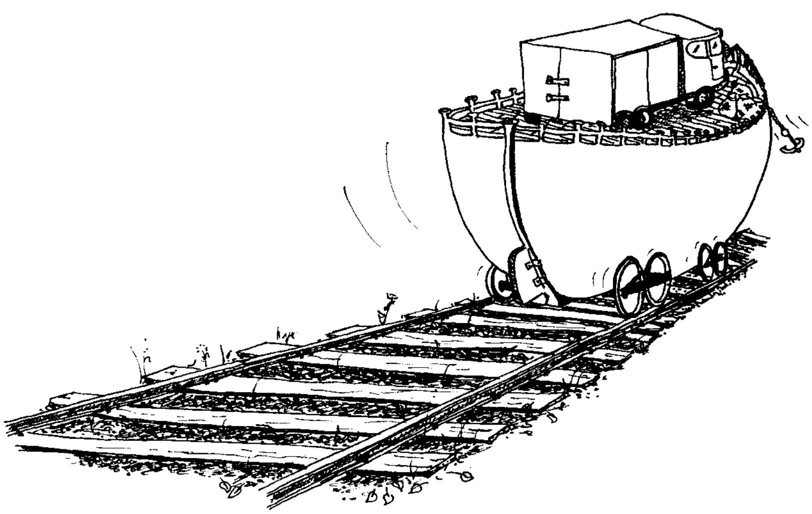
Institutionen för lantbruksteknik*

POSSIBILITIES FOR INTERMODAL GRAIN TRANSPORTS IN THE MÄLARDALEN REGION – ENVIRONMENTAL AND ECONOMICAL ASPECTS

MÖJLIGHETER FÖR INTERMODALA SPANNMÅLSTRANSPORTER I MÄLARDALEN – MILJÖMÄSSIGA OCH EKONOMISKA ASPEKTER

Mårten Kihlström



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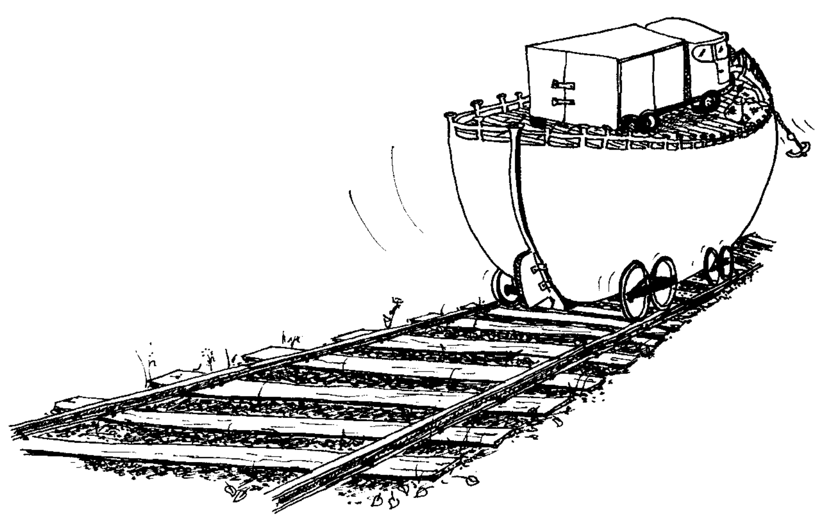

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ABSTRACT

Logistics is neither a new term nor phenomenon. It concerns more or less everybody in every context of daily life. It is appreciated as being an integral part for success in modern industry. Logistics is considered to be the process of planning, implementing, and controlling the efficient, effective flow and storage of raw materials, in-process inventory, finished goods, services and related information from point of origin to point of consumption for the purpose of conforming to customer requirements.

Intermodal transportation is a term within logistics that has gained increased international significance during the last couple of decades. Intermodal transportation is the integration of shipments across modes and it may be defined as being those integrated movements involving at least two different modes of transport under a single through rate. Its goal is to provide a seamless transport system from point of origin to the final destination under one billing and with common liability. The steady increment of environmental hazardous emissions caused by goods transport may lead to search for alternative modes of transportation other than lorry. Intermodal transportation can be a solution in order to reduce these emissions.

In Sweden, goods transport in the agricultural sector is a significant component of goods transport as a whole. In this report, the grain sector in the northern part of the Mälardalen region has been studied to determine if there are possibilities to utilise intermodal transportation for grain transports between farms, silos, and industry.

The objective of this study was to examine the possibilities for intermodal transportation in the grain industry by studying the grain related transports and material flow. Additionally economical aspects related to intermodal grain transports were studied. A case study was conducted on intermodal alternatives for the movement of 1 000 tonnes of grain from Uppsala to Stockholm.

The case study results showed that there are environmental advantages in intermodal transportation. The report indicated that there seems to be a general reluctance, lack of confidence and interest to change to an intermodal system.

The following conclusions were drawn after the study:

- After having studied, and mapped the flow of grain in the Uppsala / Mälardalen region, it is evident that the current locations of the silos in the area offer possibilities for intermodal transportation using already existing infrastructure.
- In terms of the CO_2 emission rate, if using barge, it is reduced by 23 % compared to lorry when transporting 1 000 tonnes of grain between Uppsala and Stockholm. If using rail, the same figure is 98 %. In terms of SO_2, it is significantly increased for barge, and in the case of rail significantly reduced compared to lorry. In terms of NO_X, it is also drastically increased for barge, while in the case for rail it is reduced by 17 % compared to lorry.
- When using rail instead of lorry to transport 1 000 tonnes of grain between Uppsala and Stockholm the transport time, loading, and unloading included, is reduced by nearly 76 %. When using barge the same figure is 63 % compared to lorry.
- The loading and unloading process and time for barge and rail are not impediments for the introduction of intermodal transportation.
- Economical measures, like the Polluter Pays Principle, and governmental subsidies, can be taken to promote intermodal transportation.
- Disseminations of these results could increase the awareness of intermodal transportation.

In order to further establish the benefits of intermodal transportation it is recommended that a practical study is done and that other parts of Sweden are studied in the same way as in this study.

SAMMANFATTNING

Logistik kan anses vara planeringen, implementeringen och kontrollen av flödet eller lagringen av råmaterial, produkter under tillverkning, färdiga produkter, tjänster och därtill relaterad information från ursprung till konsumtion i enlighet med kundens behov.

Intermodala transporter är en term inom logistiken som fått ökad internationell betydelse under de senaste decennierna. Intermodala transporter innebär att två eller flera transportslag, på ett medvetet, integrerat och koordinerat sätt, utnyttjas för att utföra en transport mellan två punkter. De ständigt ökande miljöutsläppen har gjort att alternativa transportmedel till lastbil måste beaktas. Intermodala transporter kan då vara en lösning för att reducera den negativa miljöpåverkan.

Transporterna inom jordbrukssektorn står för en betydande del av Sveriges samlade transporter. I denna rapport har spannmålssektorn i norra Mälardalen undersökts för att se om det finns möjligheter att använda intermodala transporter för att frakta spannmål mellan gårdar, silo och industri.

