningen på transportavstånd av Ert arbetsställes utgående inrikes godsmängd?

Om transporterna går i slinga eller krets, så räkna avståndet till den längst bort belägna kunden.

0 - ca 15 mil……………% av godsmängden
ca 15 – 30 mil……………% av godsmängden
ca 30 – 60 mil……………% av godsmängden
ca 60 - ……………% av godsmängden
Summa: 100 %

☐ Vet ej fördelningen
☐ Vi har inga godstransporter till kunder i Sverige

Kommentar:………………………………………………………………………………………………………

13. Vilket eller vilka transportslag används vanligen för Ert arbetsställes utgående transporter? Ange ungefär hur många fordon som hämtar gods vid Ert arbetsställe per vecka.

Transportslag som används dörr-till-dörr	*Antal hämtande fordon per vecka*
Lastbil[1]	………… st lastbilar
Lastbil + tåg[2]	………… st lastbilar
Lastbil + tåg + fartyg[2]	………… st lastbilar
Lastbil + fartyg[2]	………… st lastbilar
Lastbil + flyg	………… st lastbilar
Tåg[3]	……… st tågvagnar
Fartyg	………….. st fartyg

[1] Även då lastbilen delvis fraktas med färja
[2] D.v.s. där enbart lastbäraren (t.ex. semitrailer, container) överförs och transporteras på tåget och / eller fartyget
[3] Utlastning via industrispår

Kommentar:……………………………………………………………

14. Ungefär hur många lastbilar per vecka hämtar minst en fullastad större lastbärare[1]?

Svar:… … … … … ….st lastbilar per vecka hämtar minst en full lastbärare

☐ Vet ej

[1] D.v.s. växelflak, trailer, ISO-container, släp eller lastbilsflak.

15. Går några av de hämtande lastbilarna i s.k. kretstrafik (t.ex. distributionsslinga till återförsäljare)?

☐ Ja, ………. st av alla lastbilar per vecka går i kretstrafik
☐ Nej, inga av våra hämtande lastbilar går i kretstrafik

☐ Vet ej

16. a) Indela Ert gods i nedanstående kategorier. Om visst gods har flera egenskaper, indela då efter den dominerande egenskapen.[1]

Dominerande egenskap	*Andel av utgående godsmängd*
Normalt gods	Ungefär…………%
Farligt gods	Ungefär…………%
Kyl- o frys, värmegods	Ungefär…………%
Stötkänsligt gods	Ungefär…………%
Skrymmande gods[2]	Ungefär…………%
	Summa: 100 %

☐ Vet ej

[1] Om godset t.ex. är såväl stötkänsligt som skrymmande, välj då den egenskap som dominerar från transportsynpunkt.
[2] Ex. mycket långt eller brett gods som fordrar speciallastbärare.

b) Hur skickas Ert gods vanligen?

☐ Pallat
☐ I mindre specialbehållare, som kan lastas på flak e.d.
☐ Stående eller liggande direkt på flak eller i skåp
☐ I bulkbehållare eller i större tank
☐ På annat sätt, nämligen:………………………………….

☐ Vet ej

c) Används enhetslastbärare såsom ISO-container, växelflak eller semitrailer anpassad för kombinerad transport?

☐ Ja
☐ Nej
☐ Vet ej

17. Ange ungefärlig ordercykeltid[1] när Era kunder beställer från Ert arbetsställe samt Ert arbetsställes framförhållning[2] när Ni beställer transporter.

Kundkategori	*Ordercykeltid[1] antal dygn*	*Framförhållning*	*Har ej som kund*
Tillverkningsindustri	……………… dygn	……….timmar	☐
Byggindustri / -installatör	……………… dygn	……….timmar	☐
Partihandel / grossist	……………… dygn	……….timmar	☐
Detaljhandel	……………… dygn	……….timmar	☐
Annat, nämligen…………	……………… dygn	……….timmar	☐

[1] Tidsintervallet mellan Er kunds beställning och mottagande av godset
[2] Hur lång tid före transporten sker beställning alternativt bokning

Kommentar:…………………………………………………………………………………………………….

18. a) Hur fördelar sig Era kundleveranser procentuellt på transporttid[1] som är överenskommen med Er transportör?

Godset skall levereras	*Andel*
samma dag	……………..%
under nästa dag före kl 10	……………..%
under nästa dag	……………..%
senast 2 dagar efter hämtning	……………..%
senast 3 dagar efter utlastning	……………..%
……. dagar efter utlastning	……………..%
Summa	*100 %*

Ange måttenhet: ☐ % av utgående godsmängd
☐ % av antal sändningar

☐ Vet ej fördelningen

[1] D.v.s. tiden från utlastning till avlämning hos kund

b) Vilka kundkategorier kräver de snabbaste leveranstiderna?

☐ Tillverkningsindustri[1]
☐ Byggindustri / -installatörer
☐ Partihandel / grossisst
☐ Detaljhandel
☐ Annan: ………………………..

[1] Förutom byggindustri / - installatörer

Kommentar:…………………………………………………
……………………………………………………………
……………………………………………………………
……………………………………………………………
……………………………………………………………

19. a) Skulle Ni kunna boka/beställa Era utgående transporter en dag tidigare än Ni gör idag och vad skulle i så fall krävas?

☐ Ja, vi skulle kunna boka / beställa minst en dag tidigare än vi gör idag för ungefär………….% av vårt utgående gods.

För detta skulle vi kräva:
☐ att priset på transporten sänktes med ca……. %
☐ ingen speciell kompensation eller anledning
☐ annat:…………………………………………..

☐ Nej, bokning / beställning minst en dag tidigare än vi gör idag är omöjligt att göra.

☐ Vet ej

Kommentar:…………………………………………………

b) Skulle Era kunder acceptera en dags längre leveranstid och vad skulle i så fall krävas?

☐ Ja, vi tror att våra kunder skulle acceptera en extra dags leveranstid för ungefär ……% av vårt utgående gods.

För detta skulle de kräva:
☐ att priset på transporten sänktes med ca……… %
☐ ingen speciell kompensation eller anledning
☐ annat:…………………………………………

☐ Nej, längre leveranstid skulle inte accepteras våra kunder.

☐ Vet ej

Kommentar:…………………………………………………

20. *Frågan avser endast gods som skall levereras dagen efter utlastning från Ert arbetsställe.*

a) Ange vilka tidsintervall för leverans ("tidsfönster") Ni har avtalat med Era transportörer av utgående gods, samt hur stor andel av detta som faller inom dessa intervall.

Största överenskomna tidsintervall ("tidsfönster")	*Andel*
± 0,0 tim	………. %
Max ± 0,5 tim	………. %
Max ± 2,0 tim	………. %
Max ± …………….. tim	………. %
Skall levereras under dagen utan tidsrestriktion	………. %
Summa	*100 %*

Ange måttenhet: ☐ % av utgående godsmängd
☐ % av antal sändningar

☐ Vi har inga sådana avtal

Frågan avser endast gods som skall levereras dagen efter utlastning och besvaras endast om Ni har angivit tidsfönster i fråga 20a.

b) Vilka kundkategorier kräver de snävaste tidsintervallen?

☐ Tillverkningsindustri[1]
☐ Byggindustri / installatörer
☐ Partihandel / grossist
☐ Detaljhandel
☐ Annan: ………………………..

[1] Ej byggindustri eller -installatörer

Kommentar…………………………………………
…………………………………………………
…………………………………………………
…………………………………………………
…………………………………………………

21. **Ungefär hur stor andel av Ert arbetsställes leveranser kommer till kund i överenskommen tid?**

Godsmottagare i	*Andel*
Sverige	……….%
Norge	……….%
Danmark	……….%
Finland	……….%
Övriga Europa	……….%

☐ Vet ej

Kommentar: …………………………
…………………………………………
…………………………………………
…………………………………………
…………………………………………

22. **a) Var god ange ungefärlig procentuell fördelning av utleveranserna över veckan (i genomsnitt).**

Veckodag	*Andel*
Måndag	……….%
Tisdag	……….%
Onsdag	……….%
Torsdag	……….%
Fredag	……….%
Lördag	……….%
Söndag	……….%
Summa	*100%*

☐ Vet ej

Ange måttenhet:

☐ % av godsmängden

☐ % av antal sändningar

Kommentar: ……………………
…………………………………

b) Var god ange ungefärlig procentuell fördelning av utleveranserna över dagen (i genomsnitt).

Klockslag	*Andel*
Före 06	……….%
kl. 06-10	……….%
kl. 10-14	……….%
kl. 14-18	……….%
Efter 18	……….%
Summa	*100%*

☐ Vet ej

Ange måttenhet:

☐ % av godsmängden

☐ % av antal sändningar

Kommentar: ……………………
…………………………………

23. **a) Ungefär hur stor andel av Ert arbetsställes utgående godsmängd blev transportskadad? Ange i så många enheter som möjligt.**

Ungefär……………..% av utgående godsmängd

Ungefär……………..% av utgående godsvärde

Ungefär……………..% av antalet sändningar

☐ Vet ej

Kommentar:……………………………………………………
…………………………………………………………………
…………………………………………………………………
…………………………………………………………………
…………………………………………………………………

b) Ange vilket eller vilka transportslag som brukar ge mest skador? Var god besvara frågan även om Ni bara använder ett transportslag.

☐ Vi använder bara ett transportslag.

☐ Lastbil [1]
☐ Lastbil + tåg [2]
☐ Lastbil + tåg + fartyg [2]
☐ Lastbil + fartyg [2]
☐ Lastbil + flyg
☐ Tåg [3]
☐ Fartyg

☐ Vet ej

[1] Även då lastbilen delvis fraktas med färja
[2] D.v.s. där enbart lastbäraren (t.ex. semitrailer, container) transporteras på tåget och / eller fartyget
[3] Utlastning via industrispår

24. Ange vilken vikt nedanstående egenskaper hos transportörer har för Ert arbetsställes val av transportör, samt i vilken grad Er nuvarande huvudtransportör har dessa egenskaper.

Ange Er uppfattning med ett kryss på varje 7-gradig skala nedan, där 1 = mycket liten vikt / i mycket låg grad och 7 = mycket stor vikt / i mycket hög grad.

Egenskapens vikt för val av transportör (*Mycket liten vikt* ← → *Mycket stor vikt*)	**Egenskap** — **Transportören…**	**I vilken grad har Er transportör denna egenskap?** (*I mycket låg grad* ← → *I mycket hög grad*)
1 2 3 4 5 6 7		1 2 3 4 5 6 7
☐ ☐ ☐ ☐ ☐ ☐ ☐	… täcker in vårt geografiska marknadsområde tillräckligt väl	☐ ☐ ☐ ☐ ☐ ☐ ☐
☐ ☐ ☐ ☐ ☐ ☐ ☐	… har ett bra IT-stödsystem för beställning från oss (t.ex. EDI, internetbeställning)	☐ ☐ ☐ ☐ ☐ ☐ ☐
☐ ☐ ☐ ☐ ☐ ☐ ☐	… har ett bra IT-stödsystem för att följa godsets väg (t.ex. track and trace)	☐ ☐ ☐ ☐ ☐ ☐ ☐
☐ ☐ ☐ ☐ ☐ ☐ ☐	… har ett brett sortiment av kompletterande logistik-tjänster (t.ex. lagerhållning, emballering)	☐ ☐ ☐ ☐ ☐ ☐ ☐
☐ ☐ ☐ ☐ ☐ ☐ ☐	… vet hur vårt gods skall hanteras bla för att undvika godsskador	☐ ☐ ☐ ☐ ☐ ☐ ☐
1 2 3 4 5 6 7		1 2 3 4 5 6 7
☐ ☐ ☐ ☐ ☐ ☐ ☐	… är kvalitetscertifierad, t.ex. ISO 9000	☐ ☐ ☐ ☐ ☐ ☐ ☐
☐ ☐ ☐ ☐ ☐ ☐ ☐	… har bra rutiner för dokumenthantering	☐ ☐ ☐ ☐ ☐ ☐ ☐
☐ ☐ ☐ ☐ ☐ ☐ ☐	… har säkerhetsrutiner mot stölder och svinn	☐ ☐ ☐ ☐ ☐ ☐ ☐
☐ ☐ ☐ ☐ ☐ ☐ ☐	… kan erbjuda kundanpassade transportlösningar	☐ ☐ ☐ ☐ ☐ ☐ ☐
☐ ☐ ☐ ☐ ☐ ☐ ☐	… är lättillgänglig vid förfrågan och bokning	☐ ☐ ☐ ☐ ☐ ☐ ☐
☐ ☐ ☐ ☐ ☐ ☐ ☐	… är lättillgänglig vid uppföljning av order	☐ ☐ ☐ ☐ ☐ ☐ ☐
1 2 3 4 5 6 7		1 2 3 4 5 6 7
☐ ☐ ☐ ☐ ☐ ☐ ☐	… har många schemalagda avgångar	☐ ☐ ☐ ☐ ☐ ☐ ☐
☐ ☐ ☐ ☐ ☐ ☐ ☐	… kan anpassa sig till stora volymvariationer	☐ ☐ ☐ ☐ ☐ ☐ ☐
☐ ☐ ☐ ☐ ☐ ☐ ☐	… kan åtaga sig leveranser med kort varsel ("brandkårsutryckningar")	☐ ☐ ☐ ☐ ☐ ☐ ☐
☐ ☐ ☐ ☐ ☐ ☐ ☐	… håller överenskomna tider	☐ ☐ ☐ ☐ ☐ ☐ ☐
☐ ☐ ☐ ☐ ☐ ☐ ☐	… håller sina utfästelser	☐ ☐ ☐ ☐ ☐ ☐ ☐
1 2 3 4 5 6 7		1 2 3 4 5 6 7
☐ ☐ ☐ ☐ ☐ ☐ ☐	… har väl fungerande rutiner för avvikelserapportering	☐ ☐ ☐ ☐ ☐ ☐ ☐
☐ ☐ ☐ ☐ ☐ ☐ ☐	… har trevligt bemötande vid hämtning och leverans	☐ ☐ ☐ ☐ ☐ ☐ ☐
☐ ☐ ☐ ☐ ☐ ☐ ☐	… håller en jämn kvalitetsnivå	☐ ☐ ☐ ☐ ☐ ☐ ☐
☐ ☐ ☐ ☐ ☐ ☐ ☐	… har anlitats av oss tidigare	☐ ☐ ☐ ☐ ☐ ☐ ☐
☐ ☐ ☐ ☐ ☐ ☐ ☐	… har ett gott rykte	☐ ☐ ☐ ☐ ☐ ☐ ☐
1 2 3 4 5 6 7		1 2 3 4 5 6 7
☐ ☐ ☐ ☐ ☐ ☐ ☐	… erbjuder ett av de lägsta priserna	☐ ☐ ☐ ☐ ☐ ☐ ☐
☐ ☐ ☐ ☐ ☐ ☐ ☐	… ger oss tillgång till lösa lastbärare (t.ex. växelflak, semitrailers) som vi kan lasta innan hämtning	☐ ☐ ☐ ☐ ☐ ☐ ☐
☐ ☐ ☐ ☐ ☐ ☐ ☐	… kan erbjuda de transportsätt (lastbil, tåg, båt, flyg eller kombination av dessa) som vi önskar	☐ ☐ ☐ ☐ ☐ ☐ ☐
☐ ☐ ☐ ☐ ☐ ☐ ☐	… kan samordna våra in- och utgående transporter	☐ ☐ ☐ ☐ ☐ ☐ ☐
☐ ☐ ☐ ☐ ☐ ☐ ☐	… erbjuder samleveranser med andra företag för att minska tomtransporter	☐ ☐ ☐ ☐ ☐ ☐ ☐
1 2 3 4 5 6 7		1 2 3 4 5 6 7
☐ ☐ ☐ ☐ ☐ ☐ ☐	… kan erbjuda godstransporter på tåg	☐ ☐ ☐ ☐ ☐ ☐ ☐
☐ ☐ ☐ ☐ ☐ ☐ ☐	… har hög fyllnadsgrad av gods (lastfaktor)	☐ ☐ ☐ ☐ ☐ ☐ ☐
☐ ☐ ☐ ☐ ☐ ☐ ☐	… använder andra bränslen än diesel, t.ex. biobränslen, gas	☐ ☐ ☐ ☐ ☐ ☐ ☐
☐ ☐ ☐ ☐ ☐ ☐ ☐	… använder lastbilar med hög miljöklass	☐ ☐ ☐ ☐ ☐ ☐ ☐
☐ ☐ ☐ ☐ ☐ ☐ ☐	… kan erbjuda kombinerade godstransporter lastbil-tåg	☐ ☐ ☐ ☐ ☐ ☐ ☐
☐ ☐ ☐ ☐ ☐ ☐ ☐	… är miljöcertifierad, t.ex. ISO 14001	☐ ☐ ☐ ☐ ☐ ☐ ☐
☐ ☐ ☐ ☐ ☐ ☐ ☐	… har miljöeffektiva transporter	☐ ☐ ☐ ☐ ☐ ☐ ☐