Syftet med studien var att studera spannmålsflödet och dess relaterade transporter för att undersöka möjliga miljövinster med intermodala transporter. Ett ytterligare syfte var att belysa de ekonomiska aspekter relaterade till intermodala transporter. En miljömässig och ekonomisk fallstudie gjordes av hur dagens transporter mellan Stockholm och Uppsala genomförs jämfört med ett intermodalt alternativ.

Resultatet av fallstudien visar att det finns miljömässiga fördelar med intermodala transporter. Rapporten pekar på att det tycks finnas en generell tveksamhet, bristande förtroende och intresse att övergå till intermodala transporter trots att miljömässiga och ekonomiska fördelar finns att vinna.

Följande slutsatser kan dras av fallstudien:

- Efter att ha studerat och kartlagt spannmålsflödet i Uppsala / Mälardalsregionen, att lokaliseringen av dagens silos och existerande infrastruktur bevisligen erbjuder möjligheter för intermodala transporter.
- CO_2-utsläppen minskar med 23 % om pråm används istället för lastbil att transportera motsvarande mängd 1 000 ton spannmål mellan Stockholm och Uppsala. För järnväg är samma siffra 98 %. När det gäller SO_2 för pråm jämfört med lastbil sker en markant ökning och i fallet för järnväg, en markant minskning. Avseende NO_X, sker också i det fallet en markant ökning när det gäller pråm medan nyttjande av järnväg skulle minska utsläppen med 17 %.
- Vid nyttjande av järnväg för samma transport skulle tidsåtgången för transporten, inklusive lastning och lossning, minska med 76 % jämfört med lastbil. För pråm skulle motsvarande siffra vara 63 %
- Lastningsprocess och tidsåtgång för lastning av pråmar och järnvägsvagnar utgör inga begränsar för införandet av intermodala transporter.
- Ekonomiska styrmedel, såsom Polluter Pays Principle eller statsbidrag, kan utnyttjas för att uppmuntra intermodala transporter.
- En allmän spridning av fallstudiens resultat bland personal inom aktuellt område kan öka medvetenheten om fördelarna med intermodala spannmålstransporter.

För att ytterligare fastställa fördelarna med intermodala transporter rekommenderas att praktikfall genomförs och att andra delar av Sverige studeras på samma sätt för att klargöra huruvida samma slutsatser skulle kunna påvisas.

LIST OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

INTRODUCTION

Transportation is a vital activity in moving both goods and passengers around the world. Logistics is not a new phenomenon. Logistics was initially a military activity concerned with getting soldiers and munitions to the battlefront in time for fight. However, now it is appreciated as being an integral part of modern production process. Logistics concerns more or less everybody in every context of daily life. The quality of transport logistics is recognised as being vital to the success of many organisations.

In the last decade, it has been both a practical and increasingly a theoretical field of study. Today, logistics can be studied at several schools and universities with different angles of approach to it. This report has an agricultural angle to logistics.

One used and cited definition of logistics is as follows:

Logistics is the process of planning, implementing and controlling the efficient, effective flow and storage of raw materials, in-process inventory, finished goods, services and related information from point of origin to point of consumption (including inbound, outbound, internal and external movements) for the purpose of conforming to customer requirements.

(Coyle & Bardi *et al.* 1992)

This definition covers every aspect of logistics – both physical and information logistics, internal and external logistics. It is used as the backbone definition of logistics in this report.

Compared to logistics, transport is the lay-man-notion "the conveyance of people or property from one place to another" (Microsoft, CD ROM 1996) from a transport operator's perspective. Logistics is used as the corresponding but slightly wider term from a shipper's perspective (Woxenius 1998).

Transport is a second-order activity, which is generated by other economic activity. As such, the demand for transport depends heavily on economic activity and consumption and changes in both of these. Transport has continuously increased in the last decades. When the economy is growing, both production and consumption will grow. This process leads to an increase in the demand for transport. Reciprocally, an increase in transport supports growth in production and consumption and this contributes to growth in the economy.

Within Sweden, 498 million tonnes of goods were transported in 2001; the transport work[1] was 82 652 million tonne-kilometres. According to SIKA (2003), since 1992 the transport work has increased by slightly more than 18 %, and since 1975 the amount of goods has increased with 35 %. The transport work by mode in 2002 is depicted in Figure 1. Taking into consideration the evolution in modern industry, it will most likely continue to increase

[1] *Transport work* is the total amount of tonnes transported multiplied by the transported distance. Measured in tonne-kilometres. The measurement is used for large volumes when it is unknown how much goods each vehicle carries on a specific journey.

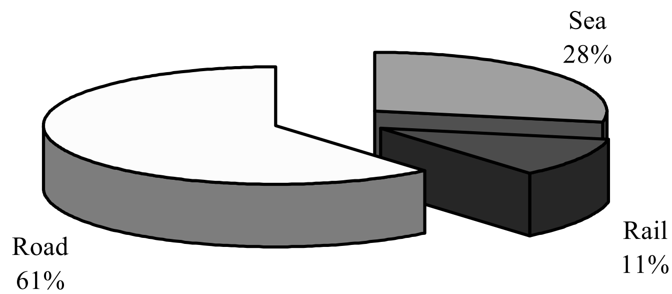

Figure 1 Total amount of goods, by tonnes, transported in Sweden in 2001 by mode (SIKA 2003).

In the same area, Figure 2 shows the goods transport work in Sweden in 2001 by mode based on the following figures (SIKA 2003):

- Sea 33.135 million tonne kilometres
- Rail 19.547 million tonne kilometres
- Road 29.970 million tonne kilometres

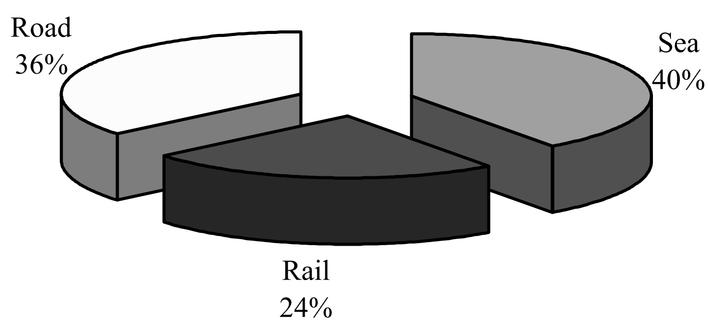

Figure 2 Goods transport work in Sweden in 2001 by mode (SIKA 2003).

If one compares Figure 1 and 2 above, it is understood that the amount of transport by road is substantial in relation to the transported amount of goods per vehicle, thus leading to environmental deterioration.

One way to reduce the environmental impacts of road transportation is to combine it with other modes of transport like rail or barge on some legs of the transport or to completely use other modes of transport for the whole leg. There are different terms, definitions, and interpretations for this for which this report will focus on the term called intermodal transportation. Especially, this report will focus on the possibilities for shift of modes and intermodal transportation in the grain industry.

Transport in the agricultural sector is a significant contribution to the total amount of goods transported in Sweden. For the past few years 10-12 % of the total amount of goods transported in Sweden have been products in the food and agricultural sector (SIKA & SCB 1999). In the agricultural sector, the number of producers, *i.e.* farmers, as well as processing locations, such as dairy industries and abattoirs, are decreasing through centralisation and structural rationalisation. As a consequence the transport work has increased significantly (Gebresenbet 1999). Thus, the agricultural transport sector is causative to considerable negative environmental influences. Encouraging the logistic actors to operate more environmentally friendly means of transportation could reduce these negative influences.

Figure 3 shows market shares divided by mode of transportation. If using intermodal transportation, the shares for railroad and sea vessels would increase.

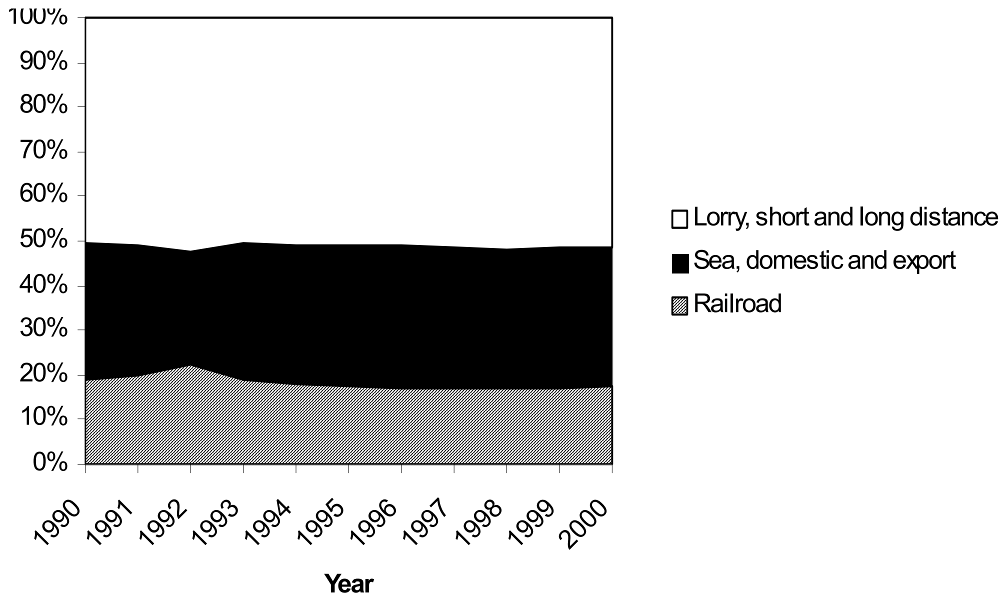

Figure 3 Market shares of goods transport work by mode of transportation (compiled from Market analysis of goods- and passenger traffic for the year 2000)

In the agricultural sector the most common way of transporting goods is on road and the trend shows no decrease. It is a trend that must be turned around in order to achieve a more sustainable environment. This can be achieved by using alternatives to the road-based transports. There are in fact more environmentally means of transportation that can be used in the agricultural sector.

LITERATURE REVIEW AND THEORETICAL REFERENCES

Though surprisingly few studies have been conducted on how agricultural related transports can be more effectively co-ordinated, previous research results (Gebresenbet & Oostra 1997; Gebresenbet 1999; Ljungberg & Gebresenbet *et al.* 2002; SEPA 1999) indicate that there are possibilities to implement transportation co-ordination (*i.e.* fewer delivery stops, fewer vehicles, increased utilisation, shorter transport distances). This could in turn improve the maximum loading capacity of the modes and produce more efficient consignments (fewer and bigger on exact timings). Ottosson and Svensson (1982) claim that co-ordination in the agricultural sector can be accomplished by first using the vehicle for distribution then for collecting products from the farms. Very often, the farmer's supplier is also his customer, thus promoting return transports.

No known studies have been conducted on how intermodal transport of grain could be introduced into the agricultural sector. The use of intermodal agricultural transport could help to reduce the intensity of road traffic, especially during harvesting season. In this way, transporters can more effectively focus on parallel activities, while at the same time achieving environmental improvements.

It is very important that all definitions and terms are clear before proceeding to explore intermodal transportation. Therefore, the concept of intermodal transportation will be presented. This is followed by a general study of the grain industry and related transports. Finally, the environmental and economical influence of [grain] transportation will be outlined. The Literature review and theoretical references should be considered as a kind of basic scientific knowledge representing the backbone of the report.

Intermodal transports

Intermodal transports has gained popularity and grown rapidly since the early 1970s. Growth in intermodal movements can be attributed to several circumstances including industry de-regulation, global business expansion and the application of new techniques to improve intermodal processes (Bloomberg & LeMay *et al.* 2002). Intermodal transport is a field attracting interest from many actors of widely different character, *e.g.* transport operators, politicians, engineers and researchers, and many concepts and definitions are in use depending on the context and objectives. Thus, it is very important that all definitions and terms are clear before proceeding to discuss intermodal transportation.

The notion of multimodal transport is generally used for the carriage of goods by at least two modes. A multimodal transport involves several modes of transport to move a consignment from the supplier to the customer. The goods are cross-docked from one mode to the other by using unitised cargo or a direct shipment to minimise handling costs. Increased efficiency is attained by the usage of unitised cargo such as containers (Lumsden 1998). Multimodal transport is by definition not equivalent to intermodal transport. It is the overarching "definition umbrella" of which intermodal transportation is one refined sub-definition and way of conducting multimodal transportation, however in an integrated manner.

The notion of intermodal transport as used in the common terminology within the European Union (EU), UN Economic Commission for Europe (UN/ECE), and the European Conference of Ministers of Transport (ECMT) concerns the movement of goods in one and the same loading unit (*e.g.* a container) or vehicle, which uses successively several modes of transport without handling the goods while changing modes (European Commission 1997 and 2002). Unlike multimodal transport, which is characterised by essentially separate movements involving different modes, intermodal transport is the integration of shipments across modes. Intermodal transport may be defined as being those integrated movements involving at least two different modes of transport under a single through rate (Brewer & Button *et al.* 2001). Its goal is to provide a seamless transport system from point of origin to the final destination under one billing and with common liability (Hayuth 1987; DeWitt & Clinger 1999).

When designing a physical transport system different modes are combined to form the actual transport chain. In the same terminology, the term combined transport is sometimes used for intermodal transport of unitised cargo when, traditionally, the major part of the journey is by rail, and any initial or final leg is carried out by road (Lumsden 1998).

Intermodalism refers to the goal of making the optimal use of all the various modes of transportation. It assumes that the use of multiple modes for a single trip can be better from an efficiency and environmental point of view. All freight movements involving two or more modes of transport, from a point of origin to a destination, can be defined as multimodal while intermodal transports are a kind refined multimodal transports. The modes involved can encompass motor carrier, railroad, barge and ship, air cargo liner, and pipeline (OECD 2002).

For this study the definition for intermodal transport used by OECD has been adopted. The definition is used in the report as a baseline for intermodal transport:

Intermodalism implies the use of at least two modes of transport in an integrated manner in a door-to-door transport chain.