25.

a) Har Ert arbetsställe infört eller håller på att införa något miljöledningssystem? ☐ Ja, har införts ☐ Håller på att införas ☐ Nej ☐ Vet ej	*Besvaras om miljöledningssystem finns eller håller på att införas.* **b) Vilket miljöledningssystem avses?** ☐ ISO 14001 ☐ EMAS ☐ Annat:……………………………………………

26.

a) Finns det eller håller ni på att utforma någon miljöpolicy på Ert arbetsställe idag? ☐ Ja, det finns ☐ Nej, det finns inte ☐ Vi håller på att utforma ☐ Vet ej	*Besvaras om en miljöpolicy finns eller håller på att utformas.* **b) Sammanfatta kort arbetsställets (företagets) miljöpolicy när det gäller transporter.** …………………………………………………… …………………………………………………… …………………………………………………… ……………………………………………………
Besvaras om en miljöpolicy finns eller håller på att utformas. **c) I vilken utsträckning påverkar Ert arbetsställes miljöpolicy transportuppläggen idag?** ☐ I mycket stor utsträckning ☐ I stor utsträckning ☐ I ganska stor utsträckning ☐ I varken stor eller liten utsträckning ☐ I ganska liten utsträckning ☐ I liten utsträckning ☐ I mycket liten utsträckning	*Besvaras om en miljöpolicy finns eller håller på att utformas.* **d) Om miljöpolicyn påverkar, beskriv på vilket sätt.** …………………………………………………… …………………………………………………… …………………………………………………… …………………………………………………… ……………………………………………………

27. **Ställer Era kunder några miljökrav som påverkar Ert arbetsställes transportmedelsval?**

För Era inkommande transporter:

☐ Ja
☐ Nej
☐ Vet ej

Om ja, vilka är Era kunders krav och hur påverkar de?

……………………………………………………
……………………………………………………
……………………………………………………

För Era utgående transporter:

☐ Ja
☐ Nej
☐ Vet ej

Om ja, vilka är Era kunders krav och hur påverkar de?

……………………………………………………
……………………………………………………
……………………………………………………

28. **Ställer Ert eget företag några konkreta miljökrav på Era transporter?**

För Era inkommande transporter:

☐ Ja
☐ Nej
☐ Vet ej

Om ja, vilka är Ert företags krav och hur påverkar de?

……………………………………………………
……………………………………………………
……………………………………………………

För Era utgående transporter:

☐ Ja
☐ Nej
☐ Vet ej

Om ja, vilka är Ert företags krav och hur påverkar de?

……………………………………………………
……………………………………………………
……………………………………………………

29. **Vilken miljöpåverkan, som Era transporter ger upphov till, anser Ni vara den mest negativa?**

………………………………………………………………………………………………………
………………………………………………………………………………………………………

30. Ange vilken betydelse Ni tror att nedanstående åtgärder skulle ha för att minska Era transporters miljöpåverkan, samt vilken möjlighet Ni tror finns att genomföra åtgärden.

Ange Er uppfattning om åtgärdens betydelse/möjlighet att genomföras med ett kryss på varje 7-gradig skala nedan, där 1 = mycket liten betydelse / mycket liten möjlighet och 7 = mycket stor betydelse / mycket stor möjlighet.

Betydelse för att minska miljöpåverkan								**Möjlighet finns att genomföra åtgärden**							
Mycket liten ←						→ *Mycket stor*	**Åtgärd**	*Mycket liten* ←						→ *Mycket stor*	*Redan genomfört*
1	2	3	4	5	6	7		1	2	3	4	5	6	7	
☐	☐	☐	☐	☐	☐	☐	Tillsätta en miljöchef/miljöavdelning	☐	☐	☐	☐	☐	☐	☐	☐
☐	☐	☐	☐	☐	☐	☐	Mer utbildning i miljöfrågor	☐	☐	☐	☐	☐	☐	☐	☐
☐	☐	☐	☐	☐	☐	☐	Bli miljöcertifierade, t.ex. ISO 14001	☐	☐	☐	☐	☐	☐	☐	☐
☐	☐	☐	☐	☐	☐	☐	Publicera miljöredovisningar	☐	☐	☐	☐	☐	☐	☐	☐
☐	☐	☐	☐	☐	☐	☐	Ökat stöd för miljöprioriteringar från ledningen	☐	☐	☐	☐	☐	☐	☐	☐
1	2	3	4	5	6	7		1	2	3	4	5	6	7	
☐	☐	☐	☐	☐	☐	☐	Införa en miljöpolicy i vårt företag	☐	☐	☐	☐	☐	☐	☐	☐
☐	☐	☐	☐	☐	☐	☐	Ökat samarbete med den miljöansvarige i vårt företag	☐	☐	☐	☐	☐	☐	☐	☐
☐	☐	☐	☐	☐	☐	☐	Ökat samarbete i miljöfrågor med transportör/speditör	☐	☐	☐	☐	☐	☐	☐	☐
☐	☐	☐	☐	☐	☐	☐	Ökat samarbete i miljöfrågor med kunder	☐	☐	☐	☐	☐	☐	☐	☐
☐	☐	☐	☐	☐	☐	☐	Ökat samarbete i miljöfrågor med leverantörer	☐	☐	☐	☐	☐	☐	☐	☐
1	2	3	4	5	6	7		1	2	3	4	5	6	7	
☐	☐	☐	☐	☐	☐	☐	Ställa hårdare miljökrav på våra leverantörers transporter till oss	☐	☐	☐	☐	☐	☐	☐	☐
☐	☐	☐	☐	☐	☐	☐	Annan insats, nämligen…………………………………	☐	☐	☐	☐	☐	☐	☐	☐

Mycket liten ←						→ *Mycket stor*	**Nedanstående frågor berör endast Era utgående transporter** **Åtgärd**	*Mycket liten* ←						→ *Mycket stor*	
1	2	3	4	5	6	7		1	2	3	4	5	6	7	
☐	☐	☐	☐	☐	☐	☐	Använda lastbilar med hög miljöklass	☐	☐	☐	☐	☐	☐	☐	☐
☐	☐	☐	☐	☐	☐	☐	Ställa hårdare miljökrav på våra utgående transporter	☐	☐	☐	☐	☐	☐	☐	☐
☐	☐	☐	☐	☐	☐	☐	Använda andra bränslen än diesel, t.ex. biobränslen, gas	☐	☐	☐	☐	☐	☐	☐	☐
☐	☐	☐	☐	☐	☐	☐	Minska tomtransporterna / öka returtransporterna av gods genom t.ex. samleveranser med andra företag	☐	☐	☐	☐	☐	☐	☐	☐
☐	☐	☐	☐	☐	☐	☐	Öka fyllnadsgraden av gods (lastfaktorn)	☐	☐	☐	☐	☐	☐	☐	☐
1	2	3	4	5	6	7		1	2	3	4	5	6	7	
☐	☐	☐	☐	☐	☐	☐	Transportera mer av vårt gods på tåg	☐	☐	☐	☐	☐	☐	☐	☐
☐	☐	☐	☐	☐	☐	☐	Använda mer kombinerade godstransporter lastbil-tåg	☐	☐	☐	☐	☐	☐	☐	☐
☐	☐	☐	☐	☐	☐	☐	Annan insats, nämligen………………………………	☐	☐	☐	☐	☐	☐	☐	☐

Kommentar:………………………………………………………………………………………………
………………………………………………………………………………………………………

Tack för din medverkan!

Var god lägg den ifyllda enkäten i det bifogade portofria svarskuvertet och returnera det till oss.
Adress: Bernt Saxin, Handelshögskolan vid Göteborgs universitet, Box 610, 405 30 Göteborg.

Appendix 12 The Survey Goods Transport in the Swedish Industry

The original Swedish survey from Appendix 11 translated into English.

School of Economics and Commercial Law
GÖTEBORG UNIVERSITY

Goods Transport in the Swedish Industry
– Facts and Desired Services

This survey mainly concerns the outgoing goods transport exceeding 150 km from your local unit. If your local unit does not have any such transports, we ask you to fill in this page and send us the survey in the enclosed post-paid envelop. It is very important for us that you send in the survey, even if you do not have any outgoing goods transport.

Which is your area of responsibility at your local unit?
- ☐ All goods transport
- ☐ Some goods transport, please specify: ……………………………………………

The answers in the survey comprise:
- ☐ All transport at the local unit
- ☐ Only the transport I am responsible for

If you cannot answer all questions in the survey, please pass it on to the appropriate person at your local unit to answer the remaining questions.

This survey has been answered by:
Name: ____________________
Position: ____________________
Local unit: ____________________
Postal address: ____________________
E-mail: ____________________
Telephone: ____________________

Remaining questions in the survey have been answered by:
Name: ____________________
Area of responsibility: ____________________
Position: ____________________
Local unit: ____________________
Postal address: ____________________
E-mail: ____________________
Telephone: ____________________

The survey is not applicable for us, since:
- ☐ we do not have any outgoing goods transport
- ☐ we have outgoing goods transport but all are *shorter than* 150 km

Please state which unit you intend to use when answering questions regarding goods quantities

- ☐ tonnes
- ☐ volumetric weight (tonnes)
- ☐ m^3
- ☐ Other unit, please specify: ……………………………………

If you do not use weight in tonnes, please state here and approximate conversion factor:

1 tonnes volumetric weight ≈ ………..tonnes (real weight)
1 m^3 ≈ ………..tonnes (real weight)
Other unit:………… ≈ ………..tonnes (real weight)

We would prefer data concerning year 2002. If you cannot give data for this year, please state here (or by each question) which year that is intended: The data is for year: ……………....

Do not hesitate to contact us if you have any questions or comments:

Bernt Saxin	Telephone 031-773 5133	E-mail: Bernt.Saxin@handels.gu.se
Catrin Lammgård	Telephone 031-773 5466	E-mail: Catrin.Lammgard@handels.gu.se
Jonas Flodén	Telephone 031-773 5131	E-mail: Jonas.Floden@handels.gu.se

Please answer each question in the survey, if nothing else is stated

1.

a) Approximately what quantity of goods does your local unit send each year? Cross the measurement unit used.