Bulk commodities are mostly in themselves shifted rather than shifting the cargo unit carrying them. Grain is not an exception to this unwritten rule. The definition does not include a specific cargo unit. Thus, the more open definition is more suitable, since it does not limit the search for efficient alternatives.

Advantages and disadvantages of intermodal transports

Because several modes are used in the logistic chain, efficient transitions between the modes must be facilitated. This implies that the efficiency of multimodal transports is completely based on the technique and the organisation of where and how unitised cargo is used in the transport system (Woxenius 1993). This is also valid for intermodal transports as it is a form of multimodal transport.

Usually, rail is used for hauling longer distances and the motor carrier for shorter. This creates flexibility and possibilities for a door-to-door transport system (Pewe 1993). When the motor carrier is substituted by rail a number of advantages are achieved: environmental, such as effluents and noise; fewer traffic accidents and less congestion (Sjögren 1996).

A mode common in most chains of intermodal transport is the motor carrier. The motor carrier's high degree of accessibility enables it to serve points that other modes are physically incapable of serving. Lorries can go the shipper's door, pick up the freight, deliver it to the airport, and at the destination airport deliver the freight from the airport to the consignee. The air carrier is incapable of providing service to points beyond the airport. Similar limitations exist for rail, water, and pipeline transportation (Coyle & Bardi *et al.* 2000).

When using more than one mode the advantages of each and every mode can be exploited wherever it is most efficient, taking into consideration the customer benefits, resource utilisation or environmental influence. Intermodal transportation allows shippers to compromise on the benefits of each mode used to transport the product.

The intermodal service combines the advantages of each mode used but also the disadvantages. For example, air-lorry intermodal transportation combines the advantage of the motor carrier's accessibility and lower cost with the speed of the air carrier. At the same time, the combined service includes the air carrier's high cost and the motor carrier's slow speed. Air-lorry intermodal rates are lower than all-air rates, but higher than all-lorry rates, and the transit times are shorter than by all-lorry but longer by all-air.

The disadvantages of intermodal transports are similar to those in combined transports. The transport time might increase due to increased handling time (Sjögren 1996). A problem with intermodal transport is difficulty in transferring the goods between the modes at the point of interchange. Because of terminal costs multimodal transports have always been placed at a disadvantage compared with one-mode systems. This has tended to relegate multimodality to trips where a transfer is unavoidable, such as overseas shipments (Brewer *et al.* 2001).

In addition, Storhagen *et al.* (1999) stated that there is lack of long-term political and organisational thinking. Furthermore, the investment costs are high and the transporters seem reluctant to invest in specialised equipment when the various types of transports and costs are uncertain.

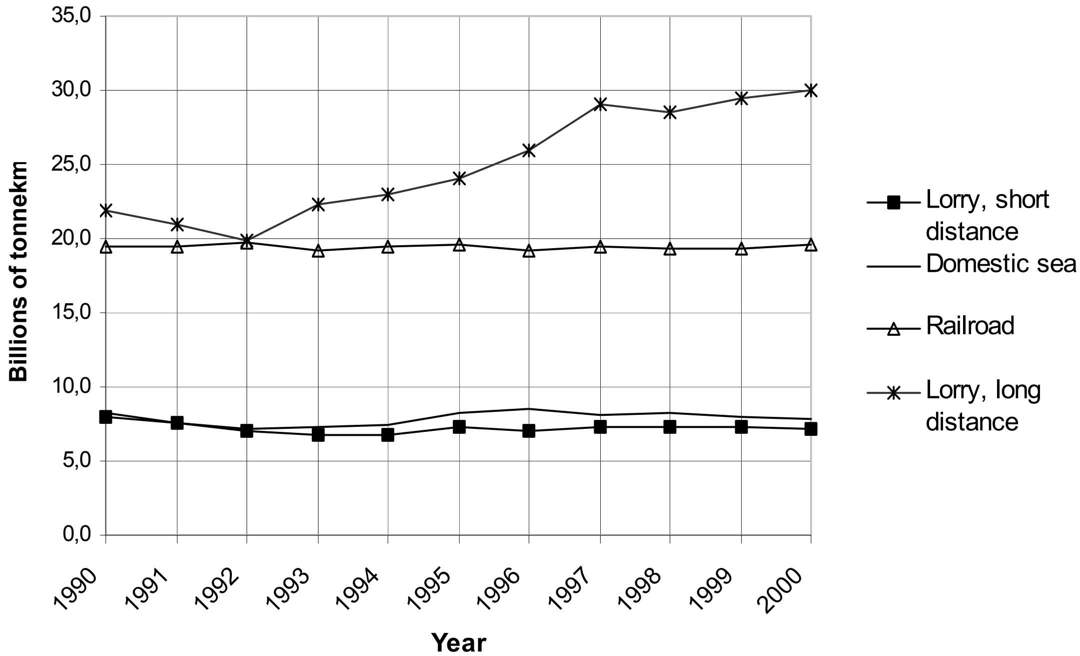

Figure 4 Goods transport work by mode of transportation in Sweden (Banverket 2001).

Figure 4 shows the continuous increment of long distance transport by lorry. Other modes of transportation have more or less during the last decade not changed in any way. Still, since transport by lorry increase, there are in total more goods to be moved today than a decade ago. It would be interesting to extend the timeline 30 years back in time. It was during the 60's in Sweden the lorry really was introduced. The lorry rapidly became a popular mode of transportation because of its flexibility. At that time, it primarily competed with railroads. The railroad in Sweden during that time was widely spread in the country connecting both small and big cities. Because of the lorry, several railroad tracks and lines had to be shut down and removed due to lack of use. The 60's in Sweden became known as the "decade for the railroad death". That still affects the railroad today – the geographical coverage is limited and to cope with competition new lines are planned. However, railroads investments today are expensive and attract a lot of discussions.

When implementing an intermodal transportation system one wants to reduce the transport work by lorries, long distance transports. By doing so, the curve for either railroad or domestic sea transports in Figure 4 would increase. The shorter distances, being transported by lorries, are difficult to compete with from a railroad or boat perspective. In average distances less than 300 km, lorries transport the goods. Thereafter, railroad or boat becomes an interesting alternative. It is generally on distances above 300 km that most companies conducting railroad transports try to compete with road.

Grain logistics

Grain is cultivated at farms, transported to silos for drying, and then transported to processing plants or ports for export trade. Industrial processing plants are generally located near population centres and available power sources. Thus, harvested crops have to be transported to the cities and towns where industry is located while machinery, animal fodder, fertilisers, pesticides, fuel, and other goods used in agricultural production have to be transported from urban areas to farms.

In Sweden in 2001 the most cultivated grain crops were barley (15 %), wheat (15 %), and oat (10 %, www.jordbruksverket.se, 2003). In 2001 43.6 % of the arable land in Sweden was used for growing grain. The same year, the total amount of grain production in Sweden was about 5.5 million tonnes, of which 6 % was produced in the Mälardalen region (SCB 2002). Thus, it is likely that many of the conducted transports in the agricultural sector are grain related. However, SIKA (2000) foresees that the amount of transported grain, as a commodity group, will decrease until 2010.

In 2003, the calculated amount of grain harvested was more or less normal. As in 2001, it is predicted to be approximately 5.5 million tonnes. This is consistent with the harvest of 2002 and only slightly more than the harvests of the last five years (www.jordbruksverket.se, 2003).

Figure 5 shows the total amount of harvested grain for the last decade.

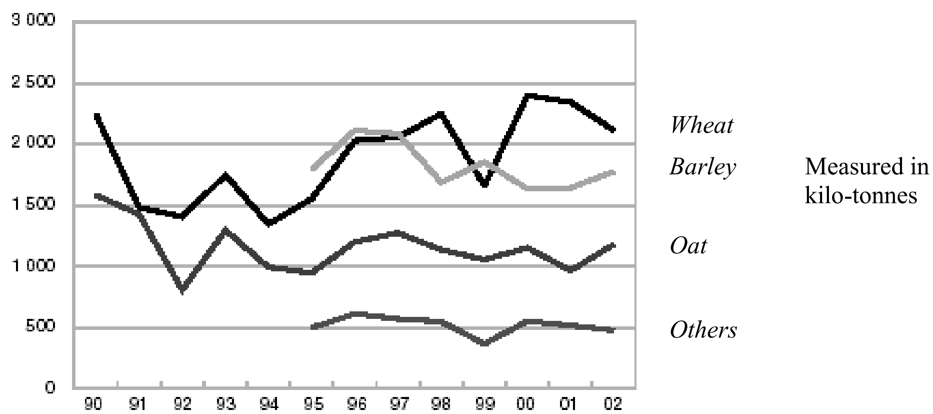

Figure 5 Total amount of harvested grain in Sweden, 1990 - 2002 (www.scb.se, 2003)

Material flow

Transportation in the food system, of which grain is one part, is more complex than just shipping food directly from the farms to homes. After being harvested, most food crops have to be processed (the grain must be dried) and packaged, then transported to large wholesale distribution centres. From there, the packaged foods are transported to retail stores located near population centres, where individuals purchase them and transport them home (Pimentel & Pimentel 1996).

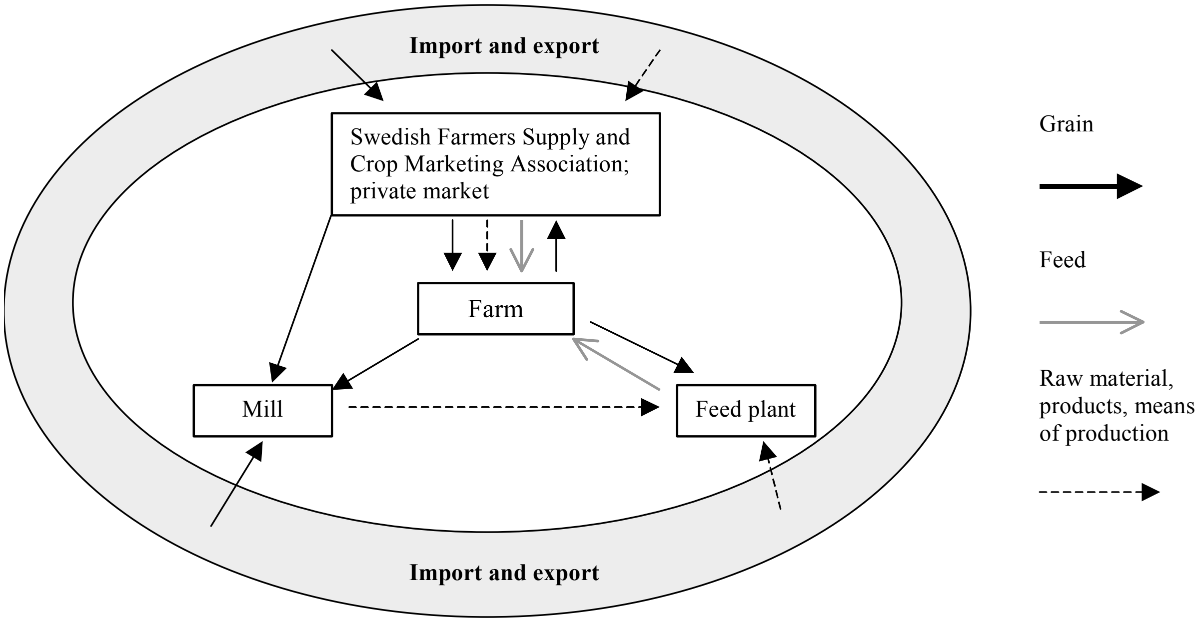

Figure 6 Material flow in the grain sector (revised, Gebresenbet & Ljungberg 2001).

Figure 6 shows the material flow associated with the farms themselves. The total flow of goods to the farms is almost as big as the flow out. Grain is usually first transported to some kind of silo or storage facility, as well as sold to feed plants and mills. At those two locations the grain is dried, stored and prepared for the next stage. A possible next stage could be a mill or other production sites. From the mill it is transported and sold to a third party, for example a bakery. In general, grain is sold directly from farms to mills; feed plants; private market and marketing associations.

To reduce the transport intensity it is in the transporters and silo operators interest that as much grain as possible can be dried and stored at the farms. By doing so, the grain can then be transported directly to the production site later on without a third party having to dry and store it. Thus, the need for increased transport capacity only for a short period in conjunction with harvesting season decreases. In addition, to promote this farmers receive an economical advantage if they have dried and stored their grain by themselves. This will be further discussed later on.

Transport modes

The energy consumption rate in the transport sector has increased by 60 % since 1970. Most of the energy is utilised in agriculture, in households, and in the food industry, but transportation represents a large proportion of Sweden's energy use (SEPA 1999). Table 1 shows the energy per mode required to transport one kilo one kilometre.

Table 1 Energy needed to transport 1 tonne 1 kilometre

Mode of transport	kWh / tonne kilometre
Lorry[a]	0.17
Sea[a]	0.11
Rail (diesel)[a]	0.064

[a] www.ntm.a.se, accessed 5th of September 2003

Combining the information in Table 1 and Figure 2 yield the following information regarding the total energy consumption per mode of transportation for the year 2001:

- Sea $3.645*10^8$ kWh
- Rail $1.251*10^6$ kWh
- Road $5.095*10^6$ kWh

The grain sector is more or less seasonal transport intensive sector with a high transport demand during harvesting. This sector has for the past few decades been associated with road transports while long ago waterways, later followed by railroad, were used to some extent for transporting grain. Those possible modes of transport instead of road based still exist today. These modes are already in use in some countries and areas but to a limited extent in the area studied in this report. Not only can alternative modes of transport be more environmentally friendly but may also offer economical benefits for logistic actors in the grain sector.

Grain related transport by motor carrier is about 3.5 million tonnes per year (SIKA & SCB 1999). However, this value cannot directly be compared to the total transported quantity (5.5 million tonnes). This is partially because the same grain is transported more than once and partially because some transports are conducted by tractor, which is not included in the statistics (Gebresenbet & Ljungberg 2001).