Approximately…………… ☐ tonnes ☐ volumetric weight, tonnes ☐ m^3 ☐ Other unit, please specify: ……………………………

b) Is your local unit *also* responsible for distribution from warehouse/s in another country, directly to customers in Sweden?

☐ Yes, apart from the in question 1a stated volume, we distribute …………………………………………(in the same unit). This volume is distributed to customers in Sweden from the following country/ies:

…………………………………………………………………

☐ No, we do not distribute from another country

2. Which is the distribution of your local unit's deliveries of the product categories below? Please state an approximate distribution in percent of the outgoing goods quantity.

Approximately …….% are products kept in stock from ☐ own manufacturing ☐ manufacturing by others

Approximately …….% are products manufactured directly to order from ☐ own manufacturing ☐ manufacturing by others

Total 100 %

3. Which activity are the main of your local unit?

☐ Manufacturing industry
☐ Wholesale industry
☐ Mail order/ e-commerce to industry
☐ Mail order/ e-commerce to consumer
☐ Retail trade
☐ Internal supplier to other unit within the company
☐ Other, please specify:………………………………….

4. Please state what customer categories (including other local units within the company) that your local unit delivers to, and their share of the outgoing goods quantity.

	Share of outgoing goods quantity
Manufacturing industry[1]	…………%
Construction industry / installation	…………%
Wholesale	…………%
Retail trade	…………%
Other, please specify:………………	…………%
Total	*100 %*

[1] Except construction industry / installation

Comments:……………………………………………

5. Who performs the outgoing transport from your local unit and to what share of the outgoing goods quantity?

	Share of outgoing goods quantity
We use forwarders / transport companies[1]	………..%
Own transports are planned and performed within the company with contracted transport service[2]	………..%
with own (or leased) vehicles	………..%
Our customers arranges their transports	………..%
Other way:……………………	………..%
Total	*100 %*

[1] Also third party logistics providers.
[2] I.e. a haulier performs the transport, but do not co-ordinate the transport in any other way

Comments……………………………………………

6. *Answer this question if outgoing transport are purchased.*
Who decides which transport provider to use?

☐ Top management / group executive board
☐ Management of the local unit
☐ Transport manager /-executive
☐ Purchasing manager
☐ Our customer
☐ Other, please specify ……………………………
☐ Do not know

Comments………………………………………………………
…………………………………………………………………
…………………………………………………………………

7. Who decides on the modal choice (lorry, train, ship, aircraft or a combination of them)?

☐ Top management / group executive board
☐ Management of the local unit
☐ Transport manager /-executive
☐ Purchasing manager
☐ Our forwarder / transporter[1]
☐ Our customer
☐ Other, please specify ……………………………
☐ Do not know

[1] Also third party logistics providers

Comments…………………………………………………
…………………………………………………………

8. *Answer this question if outgoing transport is purchased.*
How many transport providers do you have long-term contracts with (at least one year) concerning outgoing transport, and how many of these include services other than transport[1]?

We have a total of …………… long term transport contracts, of which …………… also include other logistics service[1]

☐ Do not know

Please specify the length and share of the three largest contracts.

Contract	*Length of contract*	*Share of outgoing goods*
The largest	…..year	………%
The second largest	…..year	………%
The third largest	…..year	………%

[1] Warehousing, sorting and packing, labelling, pricing, etc.

9. Distribute 100 percent among the properties below, in accordance with their importance for your local unit when selecting transport solutions for your outgoing transport.

Attribute of the transport solution	*Weight of attribute*
Price	………%
Transport time door to door	………%
Time precision[1] door to door	………%
Environmental efficiency (represented by carbon dioxide emissions)	………%
Total	*100 %*

[1] Pick-up and delivery within agreed time-window

10. What opportunities for loading and unloading are available at your local unit?

☐ Rail siding (for trains)
☐ Quay (for ships)
☐ Loading dock (for lorries)
☐ Terminal area, e.g. for positioning of trailers, containers etc.

Comments:……

11. Below, state the percentage of how the outgoing goods from your local unit are distributed on receivers in the respective geographical areas below, and which border crossing is used.

Receiver in	*Share of outgoing goods*	*Border crossing (place) for export*
Sweden	Approximately ………%	
Norway	Approximately ………%	Border crossing: …………………………………
Denmark	Approximately………%	Border crossing: …………………………………
Finland	Approximately………%	Border crossing: …………………………………
Other parts of Europe	Approximately………%	Border crossing: …………………………………
Other parts of the world	Approximately………%	Border crossing: …………………………………
Total:	*100 %*	

☐ Do not know

Comments:……

12. *This question concerns only goods transported to customers in Sweden.*
Estimate the approximate distribution of transport distances of the outgoing domestic goods quantity from your local unit.
If the transport is arrange in a circuit, please consider the distance to the customer furthest away.

0 - approx. 150 km………………% of goods quantity
approx. 150 – 300 km………………% of goods quantity
approx 300 – 600 km………………% of goods quantity
approx. 600 - ………………% of goods quantity
Total: 100 %

☐ Do not know the distribution
☐ We have no goods transport to customers in Sweden

Comments:……

13. Which modes of transport are usually used for the outgoing transport from your local unit? State the approximate number of vehicles picking up goods at your local unit each week.

Mode of transport used door to door	*Number of vehicles making a pick-up per week*
Lorry[1]	……… lorries
Lorry + train[2]	……… lorries
Lorry + train + ship[2]	……… lorries
Lorry + ship[2]	……… lorries
Lorry + aircraft	……… lorries
Train[3]	…… rail cars
Ship	……… ships

[1] Also when the lorry is partly shipped by ferry
[2] I.e. when only the load carrier (e.g. semi-trailer, container) is transferred and transported by train and / or ship
[3] Sent via rail siding at the local unit

Comments:………………………………………………

14. Approximately how many lorries per week pick up a fully-loaded, large, load carrier [1]?

………………lorries per week pick up at least one full load carrier

☐ Do not know

[1] I.e. swap body, trailer, ISO-container, lorry platform

15. Do any of the pick-up lorries run in district traffic (e.g. distribution circuits to retailers)?

☐ Yes, ……….. of all lorries per week run in district traffic
☐ No, none of our lorries are doing pick-up runs in district traffic

☐ Do not know

16. a) Group your goods according to the categories below. If certain goods have several properties, please use the dominant property.[1]

Dominant property	*Share of outgoing goods*
Normal goods	Approximately………..%
Dangerous goods	Approximately………..%
Refrigerated cargo, heated cargo	Approximately………..%
Fragile goods	Approximately………..%
Bulky goods[2]	Approximately………..%
Total:	*100* %

☐ Do not know

[1] If the goods, e.g. are both fragile and bulky, please choose the property that is predominant in a transport perspective.
[2] E.g. very long or wide cargo requiring special load-carriers.

b) How are your goods normally shipped?

☐ Palletised
☐ In smaller special containers, that can be loaded on loading platforms etc.
☐ Standing or lying down directly on a loading platform
☐ In bulk container or large tank
☐ In any other way, please specify:…………………
☐ Do not know

c) Are unit loads being used, e.g. ISO containers, swap bodies, or semi-trailers adapted for intermodal transport?

☐ Yes
☐ No
☐ Do not know

17. State the approximate order cycle time[1] when your customers order from your local unit and your local units time margin[2] when you order transport.

Customer category	*Order cycle time, no of days*	*Time margin*	*No such customer*
Manufacturing industry	……………… days	………hours	☐
Construction industry / -installation	……………… days	………hours	☐
Wholesale	……………… days	………hours	☐
Retail trade	……………… days	………hours	☐
Other, please specify…………	……………… days	………hours	☐

[1] The time-gap between your customers' order and the delivery of the goods
[2] How much time in advance you need to order or book the transport

Comments:…………………………………………………………

18. a) What have you agreed with your transport provider about transport times[1] to your customers?

The goods should be delivered	*Share*
same day	………%
the next day before 10 a.m.	………%
sometime during the next day	………%
no later than 2 days after pick-up	………%
no later than 3 days after pick-up	………%
……. days after pick-up	………..%
Total	*100 %*

Measurement unit: ☐ % of outgoing goods
☐ % of number of shipments

☐ Do not know the distribution

[1] I.e. the time from departure to delivery at the customer

b) Which customer categories demand the shortest delivery times?

☐ Manufacturing industry[1]
☐ Construction industry / installation
☐ Wholesale
☐ Retail trade
☐ Other: ………………………

[1] Except construction industry / - installation

Comments:……………………………………………
……………………………………………
……………………………………………
……………………………………………
……………………………………………

19. a) Could you book / order your transport one day earlier than you do today, and, if so, what would be required?

☐ Yes, we could book / order our transport at least one day earlier than we do today for approximately…………% of our outgoing goods

This would require that:
☐ the price of transport was reduced by approx……. %
☐ no special compensation or reason
☐ other:……………………………………

☐ No, booking / ordering at least one day earlier than today is not possible.

☐ Do not know

Comments:……………………………………

b) Would your customers accept one day longer delivery times, and, if so, what would they require?

☐ Yes, we believe that our customers would accept on day extra delivery time for approximately ……% of our outgoing goods.

This would require that:
☐ the price of transport was reduced by approx…. %
☐ no special compensation or reason
☐ other:……………………………………

☐ No, longer delivery times would not be accepted by our customers.

☐ Do not know

Comments:……………………………………
……………………………………………

20. *The question concerns only goods that shall be delivered the day after departure from your local unit.*
a) State what time-windows for delivery you have agreed with your transport provider and the share of goods within each interval for your outgoing goods.

Largest agreed time-window	*Share*
± 0,0 hours	………. %
Maximum ± 0,5 hours	………. %
Maximum ± 2,0 hours	………. %
Maximum ± ……………. hours	………. %
To be delivered sometime during the day	………. %
Total	*100 %*

Measurement unit: ☐ % of outgoing goods
☐ % of number of shipments

☐ We do not have any such agreements

The question concerns only goods that shall be delivered the day after departure from your local unit, and shall be answered only if you have stated time windows in question 20a.
b) Which customer categories demand the shortest delivery times?

☐ Manufacturing industry[1]
☐ Construction industry / installation
☐ Wholesale
☐ Retail trade
☐ Other: ………………………

[1] Excluding construction industry and installation

Comments……………………………………………
……………………………………………
……………………………………………
……………………………………………

21.

Approximately what share of your local units shipments are delivered to the customer on time?

Receiver in	*Share*
Sweden	………..%
Norway	………..%
Denmark	………..%
Finland	………..%
Rest of Europe	………..%

☐ Do not know

Comments: …………………………………
……………………………………………
……………………………………………
……………………………………………
……………………………………………

22.

a) Please state the approximate distribution of your outgoing shipments across the week (on average).

Day of week	*Share*
Monday	………..%
Tuesday	………..%
Wednesday	………..%
Thursday	………..%
Friday	………..%
Saturday	………..%
Sunday	………..%
Total	*100%*

☐ Do not know

Measurement unit:

☐ % of quantity of goods

☐ % of number of shipments

Comments: ………………………

b) Please state the approximate distribution of outgoing shipments across the day (on average).

Time	*Share*
Before 06	………..%
06-10	………..%
10-14	………..%
14-18	………..%
After 18	………..%
Total	*100%*

☐ Do not know

Measurement unit:

☐ % of quantity of goods

☐ % of number of shipments

Comments: ………………………
……………………………………………

23.

a) Approximately what share of your local units outgoing transport was damaged during transportation? Please answer in as many measurement units as possible.

Approximately……………..% of outgoing goods quantity

Approximately……………..% of outgoing goods value

Approximately……………..% of number of shipments

☐ Do not know

Comments:…………………………………………………
……………………………………………………………
……………………………………………………………
……………………………………………………………

b) State which mode of transport that normally causes the most transport damage. Please answer the question even if you only use one mode of transport.

☐ We only use one mode of transport.
☐ Lorry [1]
☐ Lorry + train[2]
☐ Lorry + train + ship[2]
☐ Lorry + ship
☐ Lorry + aircraft
☐ Train[3]
☐ Ship

☐ Do not know

[1] Also when the lorry is partly shipped by ferry
[2] I.e. when only the load carrier (e.g. semi-trailer, container) is transferred and transported by train and / or ship
[3] Sent via rail siding at the local unit

24. Below, state what weight each attribute of a transport provider has in the choice of transport service, and to what extent has your present main transport provider these properties

State your opinion with a cross on each 7-grade scale, where 1 = very small weight/extent and 7 = very large weight/extent.