In 1997, 350 000 tonnes of grain were transported by barge and 21 000 tonnes by rail (Ljungberg 2000). Grain is transported from the farms in two ways. Either the farmer transports the grain to a storage location, normally a silo, by tractor, or contracted transport operators conduct the grain pickups and delivery by lorry and trailer. The lorries used are either normal lorries or specialised grain lorries as described further on in the report. The transport requirement is by far at its peak during the harvesting season.

Considering water carrier, the major competition is with two other modes, rail and pipeline. Water carriers compete with railroads for the movement of dry bulk commodities like grain. For example, in the US the movement of grain from the Midwest to New Orleans is possible by rail as well as by water carrier. The water carriers can use the river systems to connect the plain states with New Orleans. Both modes move sizeable amounts of grain along the traffic corridors (Coyle & Bardi *et al.* 2000).

To a limited degree water carriers compete with lorries. In most cases, lorries are used to overcome the accessibility constraints of water carriers because they tie inland areas to the waterways for pickup and/or delivery. Shipment quantities argue against motor carriers since one 600 tonne barge can transport the equivalent of about 15 lorries (revised, Coyle & Bardi *et al.* 2000).

Table 2 is a set of compiled data showing the different loading capacities of different modes of transportation used in the grain sector.

Table 2 Modes of transport for grain related transports (Gebresenbet & Ljungberg 2001)

Mode of transport	Used for	Approximate loading capacity
Tractor trailer	Grain (feed, seed, fertiliser)	5-25 tonnes
EPA-tractor[a] with trailer	Grain (feed, seed, fertiliser)	At the most 50 tonnes
Lorry		
a) bed with or without tipper	Grain, packaged goods	35 tonnes

b) with swap bodies	Grain, chips, wood, waste, fertiliser	36 tonnes
c) bulk	Grain, flour, feed, fertiliser	38-42 tonnes
Barge	Grain, feed raw materials	300-50 000 tonnes
Rail	Grain, flour	22-55 tonnes per wagon

[a] An EPA-tractor is an older car, sometimes a lorry, which has been rebuilt into an agricultural vehicle

In reference to transports from the farm, one lorry equals, in transport capacity, roughly twice as much as one tractor. When taking time into consideration the lorry becomes even more attractive.

One rail car equals, in average, 1.5 lorries. This is interesting when studying transports from the silos to other silos or a third party. Barges (minimum crew of two persons) and boats transport the lower volume for domestic and inland transports. If exporting, much larger ships are used for cross Atlantic shipments or to southern Europe. In The Netherlands barges are frequently used for transporting goods, of which grain is one, as an alternative for road transports. The barges used can be connected in a flexible way to form larger barges. Each barge is about 34 metres long and has a loading capacity of about 650 tonnes. The situation in The Netherlands differs from that in Sweden in the respect to that the road traffic situation has forced goods to be moved on water in order to avoid traffic jams, accidents and hazardous emissions. The barges and boats can be loaded by using a conveyor belt of some kind. The conveyor belts suitable for grain have a capacity of loading 350 tonnes/hour to 800 tonnes/hour. When unloading the barges a suction or screw-type device may be used. The screw-type devices suitable for unloading grain have an unloading capacity of 250 tonnes/hour to 500 tonnes/hour of which the 250 tonnes/hour type is most common when handling grain. (www.bmhmarine.se, 2003). Mobile unloading equipment, as well as permanent unloading machinery exists. Mobile equipment is suitable for smaller silos or at silos with limited transport demand.

The ambition is to maximise each vehicle's loading capacity and therefore, most likely, there can be several pick up points along the route but, at least in the grain sector (unprocessed), only one delivery point. As in the case of several pick up points it occurs very seldom in reality when it comes to grain transportation. For one, it is undesirable to mix shipments from different farmers in one and the same cargo unit (lorry or trailer). One possibility is to fill the lorry at one farm and the trailer at another.

Figure 7 and Figure 8 depict some of the transports modes used for grain transportation:

Figure 7 Different types of train wagons used for grain transportation

Figure 8 Regular type lorries, with beds that can be tipped from the side or back

There are many types of lorries available. However, there are constraints such as the allowed maximum vehicle weight, in Sweden 60 tonnes (SNRA 2001), and existing physical infrastructure. Swedish road regulations, however, are generous – allowing vehicles up to 24 metres long and weighing maximum 60 tonnes – which reduces the competitiveness of intermodal transportation.

Mainly two types of motor carriers exist: grain specialised and general motor carriers. The specialised carriers are solely designed to transport grain. They can be built lighter and transport more grain. However, they cannot be used for other types of transports. General motor carriers not only transport grain but are also used during other times of the year to transport products such as seed, fertiliser, and other goods. The specialised carriers are uncommon. Most transporters agree that the degree of flexibility is more important than increased loading capacity. Flexibility is considered decisive in that it allows the transporters to combine commodity distribution and grain transport on one and the same transport route (Gebresenbet & Ljungberg 2001).

Transport and environment

Traffic has environmental costs such as air pollution and noise. It deteriorates the quality of life in our cities as well as being a contributor to global warming. At the same time, people appreciate the increased mobility that transport provides as well as the goods and services that commercial transport brings to our shops and homes. As often in life, we [the people] must find a balance between the costs to our environment and the benefits that we enjoy.

Transport and environment are increasingly considered ill matched. Yet opportunities exist to improve transport efficiency and the environment at the same time. Ljungberg (2000) states that the environmental impact of transportation can be seen as the consumption of limited resources in three different regards: a) consumption of the resources needed to create the transport system and to propel the vehicles, b) pollutants influencing the environment c) influences on the human physical environment. This report will focus on energy and the second issue, bearing in mind that it is not certain that the two other issues must also be improved just because the second one is.

The international attention to environmental problems has increased during the last decade: UN conferences in Rio de Janeiro in 1992 and in Kyoto 1997. The aim has been, and still is, to find worldwide consensus on how to deal with environmental and climate related issues. European legislation has made substantial progress in reducing the environmental impacts of vehicles and fuels. Efforts are also being made to improve the way in which the transports modes work together so that, for any one shipment, modes can be combined to minimise the effects on the environment whilst maximising the efficiency. Intermodal transports are clearly a way of conducting transports if to believe the European Union and United Nations.

A contribution to achieving this could be made by implementing an intermodal transport system where currently only motor carriers are used. According to Pewe (2002), when constructing a cost efficient transport system, very often, positive environmental aspects are a side effect. The side effect is not intentionally planned in advance but is more or less a bonus when enhancing the transport system.

Pollutants influencing the environment

Road vehicles are the most used mode of transportation in the agricultural sector today. With current technology, combustion usually results in the production of emissions. These contribute to the continuous environmental degradation and thus threaten life on earth. The hydrocarbogenic substances in the fuel combine air, especially oxygen and nitrogen and, other chemical compounds: carbon mono- and dioxide, nitrogen and sulphur oxides, other hydrocarbogenic substances, and particles. Some of these compounds will briefly be described here. Exhaust fumes from transport vehicles also contain carcinogenic substances.

Given the total amount of grain transported along a corridor, which could be substituted for either railroad or barge, it would be feasible to calculate the environmental benefits.