Weight of the attribute for choice of transport provider — *Very small weight* ← → *Very large weight*

Attribute

To what extent does your transport provider fulfil these properties? — *To a very low extent* ← → *To a very large extent*

1	2	3	4	5	6	7	**The transport provider…**	1	2	3	4	5	6	7
☐	☐	☐	☐	☐	☐	☐	…covers our market area geographically in a sufficient manner.	☐	☐	☐	☐	☐	☐	☐
☐	☐	☐	☐	☐	☐	☐	…has a good IT support system for receiving our orders (e.g. EDI, internet orders)	☐	☐	☐	☐	☐	☐	☐
☐	☐	☐	☐	☐	☐	☐	…has a good IT support system for tracking the goods (e.g. track and trace)	☐	☐	☐	☐	☐	☐	☐
☐	☐	☐	☐	☐	☐	☐	…has a wide variety of complementary logistics services	☐	☐	☐	☐	☐	☐	☐
☐	☐	☐	☐	☐	☐	☐	…knows how to handle our goods in order to avoid damage	☐	☐	☐	☐	☐	☐	☐
1	2	3	4	5	6	7		1	2	3	4	5	6	7
☐	☐	☐	☐	☐	☐	☐	…is quality certified e.g. ISO 9000	☐	☐	☐	☐	☐	☐	☐
☐	☐	☐	☐	☐	☐	☐	…has good routines for handling documents	☐	☐	☐	☐	☐	☐	☐
☐	☐	☐	☐	☐	☐	☐	…has safety routines against theft and loss	☐	☐	☐	☐	☐	☐	☐
☐	☐	☐	☐	☐	☐	☐	…can offer custom-made transport solutions	☐	☐	☐	☐	☐	☐	☐
☐	☐	☐	☐	☐	☐	☐	…is easily accessible regarding inquiries and bookings	☐	☐	☐	☐	☐	☐	☐
☐	☐	☐	☐	☐	☐	☐	…is easily accessible regarding follow-up of transport	☐	☐	☐	☐	☐	☐	☐
1	2	3	4	5	6	7		1	2	3	4	5	6	7
☐	☐	☐	☐	☐	☐	☐	…has many scheduled dispatches	☐	☐	☐	☐	☐	☐	☐
☐	☐	☐	☐	☐	☐	☐	…can adjust to large variations in volume	☐	☐	☐	☐	☐	☐	☐
☐	☐	☐	☐	☐	☐	☐	…can perform deliveries at short notice	☐	☐	☐	☐	☐	☐	☐
☐	☐	☐	☐	☐	☐	☐	… performs transport in upon agreed time	☐	☐	☐	☐	☐	☐	☐
☐	☐	☐	☐	☐	☐	☐	…fulfils its' commitments	☐	☐	☐	☐	☐	☐	☐
1	2	3	4	5	6	7		1	2	3	4	5	6	7
☐	☐	☐	☐	☐	☐	☐	…has well functioning routines for reporting deviations	☐	☐	☐	☐	☐	☐	☐
☐	☐	☐	☐	☐	☐	☐	…has pleasant approach at pick-up and delivery of goods	☐	☐	☐	☐	☐	☐	☐
☐	☐	☐	☐	☐	☐	☐	…maintains an even quality level	☐	☐	☐	☐	☐	☐	☐
☐	☐	☐	☐	☐	☐	☐	…has worked for us previously	☐	☐	☐	☐	☐	☐	☐
☐	☐	☐	☐	☐	☐	☐	…has a good reputation	☐	☐	☐	☐	☐	☐	☐
1	2	3	4	5	6	7		1	2	3	4	5	6	7
☐	☐	☐	☐	☐	☐	☐	…offers one of the lowest prices	☐	☐	☐	☐	☐	☐	☐
☐	☐	☐	☐	☐	☐	☐	…gives us access to detachable load-carriers (e.g. swap-bodies and semi-trailers)	☐	☐	☐	☐	☐	☐	☐
☐	☐	☐	☐	☐	☐	☐	…can offer the modes of transport (truck, train, boat, aircraft or a combination of these) we desire	☐	☐	☐	☐	☐	☐	☐
☐	☐	☐	☐	☐	☐	☐	…can coordinate our inbound and outbound transport	☐	☐	☐	☐	☐	☐	☐
☐	☐	☐	☐	☐	☐	☐	…offers coordinated shared deliveries with other companies in order to reduce empty load transport	☐	☐	☐	☐	☐	☐	☐
1	2	3	4	5	6	7		1	2	3	4	5	6	7
☐	☐	☐	☐	☐	☐	☐	…can offer goods transport on rail	☐	☐	☐	☐	☐	☐	☐
☐	☐	☐	☐	☐	☐	☐	…has a high loading factor of goods	☐	☐	☐	☐	☐	☐	☐
☐	☐	☐	☐	☐	☐	☐	…uses other fuels than diesel. e.g. bi-fuel and gas	☐	☐	☐	☐	☐	☐	☐
☐	☐	☐	☐	☐	☐	☐	…uses trucks with low emission standards	☐	☐	☐	☐	☐	☐	☐
☐	☐	☐	☐	☐	☐	☐	…can offer combined transport truck-train	☐	☐	☐	☐	☐	☐	☐
☐	☐	☐	☐	☐	☐	☐	…has implemented an Environmental Management System e.g. ISO 14001	☐	☐	☐	☐	☐	☐	☐
☐	☐	☐	☐	☐	☐	☐	…has environmentally efficient transport	☐	☐	☐	☐	☐	☐	☐

25.

a) Does your local unit have an Environmental Management System (EMS) or is it in the process of being implemented?	*Answer this question if an EMS has been implemented or is being implemented.* **b) Which Environmental Managements System?**
☐ Yes, has been implemented ☐ Is being implemented ☐ No	☐ ISO 14001 ☐ EMAS ☐ Other:…………………………………………

26.

a) Is there, or are you developing, a corporate environmental policy at your local unit today?	*Answer this question if a corporate environmental policy exists or is being developed.* **b) Summarize briefly the environmental policy of your local unit (company) concerning transports**
☐ Yes, there is ☐ No, there is not ☐ We are currently developing ☐ Do not know	…………………………………………… …………………………………………… …………………………………………… ……………………………………………
Answer this question if a corporate environmental policy exists or is being developed. **c) To what extend does your environmental policy affect your transport today?**	*Answer this question if a corporate environmental policy exists or is being developed.* **d) If the environmental policy affects, please describe how.**
☐ To a very large extent ☐ To a large extent ☐ To a rather large extent ☐ To neither a large or small extent ☐ To a rather small extent ☐ To a small extent ☐ To a very small extent	…………………………………………… …………………………………………… …………………………………………… …………………………………………… ……………………………………………

27. **Do your customers have an environmental demand that affect your local unit's choice of transport?**

For your inbound transport:
☐ Yes
☐ No
☐ Do not know

If yes, which are your customers' requirements and how do they affect?
……………………………………………
……………………………………………
……………………………………………

For your outgoing transport:
☐ Yes
☐ No
☐ Do not know

If yes, which are your customers' requirements and how do they affect?
……………………………………………
……………………………………………

28. **Does your company put any tangible environmental requirements on your transports?**

For your inbound transport:
☐ Yes
☐ No
☐ Do not know

If yes, which are your company's requirements and how do they affect?
……………………………………………
……………………………………………
……………………………………………

For your outgoing transport:
☐ Yes
☐ No
☐ Do not know

If yes, which are your company's requirements and how do they affect?
……………………………………………
……………………………………………

29. **Which environmental effect, caused by your transport, do you consider to be the most negative**
……………………………………………………………………………………………
……………………………………………………………………………………………

30. Please state below what importance you believe the measures would have in reducing the environmental impact of your transport, and assess the possibility you believe exists to implementing the measures.

State your opinion about the importance/possibility of the measure with a mark on each 7-grade scale below, where 1 = very small importance /possibility and 7 = very large importance / possibility.

Importance to reduce environmental impact *Very small ← → Very large* 1 2 3 4 5 6 7	**Measure**	**Possibility to implement** *Very small ← → Very large* 1 2 3 4 5 6 7	*Already implemented*
☐ ☐ ☐ ☐ ☐ ☐ ☐	To appoint an environmental manager/department	☐ ☐ ☐ ☐ ☐ ☐ ☐	☐
☐ ☐ ☐ ☐ ☐ ☐ ☐	More education in environmental issues	☐ ☐ ☐ ☐ ☐ ☐ ☐	☐
☐ ☐ ☐ ☐ ☐ ☐ ☐	To get an Environmental Management System (EMS) certification	☐ ☐ ☐ ☐ ☐ ☐ ☐	☐
☐ ☐ ☐ ☐ ☐ ☐ ☐	To publish Corporate Environmental Reports	☐ ☐ ☐ ☐ ☐ ☐ ☐	☐
☐ ☐ ☐ ☐ ☐ ☐ ☐	Increased support for environmental priorities from Senior Management	☐ ☐ ☐ ☐ ☐ ☐ ☐	☐
1 2 3 4 5 6 7		1 2 3 4 5 6 7	
☐ ☐ ☐ ☐ ☐ ☐ ☐	To implement a Corporate Environmental Policy in our company	☐ ☐ ☐ ☐ ☐ ☐ ☐	☐
☐ ☐ ☐ ☐ ☐ ☐ ☐	Increased co-operation with the person responsible for environmental issues in our company	☐ ☐ ☐ ☐ ☐ ☐ ☐	☐
☐ ☐ ☐ ☐ ☐ ☐ ☐	Increased co-operation in environmental issues with transport provider/ forwarder	☐ ☐ ☐ ☐ ☐ ☐ ☐	☐
☐ ☐ ☐ ☐ ☐ ☐ ☐	Increased co-operation in environmental issues with customers	☐ ☐ ☐ ☐ ☐ ☐ ☐	☐
☐ ☐ ☐ ☐ ☐ ☐ ☐	Increased co-operation in environmental issues with suppliers	☐ ☐ ☐ ☐ ☐ ☐ ☐	☐
1 2 3 4 5 6 7		1 2 3 4 5 6 7	
☐ ☐ ☐ ☐ ☐ ☐ ☐	Put stricter environmental demands on our suppliers' transport to us	☐ ☐ ☐ ☐ ☐ ☐ ☐	☐
☐ ☐ ☐ ☐ ☐ ☐ ☐	Other, please specify………………………	☐ ☐ ☐ ☐ ☐ ☐ ☐	☐
Very small ← → Very large	**The questions below concerns only your outgoing transports**	*Very small ← → Very large*	
1 2 3 4 5 6 7	**Measure**	1 2 3 4 5 6 7	
☐ ☐ ☐ ☐ ☐ ☐ ☐	To use trucks equipped with engines of high environmental standards	☐ ☐ ☐ ☐ ☐ ☐ ☐	☐
☐ ☐ ☐ ☐ ☐ ☐ ☐	Put stricter environmental demands on our outbound transports	☐ ☐ ☐ ☐ ☐ ☐ ☐	☐
☐ ☐ ☐ ☐ ☐ ☐ ☐	To use other alternative fuels than diesel e.g. bio-fuels, gas	☐ ☐ ☐ ☐ ☐ ☐ ☐	☐
☐ ☐ ☐ ☐ ☐ ☐ ☐	To reduce empty loads/to increase return transports of freight through e.g. shared deliveries with other companies	☐ ☐ ☐ ☐ ☐ ☐ ☐	☐
☐ ☐ ☐ ☐ ☐ ☐ ☐	To increase the load factor of goods	☐ ☐ ☐ ☐ ☐ ☐ ☐	☐
1 2 3 4 5 6 7		1 2 3 4 5 6 7	
☐ ☐ ☐ ☐ ☐ ☐ ☐	To transport more of our freight on rail	☐ ☐ ☐ ☐ ☐ ☐ ☐	☐
☐ ☐ ☐ ☐ ☐ ☐ ☐	To use more intermodal freight transports truck-rail	☐ ☐ ☐ ☐ ☐ ☐ ☐	☐
☐ ☐ ☐ ☐ ☐ ☐ ☐	Other, please specify………………………	☐ ☐ ☐ ☐ ☐ ☐ ☐	☐

Comments:……………………………………………………………………………………………………

Thank you for your participation!

Please put the filled in survey in the enclosed post-paid envelope and return it to us.
Address: Bernt Saxin, Handelshögskolan vid Göteborgs universitet, Box 610, 405 30 Göteborg.

Appendix 13 Output Data

List of train routes and demand transported per day

Train route number	From / To terminal	From / To terminal	Train departures	Distance (km)	Combined transport				Direct road transport		Total	
					Tonne	Tonnekm	Of which tonnekm		Tonne	Tonnekm	Tonne	Tonnekm
							road part	rail part				
1	Borlänge	Gävle	No traffic	115	0	0	0	0	1 400	117 600	1 400	117 600
2	Borlänge	Göteborg	Morning, evening	452	2 400	1 105 200	33 000	1 072 100	2 200	946 700	4 600	2 051 900
3	Borlänge	Hallsberg	Lunch	193	1 400	301 000	38 000	263 100	1 100	200 900	2 500	501 900
4	Borlänge	Helsingborg	Morning, evening	640	1 800	1 146 900	20 500	1 126 400	300	163 100	2 000	1 310 000
5	Borlänge	Jönköping	No traffic	406	0	0	0	0	1 400	534 900	1 400	534 900
6	Borlänge	Luleå	Lunch	1029	700	786 200	34 000	752 200	400	278 100	1 100	1 064 300
7	Borlänge	Malmö	Morning, evening	645	800	519 100	14 100	505 000	100	65 000	900	584 100
8	Borlänge	Norrköping	Lunch	281	700	247 000	41 600	205 400	100	49 500	900	296 500
9	Borlänge	Stockholm	Lunch	226	2 400	572 600	40 300	532 200	1 200	193 800	3 500	766 400
10	Borlänge	Sundsvall	Lunch	333	1 000	356 600	31 200	325 300	300	100 500	1 300	457 100
11	Borlänge	Trelleborg	Morning, evening	676	4 500	3 008 900	0	3 008 900	600	392 400	5 000	3 401 300
12	Borlänge	Umeå	No traffic	741	0	0	0	0	600	300 000	600	300 000
13	Borlänge	Älmhult	Morning, evening	511	800	459 500	66 600	393 000	200	89 300	900	548 800
14	Gävle	Göteborg	Morning, evening	512	2 400	1 252 300	25 100	1 227 300	400	212 500	2 800	1 464 800
15	Gävle	Hallsberg	Lunch	253	1 300	400 500	78 400	322 100	200	44 400	1 400	444 900
16	Gävle	Helsingborg	Morning, evening	699	1 000	708 700	16 000	692 700	200	123 900	1 200	832 600
17	Gävle	Jönköping	Morning, evening	466	600	305 000	34 500	270 400	500	218 400	1 100	523 400