This report will focus on emissions of carbon dioxide (CO_2), sulphur oxide (SO_2), and nitrogen oxides (NO_X).

Carbon dioxide

The amount carbon dioxide (CO_2) emitted is in direct proportion to the amount of combusted fuel. The efforts to reduce the amount of carbon dioxide emitted are crucial for the well being of the planet. This is due to the fact that carbon dioxide indirectly contributes to global warming. Another term for this is the green house effect. This one issue has been emphasised many times during United Nation's conferences. The Swedish government has decided that the emission of green house gases for the period 2008 – 2012 in Sweden should be 4 % lower than in 1990. In 1999, the goods transport sector in Sweden was causative to 13.5 % of the total emissions of carbon monoxide in Sweden (Godstransportdelegationen, 2001).

Road vehicles such as lorries and tractors contribute severely to the emission of carbon dioxide. This alone should encourage intermodal transportation.

Sulphur oxide

Like carbon dioxide the emission of sulphur oxide (SO_2) is in direct proportion to the amount of combusted fuel. The amount of sulphur oxides emitted by an engine depends primarily on its fuel consumption and on the amount of sulphur in the fuel. The sulphur oxide causes acid rain when the sulphur is transformed to sulphur acid (H_2SO_4). The amount emitted has significantly decreased during the last decade thanks to the reduced sulphur content now used in the fuel. The problem still remains for some barges and boats, which sometimes use a lower diesel quality than road based diesel vehicles. This is one environmental disadvantage using barges for intermodal transportation.

Nitrogen oxide

Nitrogen oxides (NO_X) are a dangerous family of pollutants. Because of the agricultural run-off these oxides contribute to acidification, and the green house effect. More significantly, it directly causes deterioration of the ozone layer. The problem is more pronounced with diesel-powered vehicles than petroleum because of the combustion temperature that is higher in diesel vehicles.

Modes of transportation emission data

Emission factors are not exact and should be considered as rough estimations of the emissions. However, they offer a feasible approach to approximate calculations. To acquire exact information it would be required to place measuring equipment on the specific vehicles used in the respective transports, or to apply advanced simulation modelling. This could be done in the frame of a future extended and more detailed study. There are a number of factors that affect the emission amount. Such factors can be: the driving behaviour, which differs from driver to driver; the specific engine type and its characteristics; the road conditions and road surface type. Currently, for further information regarding the emission data the reader may find detailed information at www.ntm.a.se.

The modes of transportation used within Mälardalen are lorries, boat and railroad. Table 3 shows the emissions of the substances mentioned earlier for the modes currently used to transport grain in the Mälardalen region.

Table 3 Emission data for different modes of transportation (gram / tonne kilometre)

Mode of transportation	CO_2	SO_2	NO_X	Electric consumption
Lorry[b]	48.0	0.01	0.42	-
Boat[a, b]	31.0	0.54	0.67	-
Rail (diesel)[b]	18.0	$14*10^{-5}$	0.36	-
Rail (electric)[b]	0.004	$6*10^{-6}$	$1*10^{-5}$	0.050 kWh / tonne

[a] Transport Research Laboratory (1999).
[b] www.ntm.a.se, accessed 5th of September 2003

This report did not consider data for tractors, as transports between the farms and silos were not of primary interest for the case study comparisons.

The emission data from electric trains is based on analysis of the electric energy life cycle and estimations from the usage of power and thus power production and distribution. It takes into consideration, among other things, how the electricity has been produced, transported, running and maintenance of the power stations, and the handling of residue products. The figures for the other modes of transportation also include life cycle analysis. In the same way as for electricity, the values take into consideration how the fuel has been produced, transported *etc.*

The estimations of emissions from lorries vary depending on the type what kind of lorry, its size of engine, loaded volume, *etc.* Table 3 indicates the estimated emissions for a heavy sized lorry, Euro 2 engine and with a maximum loading capacity of 40 tonnes.

There were no specific emission rates to be found regarding barges. The rates for sea vessels on www.ntm.a.se covered only normal type cargo sea vessels with the transport capacity of about 2 000 tonnes and above. The barges in this study do not fall in that category. For barges there are no standards or laws stipulating maximum emission rates. Because of this, the emissions will likely vary between different barges and engines. The engines are normally optimised towards as low fuel consumption as possible rather than low emission rates. Therefore, the data used are combined emission factors for standard medium-slow speed tug and fishing type diesel engines (loading rate of 85 %) and smaller cargo ships. The emissions are based on the average fuel consumption per day assuming that during one day a round trip is theoretically possible between Uppsala and Stockholm.

Figure 9 shows how the fuel consumption is related to the distance different modes can carry goods. Figure 9 does not take fuel life cycle analysis into account.

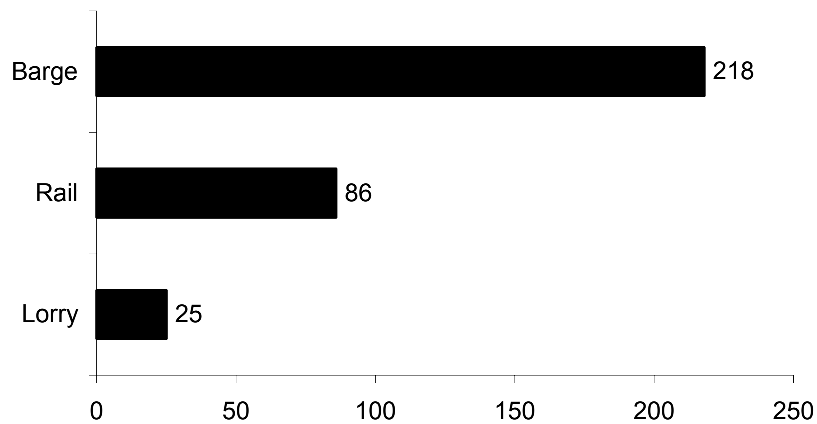

Figure 9 Number of kilometres one tonne can be carried per litre of fuel (revised, U.S Department of Transportation, 1994)

Grain related transport and economy

The coin of economy has two sides: national economy and corporate economy. The interests of the two do not always coincide. It would be best if they did, but unfortunately this is not the case. Since the grain logistic companies are either privately owned or in some cases co-operative businesses, corporate economy interests take precedence over national. The primary desire, more or less, of corporate economy is to maximise profit. By contrast, national economy focuses more on factors such as environmental and economical issues and questions related to the public benefit rather than isolated profits of a single company.

It is a misconception that intermodal transportation is conducted only on the basis of a desire for a better environment – reduction of noise, pollutants *etc.* As previously mentioned, intermodal transportation can offer economical advantages to logistic companies. Anyhow, it seems the grain industry has economic reasons for avoiding intermodal transportation and these reasons will be discussed later in the report.

To consider transport in isolation is an over-simplification. The transport itself would include payment for the driver, cost to use the track, cost to use the cars and locomotive and the cost of diesel. Diesel must also be used when conducting railroad transport since most industry sidetracks are not electrified. Additionally, in the case of railroad one must also take the following issues into consideration:

- The time and cost resulting from the switching of cars at both ends of the line
- The additional handling costs for engaged personnel, excluding the driver

These factors are not directly associated with the transports but nonetheless affect the decision whether or not use any other mode of transportation than lorry.