18	Gävle	Luleå	Lunch	932	500	451 400	29 200	422 200	400	250 600	800	702 000
19	Gävle	Malmö	Lunch	705	300	181 900	0	181 900	200	151 100	500	333 000
20	Gävle	Norrköping	Lunch	311	700	236 000	30 100	205 900	100	37 600	800	273 600
21	Gävle	Stockholm	Lunch	180	3 300	622 600	27 900	594 700	3 400	497 700	6 700	1 120 300
22	Gävle	Sundsvall	Lunch	221	600	162 700	24 600	138 100	900	190 900	1 500	353 600
23	Gävle	Trelleborg	Morning, evening	736	1 100	829 500	0	829 500	1 000	713 500	2 100	1 543 000
24	Gävle	Umeå	No traffic	644	0	0	0	0	600	280 000	600	280 000
25	Gävle	Älmhult	Morning, evening	571	1 100	748 900	124 800	624 100	100	87 300	1 200	836 200
26	Göteborg	Hallsberg	Lunch	259	4 900	1 628 800	371 600	1 257 200	4 800	1 188 400	9 600	2 817 200
27	Göteborg	Helsingborg	Lunch	241	7 300	1 885 600	122 400	1 763 200	4 300	738 700	11 700	2 624 300
28	Göteborg	Jönköping	Lunch	184	1 600	387 500	102 300	285 200	8 500	1 336 000	10 100	1 723 500
29	Göteborg	Luleå	Lunch	1426	4 500	6 777 400	308 800	6 468 700	1 000	1 137 900	5 500	7 915 300
30	Göteborg	Malmö	Lunch	297	4 000	1 261 300	84 600	1 176 700	1 200	312 400	5 200	1 573 700
31	Göteborg	Norrköping	Lunch	373	4 700	1 975 100	220 900	1 754 200	2 700	740 900	7 400	2 716 000
32	Göteborg	Stockholm	Morning, evening	456	9 300	4 744 700	523 500	4 221 200	8 500	3 534 100	17 800	8 278 800
33	Göteborg	Sundsvall	Morning, evening	730	3 300	2 609 400	223 700	2 385 600	1 900	1 328 500	5 200	3 937 900
34	Göteborg	Trelleborg	Morning, evening	327	7 500	2 646 200	202 900	2 443 300	5 600	1 812 300	13 100	4 458 500
35	Göteborg	Umeå	Lunch	1137	2 800	3 331 500	149 000	3 182 500	1 100	970 700	3 900	4 302 200
36	Göteborg	Älmhult	Lunch	270	7 500	2 645 600	623 100	2 022 600	4 400	1 091 100	11 800	3 736 700
37	Hallsberg	Helsingborg	Morning, evening	447	1 600	870 300	146 200	724 100	1 500	600 700	3 100	1 471 000
38	Hallsberg	Jönköping	No traffic	214	0	0	0	0	4 100	858 100	4 100	858 100
39	Hallsberg	Luleå	Lunch	1167	2 400	3 015 700	192 700	2 823 000	400	358 900	2 800	3 374 600
40	Hallsberg	Malmö	Morning, evening	453	1 600	865 200	132 300	733 000	700	344 600	2 300	1 209 800
41	Hallsberg	Norrköping	No traffic	114	0	0	0	0	2 600	409 200	2 600	409 200
42	Hallsberg	Stockholm	Lunch	197	4 600	1 100 300	193 900	906 400	5 700	1 039 000	10 300	2 139 300

43	Hallsberg	Sundsvall	Morning, evening	471	1 700	1 017 700	216 100	801 600	600	292 100	2 300	1 309 800
44	Hallsberg	Trelleborg	Morning, evening	483	4 000	2 227 100	273 800	1 953 300	800	404 600	4 800	2 631 700
45	Hallsberg	Umeå	Morning, evening	878	1 000	986 000	105 400	880 600	400	289 800	1 400	1 275 800
46	Hallsberg	Älmhult	Lunch	319	1 500	701 900	222 100	479 800	900	342 400	2 400	1 044 300
47	Helsingborg	Jönköping	Lunch	277	2 800	952 900	177 600	775 300	3 400	697 400	6 200	1 650 300
48	Helsingborg	Luleå	Lunch	1614	600	1 008 100	48 700	959 400	1 200	1 634 900	1 800	2 643 000
49	Helsingborg	Malmö	No traffic	66	0	0	0	0	4 200	313 300	4 200	313 300
50	Helsingborg	Norrköping	Morning, evening	430	1 400	691 800	74 300	617 500	1 400	472 200	2 800	1 164 000
51	Helsingborg	Stockholm	Morning, evening	592	7 800	4 964 300	364 400	4 599 800	2 700	1 279 800	10 500	6 244 100
52	Helsingborg	Sundsvall	Morning, evening	917	1 500	1 498 300	99 000	1 399 300	400	292 900	1 900	1 791 200
53	Helsingborg	Trelleborg	Lunch	96	5 500	702 200	170 100	532 100	5 300	574 700	10 800	1 276 900
54	Helsingborg	Umeå	Lunch	1325	1 100	1 565 900	48 800	1 517 100	200	197 300	1 300	1 763 200
55	Helsingborg	Älmhult	Lunch	128	800	172 500	70 200	102 300	5 600	871 600	6 400	1 044 100
56	Jönköping	Luleå	Lunch	1380	1 800	2 741 900	205 400	2 536 400	600	625 700	2 400	3 367 600
57	Jönköping	Malmö	Lunch	305	1 500	534 000	81 700	452 300	1 500	409 800	3 000	943 800
58	Jönköping	Norrköping	No traffic	211	0	0	0	0	2 900	481 700	2 900	481 700
59	Jönköping	Stockholm	Lunch	373	4 500	1 922 600	257 200	1 665 400	5 600	1 724 400	10 000	3 647 000
60	Jönköping	Sundsvall	Morning, evening	684	1 400	1 122 800	180 900	941 900	600	373 600	2 000	1 496 400
61	Jönköping	Trelleborg	Lunch	336	3 500	1 431 900	258 900	1 173 000	1 800	515 100	5 300	1 947 000
62	Jönköping	Umeå	Lunch	1092	1 000	1 222 300	77 800	1 144 400	600	475 900	1 600	1 698 200
63	Jönköping	Älmhult	Lunch	171	800	227 700	90 900	136 800	4 600	761 300	5 400	989 000
64	Luleå	Malmö	Lunch	1619	400	745 700	31 000	714 700	600	901 200	1 100	1 646 900
65	Luleå	Norrköping	Lunch	1225	800	1 097 400	69 600	1 027 800	100	111 600	1 000	1 209 000
66	Luleå	Stockholm	Lunch	1112	4 800	5 500 600	188 600	5 312 000	1 000	863 900	5 800	6 364 500
67	Luleå	Sundsvall	Morning, evening	711	1 300	1 018 800	111 600	907 200	1 600	744 000	2 900	1 762 800

68	Luleå	Trelleborg	Morning, evening	1650	3 900	6 539 000	28 300	6 510 800	3 200	4 684 200	7 200	11 223 300
69	Luleå	Umeå	Lunch	351	1 400	516 000	19 700	496 300	1 600	280 800	3 000	796 800
70	Luleå	Älmhult	Lunch	1485	600	1 010 600	82 600	928 000	900	1 187 600	1 600	2 198 200
71	Malmö	Norrköping	Morning, evening	436	1 000	471 500	44 200	427 300	700	283 700	1 700	755 200
72	Malmö	Stockholm	Morning, evening	598	4 600	2 890 200	148 300	2 741 800	1 000	562 700	5 600	3 452 900
73	Malmö	Sundsvall	Evening	923	800	740 900	33 800	707 000	100	93 000	900	833 900
74	Malmö	Trelleborg	No traffic	34	0	0	0	0	2 400	79 300	2 400	79 300
75	Malmö	Umeå	Lunch	1331	800	1 054 600	33 700	1 020 900	100	115 000	900	1 169 600
76	Malmö	Älmhult	No traffic	134	0	0	0	0	5 000	749 100	5 000	749 100
77	Norrköping	Stockholm	Lunch	162	3 200	643 400	127 600	515 800	3 800	637 600	7 000	1 281 000
78	Norrköping	Sundsvall	Morning, evening	529	1 600	966 100	140 800	825 200	400	221 200	2 000	1 187 300
79	Norrköping	Trelleborg	Morning, evening	466	1 600	835 300	69 400	765 900	1 900	814 100	3 500	1 649 400
80	Norrköping	Umeå	Morning, evening	937	400	398 200	23 400	374 800	400	295 600	800	693 800
81	Norrköping	Älmhult	Lunch	301	1 200	508 800	135 000	373 800	1 100	256 200	2 300	765 000
82	Stockholm	Sundsvall	Lunch	401	2 700	1 233 100	135 900	1 097 100	1 700	688 700	4 400	1 921 800
83	Stockholm	Trelleborg	Morning, evening	628	5 300	3 476 100	140 800	3 335 300	1 100	626 500	6 400	4 102 600
84	Stockholm	Umeå	Morning, evening	824	1 800	1 595 900	89 600	1 506 300	1 400	828 200	3 200	2 424 100
85	Stockholm	Älmhult	Morning, evening	464	5 000	2 817 300	505 700	2 311 600	3 200	1 273 300	8 200	4 090 600
86	Sundsvall	Trelleborg	Evening	954	5 500	5 419 100	155 900	5 263 200	700	666 000	6 200	6 085 100
87	Sundsvall	Umeå	Lunch	423	1 400	616 000	3 500	612 500	1 500	353 800	2 900	969 800
88	Sundsvall	Älmhult	Morning, evening	789	1 200	1 113 800	166 300	947 600	600	417 200	1 800	1 531 000
89	Trelleborg	Umeå	Lunch	1361	500	687 100	17 500	669 600	100	75 600	600	762 700
90	Trelleborg	Älmhult	Lunch	165	3 300	846 300	297 200	549 100	3 800	591 300	7 100	1 437 600
91	Älmhult	Umeå	Lunch	1196	1 700	2 181 500	180 600	2 000 900	300	275 400	1 900	2 456 900
				Total (in thousands):	198	120 762	10 312	110 450	162	55 748	360	176 511

Costs per day in thousands SEK and emissions

Train route number	Business economic cost				Societal cost				CO_2 kg	CO kg	SO_2 grams	NO_x kg	PM grams	HC grams	Energy GJ	Monetary estimation of emissions
	Cost combined transport	Of which rail part	Of which road part	Direct road	Cost combined transport	Of which rail part	Of which road part	Direct road								
1	0	0	0	31	0	0	0	40	4 509	4	10	4 509	480	2 400	60	9
2	140	128	12	280	147	132	15	357	41 309	40	4 160	41 309	4 570	21 100	738	79
3	61	48	13	73	66	50	16	93	12 336	14	1 000	12 336	1 540	6 800	209	23
4	134	129	6	53	140	133	7	68	10 048	11	4 250	10 048	1 320	5 000	323	19
5	0	0	0	151	0	0	0	193	21 084	19	30	21 084	2 210	11 000	283	41
6	111	98	13	105	118	101	17	134	17 978	18	3 680	17 978	2 120	9 100	404	34
7	95	89	6	27	99	91	7	35	5 584	6	2 310	5 584	760	2 800	178	11
8	53	39	14	18	58	40	17	23	4 880	6	930	4 880	680	2 700	107	9
9	112	97	15	69	119	100	19	88	13 108	17	2 220	13 108	1 940	7 700	274	25
10	61	51	10	39	66	52	13	50	7 553	9	1 370	7 553	1 040	4 200	162	14
11	290	290	0	108	299	299	0	139	18 282	15	10 290	18 282	2 030	7 500	703	35
12	2	2	0	123	2	2	0	157	16 375	15	20	16 375	1 670	8 300	220	32
13	101	77	24	48	110	79	30	61	10 770	13	1 940	10 770	1 450	5 900	231	20
14	172	163	9	72	179	168	11	92	13 192	14	5 090	13 192	1 710	6 500	403	25
15	80	55	25	20	89	56	32	25	6 761	8	1 310	6 761	940	3 800	149	13
16	111	106	5	46	116	109	6	59	8 340	9	3 070	8 340	1 070	4 100	248	16
17	67	55	12	86	72	56	15	109	14 000	15	1 240	14 000	1 660	7 500	243	27
18	78	68	10	81	82	70	12	103	13 549	13	2 110	13 549	1 550	6 900	275	26
19	41	41	0	40	42	42	0	50	6 136	6	840	6 136	700	3 200	119	12
20	42	34	8	14	46	35	11	17	3 326	4	760	3 326	450	1 800	79	6

21	113	103	10	146	119	106	13	186	23 367	25	2 060	23 367	2 910	12 900	403	45
22	39	31	8	66	42	32	10	84	10 595	11	630	10 595	1 250	5 700	170	20
23	117	117	0	210	120	120	0	268	29 097	26	3 640	29 097	3 010	14 100	553	56
24	0	0	0	89	0	0	0	114	12 472	11	20	12 472	1 310	6 500	167	24
25	141	101	40	51	155	104	51	66	13 999	16	2 920	13 999	1 890	7 600	317	26
26	286	177	108	373	321	183	138	475	67 923	69	4 450	67 923	7 850	36 000	1 107	130
27	310	272	38	216	329	281	48	275	37 995	40	6 720	37 995	4 680	20 000	807	72
28	86	54	32	411	96	55	41	523	61 391	59	1 110	61 391	6 720	32 300	870	118
29	792	695	97	414	843	719	124	528	81 119	75	29 030	81 119	9 330	37 800	2 375	155
30	196	168	29	102	210	173	36	130	20 659	24	4 510	20 659	2 830	11 400	476	39
31	265	201	64	212	289	207	82	270	40 786	41	6 090	40 786	4 820	21 200	816	78
32	620	455	165	1 037	681	470	211	1 320	173 070	170	15 320	173 070	19 650	90 300	2 994	332
33	408	320	89	433	443	330	113	551	76 533	75	11 780	76 533	8 790	39 000	1 547	146
34	382	326	55	508	407	336	71	650	78 193	71	9 290	78 193	8 200	38 300	1 462	150
35	420	361	60	344	450	373	76	438	62 890	61	14 930	62 890	7 310	31 200	1 503	120
36	482	289	194	376	545	297	248	479	82 042	86	7 440	82 042	9 820	43 900	1 428	156
37	149	105	44	187	164	108	56	238	33 520	33	3 140	33 520	3 860	17 600	587	64
38	0	0	0	260	0	0	0	331	36 412	33	50	36 412	3 830	19 000	488	70
39	335	267	68	146	364	276	87	186	34 284	34	11 550	34 284	4 150	16 600	972	65
40	146	103	43	117	162	107	55	149	23 531	25	3 030	23 531	2 820	12 400	450	45
41	0	0	0	117	0	0	0	148	16 576	15	20	16 576	1 760	8 700	222	32
42	231	163	68	306	254	167	87	388	54 823	60	3 400	54 823	6 790	30 300	883	105
43	198	122	76	127	223	126	97	163	29 713	32	3 800	29 713	3 650	15 900	567	56
44	281	207	74	126	308	213	95	161	29 625	27	6 940	29 625	3 260	14 200	706	57
45	186	144	42	120	202	148	53	153	24 455	25	4 770	24 455	2 950	12 600	539	47

46	135	70	65	134	155	72	83	171	28 603	32	1 830	28 603	3 610	15 900	464	54
47	170	115	54	210	188	119	69	267	38 802	41	2 970	38 802	4 710	21 100	650	74
48	137	121	17	486	146	125	21	619	70 526	65	4 410	70 526	7 540	36 000	1 140	136
49	0	0	0	79	0	0	0	100	11 207	10	10	11 207	1 190	5 900	150	22
50	110	88	22	143	118	90	28	182	24 068	24	2 410	24 068	2 800	12 700	429	46
51	648	532	116	421	698	550	148	536	82 770	84	19 120	82 770	9 990	42 100	1 955	158
52	227	186	41	135	245	192	53	173	27 427	29	6 960	27 427	3 450	14 100	676	52
53	174	129	45	157	190	133	57	201	27 717	26	1 660	27 717	2 940	14 000	446	53
54	184	157	27	96	197	162	34	123	19 852	21	7 140	19 852	2 510	9 800	583	38
55	52	29	23	261	59	30	29	332	40 040	39	450	40 040	4 420	21 300	554	77
56	372	292	80	280	405	303	102	356	54 517	54	12 720	54 517	6 420	27 300	1 295	104
57	93	66	27	122	103	68	35	155	22 425	24	1 730	22 425	2 740	12 300	376	43
58	0	0	0	137	0	0	0	174	19 379	18	30	19 379	2 060	10 200	259	38
59	295	209	86	549	326	216	110	698	92 010	93	6 410	92 010	10 710	49 100	1 513	176
60	237	155	82	217	265	160	105	277	43 414	46	5 570	43 414	5 240	22 900	829	82
61	203	132	71	156	227	136	91	200	32 011	31	3 830	32 011	3 520	16 100	599	61
62	172	132	40	235	187	137	51	299	39 804	39	5 760	39 804	4 540	20 300	789	76
63	58	31	27	237	67	32	35	302	36 854	35	570	36 854	4 020	19 400	518	71
64	120	110	9	256	126	114	12	326	39 028	36	3 610	39 028	4 270	20 000	681	75
65	142	122	20	55	152	126	25	71	12 408	13	4 840	12 408	1 600	6 100	381	23
66	470	409	61	274	502	425	78	349	53 556	50	18 320	53 556	6 270	25 500	1 531	103
67	182	135	47	221	199	139	60	281	39 711	39	4 560	39 711	4 600	20 800	733	76
68	476	468	8	1 300	495	485	10	1 662	180 849	161	21 070	180 849	18 630	87 900	3 365	347
69	71	64	7	94	75	66	9	119	14 997	16	1 860	14 997	1 830	8 000	283	29
70	174	131	42	422	190	136	54	537	66 537	64	5 390	66 537	7 380	34 400	1 129	128

71	88	73	15	87	94	75	19	110	14 933	15	1 840	14 933	1 740	7 800	281	29
72	356	308	49	208	380	318	62	265	40 607	44	10 970	40 607	5 210	21 100	1 030	77
73	99	86	13	50	105	89	17	64	9 816	10	3 050	9 816	1 240	4 900	267	19
74	0	0	0	24	0	0	0	30	3 128	3	0	3 128	320	1 600	42	6
75	124	114	10	47	131	118	13	60	9 659	10	4 330	9 659	1 230	4 600	322	18
76	0	0	0	226	0	0	0	287	31 712	29	40	31 712	3 350	16 600	425	61
77	139	100	39	183	153	103	50	233	32 636	35	1 870	32 636	3 970	18 000	518	62
78	162	118	44	76	178	121	56	97	18 118	19	3 810	18 118	2 220	9 300	412	34
79	111	93	19	224	119	95	24	287	33 192	30	2 930	33 192	3 420	16 300	576	64
80	82	71	11	119	87	73	14	151	18 767	18	2 250	18 767	2 090	9 600	351	36
81	95	54	40	80	108	56	52	102	17 104	18	1 450	17 104	2 020	9 100	293	33
82	183	137	46	243	200	141	58	310	42 248	43	4 310	42 248	5 000	22 400	756	81
83	380	342	39	181	402	353	49	232	33 808	30	11 880	33 808	3 720	15 300	982	65
84	217	185	32	263	232	191	41	334	44 743	44	7 120	44 743	5 220	23 100	913	86
85	452	285	167	483	508	295	213	616	93 755	97	9 390	93 755	11 110	49 700	1 671	179
86	537	490	47	198	567	507	60	253	39 944	34	19 290	39 944	4 470	17 200	1 393	76
87	75	71	4	130	78	73	5	166	19 709	19	2 260	19 709	2 260	10 300	364	38
88	270	173	97	223	303	179	124	285	46 619	48	6 520	46 619	5 540	24 300	914	89
89	97	91	6	39	102	94	8	50	7 241	7	2 940	7 241	880	3 400	228	14
90	175	96	78	168	199	99	100	215	33 720	32	1 820	33 720	3 630	17 200	533	65
91	341	256	85	197	374	266	109	252	42 449	44	10 860	42 449	5 210	21 400	1 052	80
Total:	16 819	13 377	3 444	18 104	18 212	13 808	4 393	23 076	3 156 614	3 126	455 000	3 156 614	364 000	1 620 000	62 465	6 038

Reason for modal split in percent of input demand and number of lorries (per average day) and load factor

Train route number	Reason for modal split: Direct road transport: Combined transport cannot meet time constraints	Reason for modal split: Direct road transport: Economic constraints	Reason for modal split: Direct road transport: No combined transport allowed	Reason for modal split: Combined transport	Combined transport 25.25 m No	Combined transport 25.25 m Load factor	Combined transport Trailer No	Combined transport Trailer Load factor	Combined transport 40 foot No	Combined transport 40 foot Load factor	Direct road 25.25 m No	Direct road 25.25 m Load factor	Direct road Trailer No	Direct road Trailer Load factor	Direct road 40 foot No	Direct road 40 foot Load factor
1			100%								37	83%	7	69%		
2	43.01%	5.32%		51.68%	3	88%	34	84%	63	97%	18	82%	35	68%	41	96%
3	13.63%	31.56%		54.80%			36	85%	25	97%	15	84%	39	61%	1	100%
4	13.89%			86.11%	2	92%	30	90%	41	98%	4	93%	9	60%		
5			100%								24	84%	28	77%	4	100%
6	33.00%			67.00%	1	81%	27	77%	8	98%	7	84%	11	36%	1	100%
7	11.53%			88.47%			31	81%	7	98%	2	96%	4	25%		
8	16.74%			83.26%	1	86%	36	81%			2	86%	6	52%		
9	19.08%	14.15%		66.77%	7	86%	53	80%	51	84%	25	81%	21	56%	6	46%
10	23.01%			76.99%	4	89%	31	84%	9	96%	2	90%	14	55%	1	100%
11	11.63%			88.37%					175	98%			24	98%		
12	43.93%	56.07%									3	81%	31	60%		
13	18.28%			81.72%	5	88%	29	73%	4	97%	2	84%	11	38%		
14	15.03%			84.97%	4	80%	22	80%	75	95%	2	94%	9	48%	10	92%
15	11.60%			88.40%			53	80%	10	97%	1	80%	10	54%		
16	16.02%			83.98%	2	78%	33	83%	11	97%	2	88%	8	60%		
17	46.32%			53.68%	2.33	81%	22.33	78%	3.67	98%	6.33	75%	21.33	58%		
18	45.02%			54.98%			15	78%	7	96%	8	87%	8	47%		

19	45.11%			54.89%			12	90%			6	80%	1	80%		
20	11.50%	5.75%		82.75%	2	86%	16	97%	9	97%			8	69%		
21	22.84%	28.06%		49.10%	2	82%	31	77%	110	93%	77	84%	45	60%	9	71%
22	30.06%	27.91%		42.03%	4	89%	23	85%	1	100%	11	81%	32	60%	1	100%
23	44.95%	1.15%		53.90%					44	99%			42	92%		
24			100%								12	82%	16	59%		
25	11.57%			88.43%	10	85%	34	74%	7	98%	2	69%	10	35%		
26	13.35%	36.33%		50.32%	8	89%	102	88%	101	93%	58	83%	86	62%	64	93%
27	19.71%	17.55%		62.73%	4	90%	87	86%	214	97%	48	86%	73	67%	60	95%
28	31.03%	53.62%		15.35%	3	89%	29	81%	38	90%	113	83%	141	69%	101	89%
29	17.77%	0.01%		82.22%	6.03	88%	67.03	79%	126.17	93%	10.97	78%	18.97	35%	20.83	87%
30	11.64%	11.52%		76.84%	5	81%	85	83%	87	93%	26	80%	24	49%	3	85%
31	18.84%	17.21%		63.94%	6	88%	74	85%	118	98%	41	89%	36	64%	25	95%
32	41.46%	6.38%		52.15%	14	84%	143	80%	253	93%	135	87%	104	55%	105	86%
33	35.69%	0.89%		63.42%	5	91%	94	75%	61	89%	26	90%	32	39%	28	88%
34	42.98%			57.02%	1	78%	27	89%	268	99%	1	70%	233	96%		
35	13.86%	13.65%		72.49%	4	88%	55	71%	77	87%	22	89%	26	37%	3	51%
36	12.70%	24.06%		63.24%	17	86%	109	76%	205	93%	74	80%	104	55%	26	82%
37	42.38%	4.97%		52.65%	3	93%	39	78%	32	95%	26	85%	36	63%		
38			100%								83	79%	77	68%	5	100%
39	11.66%	2.07%		86.27%	5	75%	62	75%	46	97%	4	78%	18	52%	1	100%
40	30.85%			69.15%	1	78%	46	77%	30	95%	13	88%	21	51%		
41			100%								58	82%	40	63%	2	100%
42	17.45%	37.87%		44.68%	19	89%	61	76%	126	87%	118	86%	96	63%	9	48%
43	25.39%	1.63%		72.98%	9	86%	65	68%	14	98%	8	82%	32	46%		

44	12.26%	3.70%		84.04%	1	84%	16	91%	145	97%	1	73%	35	84%		
45	29.27%			70.73%	3	88%	42	70%	8	98%	9	79%	15	35%		
46	18.92%	19.08%		62.00%	19	86%	34	83%	9	97%	12	83%	37	54%	1	100%
47	14.48%	40.70%		44.83%	9	89%	75	81%	41	97%	72	84%	55	61%	8	100%
48	66.46%	0.68%		32.86%	3.98	84%	11.10	73%	11.10	96%	13.97	85%	36.85	80%		
49			100%								89	89%	52	82%		
50	42.94%	5.62%		51.43%	3	98%	22	74%	37	97%	25	82%	30	71%		
51	20.46%	5.65%		73.89%	9	87%	128	76%	214	92%	46	89%	63	56%	17	53%
52	15.14%	3.77%		81.08%	10	84%	57	69%	11	96%	6	83%	17	37%		
53	35.36%	13.29%		51.35%					216	99%	10	85%	203	97%		
54	11.44%	2.41%		86.16%	2	88%	53	63%	11	95%	3	80%	10	35%		
55	29.24%	58.24%		12.52%	2	86%	18	73%	17	95%	110	83%	109	66%	5	100%
56	11.65%	12.43%		75.92%	7	89%	85	71%	6	97%	10	78%	26	42%		
57	11.62%	38.89%		49.50%	6	92%	46	80%	16	95%	39	79%	19	53%	1	100%
58			100%								68	85%	33	63%	3	100%
59	32.59%	22.96%		44.45%	8	88%	70	71%	133	87%	119	85%	92	53%	33	39%
60	25.04%	4.60%		70.36%	6	91%	74	59%	5	96%	5	75%	45	38%		
61	14.30%	20.21%		65.50%	1	95%	25	89%	117	96%	5	78%	76	89%		
62	16.09%	18.82%		65.09%	1	89%	56	64%	6	97%	9	87%	31	32%		
63	31.90%	53.33%		14.77%	3	78%	30	92%	2	96%	81	83%	101	70%	7	100%
64	58.30%	0.56%		41.14%	3.97	91%	13.12	82%	2.03	96%	13.98	80%	9.9	75%		
65	11.68%			88.32%	9	89%	26	83%	1	96%	1	83%	6	35%	1	100%
66	17.68%			82.32%	1	97%	66	80%	139	96%	18	85%	14	43%	12	85%
67	47.79%	7.53%		44.68%	6	83%	48	68%	12	98%	37	88%	23	49%		
68	44.54%	0.52%		54.94%	0.02	84%	4	86%	151.08	98%	2	81%	130.88	97%		

69	31.47%	21.10%		47.43%	2	81%	45	88%	16	97%	35	81%	31	53%	1	100%
70	58.64%	1.38%		39.98%	8.93	87%	29.60	44%	1	96%	17.28	88%	26.98	42%	2	100%
71	41.53%			58.47%			20	79%	24	96%	13	87%	16	61%		
72	12.87%	5.32%		81.82%	6	83%	86	79%	120	89%	17	91%	33	43%	4	46%
73	11.55%			88.45%	2	80%	27	78%	8	96%			8	50%		
74			100%										103	92%		
75	11.64%			88.36%	3	83%	26	84%	6	97%	1	78%	5	56%		
76			100%								104	86%	81	60%	8	99%
77	19.89%	34.37%		45.75%	2	78%	43	77%	98	92%	84	87%	53	54%	8	67%
78	19.15%	2.02%		78.83%	3	79%	52	86%	16	96%	5	93%	14	59%	1	100%
79	53.38%			46.62%			5.33	96%	60	97%			77	98%		
80	33.80%	15.57%		50.63%	1	73%	18	69%	3	94%	7	78%	14	42%	1	100%
81	16.96%	29.43%		53.60%	2	84%	42	89%	11	98%	12	84%	31	73%	4	100%
82	33.51%	4.97%		61.52%	1	92%	69	83%	61	83%	36	85%	40	45%	6	30%
83	16.05%	0.57%		83.39%			3	60%	206	98%	2	88%	43	92%		
84	30.61%	12.36%		57.04%	2	80%	57	81%	31	82%	35	81%	21	46%	1	12%
85	31.02%	8.19%		60.79%	19	89%	153	84%	68	71%	50	84%	106	49%	25	36%
86	11.60%			88.40%	1	95%	8	36%	214	97%			32	91%		
87	36.77%	14.11%		49.12%			48	85%	19	95%	33	79%	39	44%	1	100%
88	25.39%	6.10%		68.51%	4	85%	70.67	46%	12	96%	8.67	84%	33	32%		
89	11.67%			88.33%	1	86%	23	83%					5	52%		
90	19.79%	33.37%		46.84%	10	98%	9	98%	110	96%	1	88%	158	95%		
91	13.36%			86.64%	8	87%	87	63%	4	96%			28	37%		
Total:	23.84%	14.37%	6.82%	54.97%	349.27	87%	3634.18	77%	4855.05	94%	3672.20	84%	4770.92	68%	1126.83	87%

Time adjustment (earlier departure + later delivery) in hours and share of combined transport per train route[155]

Train route number	0 - 1	1 - 2	2 - 3	3-4	4 - 5	5 - 6	6 - 7	7 - 8	8 - 9	9 - 10	10 - 11	11 - 12	12 - 13	13 - 14
2	48%	2%	35%	11%	1%	2%	0%	0%	0%	0%	0%	0%	0%	0%
3	22%	15%	0%	0%	62%	1%	0%	0%	0%	0%	0%	0%	0%	0%
4	33%	0%	0%	26%	3%	2%	0%	30%	4%	2%	0%	0%	0%	0%
6	36%	0%	0%	0%	25%	5%	0%	7%	21%	6%	0%	0%	0%	0%
7	30%	0%	5%	28%	2%	0%	0%	33%	3%	0%	0%	0%	0%	0%
8	24%	11%	2%	0%	42%	20%	0%	0%	0%	0%	0%	0%	0%	0%
9	33%	3%	0%	1%	62%	1%	0%	0%	0%	0%	0%	0%	0%	0%
10	32%	0%	0%	1%	31%	31%	1%	4%	0%	0%	0%	0%	0%	0%
11	38%	0%	0%	27%	0%	0%	0%	35%	0%	0%	0%	0%	0%	0%
13	30%	3%	22%	10%	5%	0%	18%	11%	1%	0%	0%	0%	0%	0%
14	33%	3%	25%	4%	1%	0%	29%	3%	0%	0%	0%	0%	0%	0%
15	23%	11%	1%	5%	35%	24%	0%	0%	0%	0%	0%	0%	0%	0%
16	30%	0%	0%	27%	3%	2%	0%	30%	4%	3%	0%	0%	0%	0%
17	29%	9%	10%	33%	3%	4%	3%	9%	0%	0%	0%	0%	0%	0%
18	28%	0%	0%	0%	26%	6%	0%	40%	0%	0%	0%	0%	0%	0%
19	57%	0%	0%	0%	43%	0%	0%	0%	0%	0%	0%	0%	0%	0%
20	31%	0%	5%	0%	60%	5%	0%	0%	0%	0%	0%	0%	0%	0%
21	36%	1%	0%	1%	62%	0%	0%	0%	0%	0%	0%	0%	0%	0%
22	32%	10%	0%	0%	58%	0%	0%	0%	0%	0%	0%	0%	0%	0%

[155] Train routes with no combined transport excluded.

23	0%	0%	0%	43%	0%	0%	0%	57%	0%	0%	0%	0%	0%	0%
25	15%	10%	22%	11%	3%	3%	14%	13%	4%	4%	0%	0%	0%	0%
26	19%	15%	2%	13%	38%	11%	2%	0%	0%	0%	0%	0%	0%	0%
27	33%	3%	0%	2%	60%	2%	0%	0%	0%	0%	0%	0%	0%	0%
28	35%	13%	0%	13%	25%	14%	0%	0%	0%	0%	0%	0%	0%	0%
29	20%	0%	0%	0%	14%	2%	5%	2%	36%	4%	15%	1%	1%	0%
30	29%	7%	1%	2%	56%	6%	0%	0%	0%	0%	0%	0%	0%	0%
31	14%	2%	18%	3%	29%	22%	12%	0%	0%	0%	0%	0%	0%	0%
32	30%	6%	29%	22%	6%	4%	1%	1%	0%	0%	0%	0%	0%	0%
33	0%	3%	7%	22%	13%	6%	6%	22%	15%	5%	0%	0%	0%	0%
34	48%	18%	33%	2%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
35	25%	0%	0%	0%	14%	10%	14%	3%	23%	8%	3%	0%	0%	0%
36	14%	18%	1%	5%	38%	23%	0%	0%	0%	0%	0%	0%	0%	0%
37	34%	5%	14%	21%	22%	3%	0%	1%	0%	0%	0%	0%	0%	0%
39	21%	0%	0%	0%	8%	11%	8%	6%	21%	12%	7%	4%	1%	0%
40	34%	11%	27%	11%	0%	0%	7%	10%	0%	0%	0%	0%	0%	0%
42	37%	7%	0%	4%	48%	4%	0%	0%	0%	0%	0%	0%	0%	0%
43	21%	10%	17%	22%	6%	3%	6%	10%	5%	0%	0%	0%	0%	0%
44	26%	9%	25%	4%	0%	0%	32%	4%	0%	0%	0%	0%	0%	0%
45	0%	0%	0%	0%	7%	10%	17%	15%	4%	11%	22%	6%	5%	2%
46	11%	19%	7%	11%	37%	16%	0%	0%	0%	0%	0%	0%	0%	0%
47	26%	7%	3%	0%	31%	30%	3%	0%	0%	0%	0%	0%	0%	0%
48	1%	0%	0%	0%	0%	38%	2%	17%	27%	1%	15%	0%	0%	0%
50	33%	1%	18%	22%	21%	5%	0%	0%	0%	0%	0%	0%	0%	0%
51	33%	0%	2%	23%	4%	9%	1%	23%	1%	3%	0%	0%	0%	0%

52	21%	0%	2%	4%	19%	7%	6%	5%	20%	7%	3%	4%	2%	0%
53	43%	5%	0%	0%	47%	4%	0%	0%	0%	0%	0%	0%	0%	0%
54	29%	0%	0%	0%	17%	0%	6%	6%	28%	3%	8%	2%	1%	0%
55	16%	4%	10%	14%	50%	6%	0%	0%	0%	0%	0%	0%	0%	0%
56	21%	0%	0%	0%	0%	11%	11%	4%	8%	21%	16%	4%	3%	1%
57	25%	10%	3%	6%	44%	13%	0%	0%	0%	0%	0%	0%	0%	0%
59	13%	9%	11%	1%	39%	27%	0%	0%	0%	0%	0%	0%	0%	0%
60	5%	3%	2%	24%	9%	15%	8%	12%	9%	10%	2%	0%	0%	0%
61	27%	7%	10%	7%	24%	23%	3%	0%	0%	0%	0%	0%	0%	0%
62	26%	0%	0%	0%	14%	4%	12%	7%	20%	6%	10%	0%	0%	0%
63	30%	15%	0%	39%	14%	2%	0%	0%	0%	0%	0%	0%	0%	0%
64	1%	0%	0%	0%	0%	64%	12%	0%	23%	1%	0%	0%	0%	0%
65	16%	0%	0%	0%	18%	2%	8%	0%	38%	7%	9%	3%	0%	0%
66	29%	0%	0%	0%	20%	1%	5%	9%	30%	3%	3%	0%	0%	0%
67	1%	0%	0%	2%	7%	30%	17%	4%	5%	30%	0%	4%	0%	0%
68	56%	0%	0%	0%	0%	0%	0%	39%	4%	0%	0%	0%	0%	0%
69	31%	3%	0%	1%	29%	34%	1%	0%	0%	0%	0%	0%	0%	0%
70	0%	0%	0%	0%	14%	5%	33%	0%	25%	13%	10%	0%	0%	0%
71	37%	14%	13%	30%	2%	0%	3%	0%	0%	0%	0%	0%	0%	0%
72	29%	5%	6%	24%	0%	1%	1%	31%	3%	0%	0%	0%	0%	0%
73	0%	0%	4%	18%	4%	1%	5%	24%	5%	2%	5%	25%	5%	2%
75	21%	0%	0%	0%	13%	15%	0%	13%	27%	6%	0%	4%	0%	0%
77	33%	0%	1%	19%	47%	0%	0%	0%	0%	0%	0%	0%	0%	0%
78	27%	10%	12%	17%	7%	2%	7%	19%	0%	0%	0%	0%	0%	0%
79	16%	37%	0%	47%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%

80	0%	0%	0%	7%	3%	29%	3%	10%	0%	38%	0%	11%	0%	0%
81	3%	30%	3%	0%	45%	15%	4%	0%	0%	0%	0%	0%	0%	0%
82	28%	5%	5%	5%	46%	12%	0%	0%	0%	0%	0%	0%	0%	0%
83	28%	0%	6%	25%	4%	0%	0%	33%	5%	0%	0%	0%	0%	0%
84	0%	0%	0%	6%	5%	30%	10%	1%	2%	30%	6%	6%	4%	0%
85	19%	10%	22%	20%	6%	9%	9%	5%	0%	0%	0%	0%	0%	0%
86	0%	0%	0%	19%	8%	0%	1%	25%	10%	0%	1%	26%	11%	0%
87	34%	0%	0%	0%	29%	1%	36%	0%	0%	0%	0%	0%	0%	0%
88	4%	4%	9%	14%	11%	13%	7%	11%	7%	15%	3%	3%	0%	0%
89	27%	0%	0%	0%	18%	0%	0%	17%	26%	9%	0%	3%	0%	0%
90	22%	23%	8%	6%	31%	9%	0%	0%	0%	0%	0%	0%	0%	0%
91	14%	0%	0%	0%	14%	21%	10%	7%	20%	11%	2%	2%	0%	0%
Total:	26%	6%	7%	10%	21%	8%	4%	8%	5%	2%	1%	1%	0%	0%

Road transport distance (km) to and from terminal and share of combined transport per train route[156]

Train route number	**0 - 10**	**10 - 20**	**20 - 30**	**30 - 40**	**40 - 50**	**50 - 60**	**60 - 70**	**70 - 80**	**80 - 90**	**90 - 100**	**100 - 110**	**110 - 120**	**120 - 130**	**130 - 140**	**140 - 150**	**150 - 160**	**160 - 170**	**170 - 180**	**180 - 190**	**190 - 200**	**>200**
2	78%	0%	4%	0%	5%	0%	4%	1%	5%	0%	0%	0%	0%	1%	0%	0%	0%	0%	0%	0%	0%
3	54%	0%	24%	0%	3%	0%	0%	4%	4%	4%	0%	0%	8%	0%	0%	0%	0%	0%	0%	0%	0%
4	82%	0%	3%	0%	4%	0%	0%	0%	12%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
6	40%	0%	29%	0%	0%	0%	0%	7%	0%	7%	0%	0%	0%	8%	0%	0%	0%	6%	0%	0%	3%

[156] Train routes with no combined transport excluded.

7	75%	0%	6%	6%	0%	0%	0%	0%	6%	0%	0%	0%	7%	0%	0%	0%	0%	0%	0%	0%	0%
8	5%	0%	0%	0%	72%	0%	6%	7%	0%	0%	0%	0%	0%	0%	0%	0%	0%	10%	0%	0%	0%
9	63%	0%	17%	6%	0%	7%	0%	0%	0%	5%	0%	0%	2%	0%	0%	0%	0%	0%	0%	0%	0%
10	56%	0%	7%	0%	13%	0%	4%	0%	13%	0%	0%	1%	0%	0%	0%	0%	0%	0%	5%	0%	0%
11	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
13	0%	0%	0%	0%	11%	0%	52%	0%	19%	0%	0%	0%	0%	9%	0%	0%	0%	0%	0%	0%	7%
14	83%	0%	6%	0%	2%	0%	3%	0%	4%	0%	0%	0%	0%	2%	0%	0%	0%	0%	0%	0%	0%
15	21%	0%	38%	0%	0%	0%	0%	0%	0%	0%	4%	0%	34%	0%	0%	4%	0%	0%	0%	0%	0%
16	80%	0%	0%	0%	0%	0%	0%	0%	20%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
17	27%	0%	0%	0%	11%	0%	0%	31%	0%	18%	0%	4%	9%	0%	0%	0%	0%	0%	0%	0%	0%
18	44%	0%	0%	0%	0%	6%	7%	0%	0%	0%	0%	0%	0%	43%	0%	0%	0%	0%	0%	0%	0%
19	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
20	0%	0%	0%	0%	87%	0%	13%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
21	81%	5%	4%	1%	1%	3%	0%	2%	2%	2%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
22	68%	0%	15%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	7%	0%	10%
23	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
25	0%	0%	0%	0%	20%	0%	30%	0%	6%	0%	0%	0%	0%	14%	4%	0%	0%	0%	0%	0%	26%
26	5%	0%	28%	4%	0%	1%	1%	4%	14%	5%	13%	4%	8%	13%	0%	0%	0%	0%	0%	0%	0%
27	68%	0%	15%	1%	0%	1%	5%	1%	9%	0%	0%	0%	1%	0%	0%	0%	0%	0%	0%	0%	0%
28	35%	0%	0%	0%	3%	0%	0%	23%	0%	0%	0%	0%	39%	0%	0%	0%	0%	0%	0%	0%	0%
29	46%	0%	0%	0%	0%	1%	4%	7%	6%	0%	0%	0%	1%	27%	0%	0%	0%	0%	0%	3%	4%
30	62%	8%	2%	4%	0%	2%	7%	3%	12%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
31	12%	0%	0%	2%	74%	0%	3%	1%	0%	0%	1%	1%	0%	5%	0%	0%	0%	0%	0%	2%	0%
32	33%	2%	7%	3%	2%	4%	8%	0%	7%	0%	20%	1%	9%	2%	0%	0%	0%	0%	0%	1%	0%
33	36%	0%	2%	0%	0%	10%	9%	0%	24%	0%	0%	2%	0%	0%	1%	0%	0%	1%	11%	0%	4%

34	68%	0%	0%	0%	0%	0%	7%	0%	25%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
35	49%	0%	0%	0%	0%	5%	5%	0%	15%	0%	2%	15%	4%	0%	0%	0%	1%	1%	1%	0%	2%
36	0%	0%	0%	1%	0%	2%	63%	1%	9%	1%	2%	1%	0%	15%	1%	2%	1%	0%	0%	0%	0%
37	4%	0%	31%	0%	0%	2%	0%	0%	2%	0%	15%	0%	38%	0%	0%	0%	0%	0%	0%	0%	7%
39	30%	0%	16%	0%	0%	2%	0%	0%	13%	0%	3%	0%	12%	9%	0%	0%	5%	0%	2%	0%	8%
40	7%	0%	33%	0%	3%	0%	1%	1%	3%	2%	3%	0%	37%	2%	0%	3%	0%	0%	0%	4%	0%
42	39%	1%	25%	5%	1%	1%	0%	3%	1%	4%	3%	0%	14%	1%	2%	0%	0%	0%	0%	0%	0%
43	13%	0%	15%	0%	0%	0%	0%	0%	12%	0%	6%	2%	19%	0%	0%	0%	0%	0%	7%	0%	27%
44	0%	0%	58%	0%	0%	0%	0%	1%	0%	0%	0%	1%	40%	0%	0%	0%	0%	0%	0%	0%	0%
45	1%	0%	40%	0%	0%	0%	0%	0%	0%	0%	4%	4%	17%	15%	0%	6%	0%	0%	0%	0%	12%
46	0%	0%	0%	0%	0%	0%	4%	0%	0%	31%	10%	0%	0%	0%	0%	4%	10%	5%	3%	19%	14%
47	35%	0%	0%	0%	2%	0%	2%	10%	5%	27%	0%	5%	8%	0%	5%	0%	0%	0%	0%	0%	0%
48	39%	0%	0%	0%	0%	2%	0%	0%	17%	0%	0%	0%	0%	27%	0%	0%	0%	0%	0%	0%	15%
50	9%	0%	0%	0%	67%	0%	4%	0%	9%	0%	0%	2%	6%	0%	3%	0%	0%	0%	0%	0%	0%
51	44%	1%	2%	1%	1%	10%	4%	0%	11%	0%	23%	0%	1%	1%	0%	0%	0%	0%	1%	0%	0%
52	56%	0%	0%	0%	0%	0%	0%	0%	16%	0%	0%	5%	0%	0%	0%	0%	3%	0%	15%	0%	5%
53	62%	0%	0%	0%	0%	0%	0%	0%	38%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
54	62%	0%	0%	0%	0%	0%	0%	0%	16%	0%	0%	12%	0%	0%	3%	0%	5%	0%	0%	2%	0%
55	0%	0%	0%	0%	0%	0%	72%	0%	0%	0%	0%	0%	0%	17%	3%	0%	5%	0%	0%	3%	0%
56	14%	0%	0%	0%	2%	2%	0%	17%	0%	9%	0%	5%	25%	4%	0%	0%	0%	0%	0%	3%	18%
57	42%	0%	0%	2%	4%	0%	0%	1%	7%	27%	0%	8%	8%	0%	0%	0%	0%	0%	0%	0%	0%
59	35%	0%	2%	1%	5%	1%	2%	21%	1%	15%	3%	2%	5%	0%	1%	0%	0%	4%	1%	0%	0%
60	14%	0%	0%	0%	2%	0%	0%	16%	3%	12%	0%	7%	5%	0%	5%	3%	0%	2%	9%	0%	22%
61	18%	0%	0%	0%	0%	0%	0%	26%	0%	48%	0%	0%	9%	0%	0%	0%	0%	0%	0%	0%	0%
62	30%	0%	0%	0%	0%	0%	0%	19%	0%	31%	0%	9%	2%	0%	0%	0%	0%	0%	3%	4%	2%

63	0%	0%	0%	0%	0%	0%	39%	0%	18%	0%	0%	0%	0%	0%	0%	0%	35%	8%	0%	0%	0%
64	24%	0%	0%	0%	0%	12%	0%	41%	0%	0%	0%	0%	0%	23%	0%	0%	0%	0%	0%	0%	0%
65	8%	0%	0%	7%	42%	5%	0%	0%	0%	7%	0%	0%	0%	0%	0%	0%	0%	31%	0%	0%	0%
66	60%	0%	1%	13%	0%	1%	2%	0%	0%	1%	9%	0%	0%	10%	0%	0%	0%	0%	0%	1%	4%
67	39%	0%	0%	0%	0%	4%	11%	3%	5%	0%	0%	0%	0%	12%	0%	0%	0%	0%	15%	0%	10%
68	95%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	5%	0%	0%	0%	0%	0%	0%	0%
69	83%	0%	0%	0%	0%	6%	0%	3%	0%	0%	0%	7%	0%	0%	0%	0%	0%	0%	0%	0%	0%
70	0%	0%	0%	0%	0%	0%	32%	0%	24%	0%	0%	0%	0%	8%	0%	0%	0%	0%	0%	10%	27%
71	13%	0%	0%	0%	68%	0%	9%	4%	0%	0%	0%	3%	0%	0%	0%	0%	0%	3%	0%	0%	0%
72	56%	1%	7%	6%	2%	1%	4%	1%	0%	2%	13%	4%	1%	0%	1%	0%	0%	0%	0%	0%	0%
73	67%	0%	0%	0%	0%	0%	0%	0%	17%	0%	0%	0%	0%	0%	0%	0%	0%	0%	16%	0%	0%
75	48%	0%	0%	6%	0%	0%	19%	0%	0%	0%	0%	27%	0%	0%	0%	0%	0%	0%	0%	0%	0%
77	11%	3%	9%	1%	61%	4%	8%	1%	0%	2%	0%	0%	0%	0%	0%	0%	0%	1%	0%	0%	0%
78	13%	0%	0%	0%	34%	0%	0%	0%	3%	21%	0%	0%	4%	0%	0%	0%	0%	16%	0%	0%	9%
79	0%	0%	0%	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
80	35%	0%	0%	0%	39%	0%	0%	0%	0%	0%	0%	8%	0%	0%	0%	10%	0%	0%	0%	0%	9%
81	0%	0%	0%	0%	0%	0%	5%	0%	14%	0%	12%	43%	22%	4%	0%	0%	0%	0%	0%	0%	0%
82	58%	3%	2%	2%	0%	0%	0%	0%	11%	0%	5%	1%	4%	0%	0%	0%	0%	0%	11%	0%	2%
83	75%	0%	0%	0%	0%	0%	0%	0%	0%	0%	24%	1%	0%	0%	0%	0%	0%	0%	0%	0%	0%
84	33%	3%	12%	11%	0%	5%	7%	0%	0%	0%	17%	8%	0%	0%	0%	0%	0%	0%	0%	0%	4%
85	1%	0%	0%	2%	0%	3%	37%	2%	18%	5%	2%	0%	3%	6%	0%	0%	6%	7%	4%	3%	1%
86	69%	0%	0%	0%	0%	0%	0%	0%	28%	0%	0%	0%	0%	0%	0%	0%	0%	0%	2%	0%	0%
87	96%	1%	0%	0%	0%	0%	0%	0%	2%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
88	0%	0%	0%	2%	0%	0%	29%	0%	28%	0%	0%	0%	0%	4%	1%	4%	3%	0%	0%	0%	28%
89	68%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	32%	0%	0%	0%	0%	0%	0%	0%	0%	0%

90	0%	0%	0%	0%	0%	0%	47%	0%	24%	0%	0%	0%	0%	29%	0%	0%	0%	0%	0%	0%	0%
91	0%	0%	0%	0%	9%	0%	27%	0%	25%	3%	0%	9%	0%	4%	0%	3%	3%	2%	3%	6%	5%
Total:	41%	1%	6%	1%	6%	2%	8%	3%	9%	3%	4%	2%	5%	4%	0%	0%	1%	1%	1%	1%	2%

Number of trains, train length and load factor per train route[157]

Train route number	**Number of trains**	**Number of train loops**	**Average train length (excl. engine) meter**	**Load factor (length)**		**Train route number**	**Number of trains**	**Number of train loops**	**Average train length (excl. engine) meter**	**Load factor (length)**		**Train route number**	**Number of trains**	**Number of train loops**	**Average train length (excl. engine) meter**	**Load factor (length)**
2	6	6	598.5	73%		32	18	6	614.2	97%		63	2	2	342.0	91%
3	2	2	615.6	85%		33	12	6	583.5	60%		64	4	4	307.8	59%
4	6	6	414.7	76%		34	21	6	560.6	65%		65	4	4	564.3	61%
6	4	4	504.5	62%		35	12	4	612.8	64%		66	12	4	609.9	96%
7	6	6	205.2	79%		36	10	2	613.9	95%		67	6	6	410.4	72%
8	2	2	401.9	80%		37	6	6	453.2	71%		68	12	8	473.1	93%
9	4	2	602.8	81%		39	8	4	611.3	81%		69	2	2	615.6	89%
10	2	2	521.6	75%		40	6	6	389.0	85%		70	4	4	393.3	96%
11	12	6	466.0	80%		42	6	2	615.6	100%		71	6	6	256.5	73%
13	6	6	218.0	79%		43	6	6	491.6	80%		72	12	6	555.8	83%
14	9	6	456.0	64%		44	9	6	615.6	75%		73	2	2	393.3	83%
15	2	2	598.5	90%		45	6	6	371.9	63%		75	4	4	401.9	78%

[157] Train routes with no combined transport excluded.

16	6	6	265.1	76%		46	2	2	615.6	99%		77	4	2	615.6	100%
17	5	5	157.3	96%		47	4	2	611.3	91%		78	6	6	517.3	60%
18	4	4	307.8	61%		48	4	4	350.6	69%		79	5	5	513.0	65%
19	4	4	119.7	86%		50	6	6	320.6	85%		80	3	3	342.0	56%
20	2	2	273.6	88%		51	21	6	611.9	71%		81	2	2	581.4	82%
21	4	2	615.6	100%		52	6	6	495.9	72%		82	4	2	607.1	93%
22	2	2	359.1	71%		53	6	2	615.6	100%		83	15	6	489.1	73%
23	6	3	376.2	50%		54	4	4	607.1	94%		84	6	6	598.5	65%
25	6	6	307.8	78%		55	2	2	324.9	100%		85	12	6	557.9	96%
26	6	2	612.8	100%		56	8	4	611.3	71%		86	10	2	528.4	72%
27	12	2	615.6	71%		57	2	2	607.1	100%		87	4	4	581.4	99%
28	2	2	615.6	99%		59	6	2	612.8	100%		88	6	6	554.3	68%
29	20	4	605.3	57%		60	6	6	538.7	70%		89	4	4	239.4	88%
30	6	2	612.8	83%		61	4	2	615.6	100%		90	4	2	611.3	94%
31	6	2	615.6	93%		62	4	4	615.6	88%		91	8	4	577.1	76%
												Total:	520	324	515.9	80%