The same arguments apply to the use of boat and barge. There are more costs involved than just the actual transport. If the boat does not have on board unloading equipment, special equipment at the ports must be used and maybe specially brought there for each time. This equipment must be paid for when used. In some cases, a port usage fee is assessed in much the same way as usage fees for railroad tracks.

When using lorries, the driver does much of the work himself as in unloading and operating the vehicle. The transport company must pay road tax for the lorry depending on size of the lorry. The fewer external factors that exist, the easier the cost estimation for each mode of transportation becomes.

The hypothesis for the report is that environmentally hazardous emissions will reduce if shifting grain transportation mode from road based vehicles to either waterway or railroad transportation. Also, it is foreseen that corporate and national economical interests will improve.

OBJECTIVE

By studying the grain related transports and material flow, the objective of this study was to examine the possibilities for intermodal transportation in the grain industry. Specifically, the possibility for railway or waterway transport in the geographical area in Sweden called Mälardalen was studied. A comparison was conducted between the present transport system and an intermodal alternative in the Lake Mälaren area, taking economical aspects and mainly environmental influences into consideration.

The reason, for conducting the report was based on a desire to reduce the environmental impacts from road based grain transports and to improve corporate and national economical aspects by using alternate modes of transportation in an integrated manner.

Limitations

Examining the whole sector would prove too exhaustive for the purpose of this study. Therefore this report is solely concentrated on the grain industry, specifically on the grain types barley, oat, rye and wheat.

Mainly, transports between production sites related to the grain sector and between silos will be studied. Transports to and from the individual farmers will be addressed, but not deeply analysed or discussed, since these offer limited possibilities for transport by rail or waterways.

Specifically, one year of transportation requirements concerning domestic transport in Sweden will be taken into consideration. Geographically, the report focuses on transports within the Uppsala and the wider Mälardalen region north of Lake Mälaren – 70 km north of Stockholm as depicted in Figure 10. Since Lantmännen, the Swedish Farmers Supply and Crop Marketing Association, is the major company in the Uppsala and Mälardalen region to transport, store, and dry grain and to own and operate silos, only transports related to Lantmännen were studied.

Regarding environmental studies and comparisons three types of emissions will be discussed: being carbon dioxide, sulphur oxide and nitric oxide. Without further research in other geographic locations, the case studied is not intended to be representative or directly applicable to other areas in Sweden.

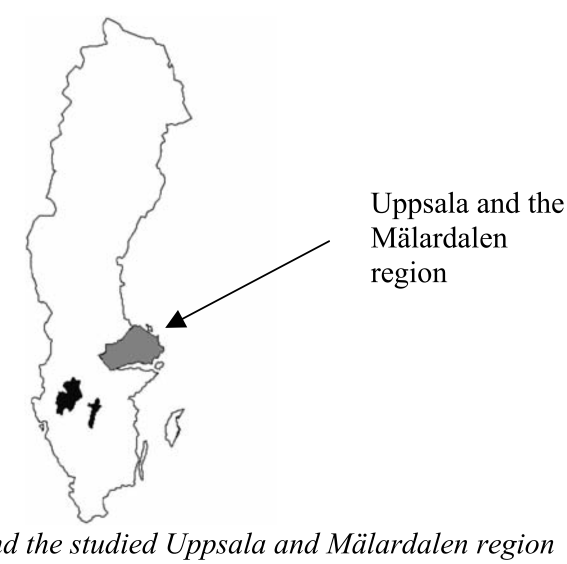

Figure 10 Sweden and the studied Uppsala and Mälardalen region

MATERIALS AND METHODS

The working method used in this study has been conducted in the following steps:

- *Stating the objective of the study*
- *Literature reviews and theoretical studies*
  Books and brochures concerning intermodal transportation; grain production, industry, and transportation were studied. However, this task was difficult due to the lack of references that simultaneously relate to both subjects. Thus, one set of literature regarding intermodal and similar transportation was studied with a parallel literature study of grain and agricultural transportation.
- *Interviews and questionnaires*
  Interviews with private companies, such as the Swedish Farmers Supply and Crop Marketing Association, Svenska Foder, individuals, and universities were conducted in parallel with the literature reviews.
- *Mapping of logistic locations and material flow*
  Logistic locations, (*e.g.* silos, ports, railway stations), were examined. The material flow between these locations has also been taken into consideration. Several silos were visited and photographed.
- *Calculations and analysis*
  The data for economic and environmental concerns were taken into consideration as one of the fundamental elements for the analysis. The discussion based on inputs from involved logistic actors and actual data formed the concluding remarks. Finally, the analysis discussion and results formed a conclusion. The major analysis was conducted as a comparison, mainly in environmental regards, between the presently used transportation system and when implementing an intermodal alternative. The discussion is based on findings through out the work of the report. The discussion should be considered more as the author's view than those interviewed.

Figure 11 shows in brief the methodology used in the study:

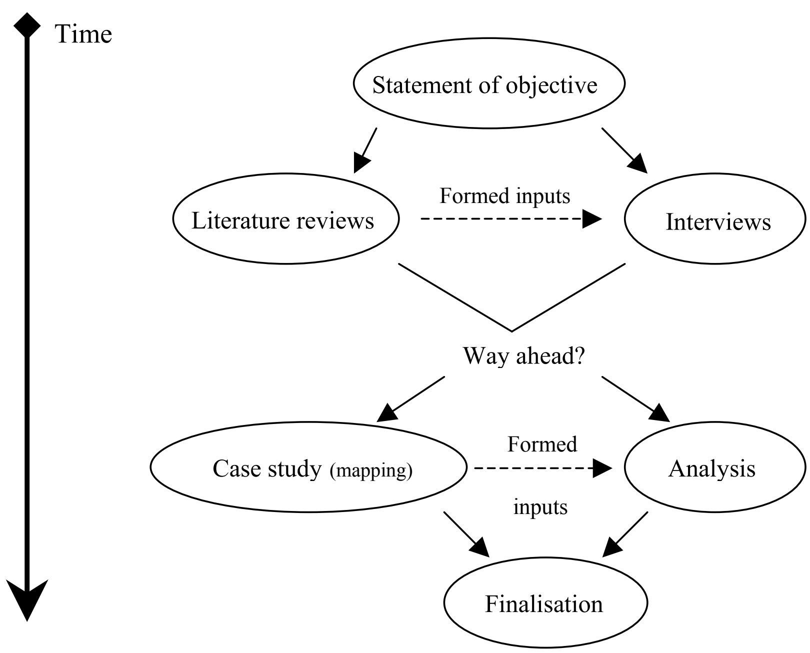

Figure 11 Methodology used in the study

The data were collected through interviews, statistics, archives, practical studies, books and reports – all open sources of information. The interviews did not entirely follow a set template, but were instead adjusted to match the position and experience of the respondent. To acquire as broad picture as possible, the interviews have been conducted on all levels concerned with grain starting from farmer and up. The purpose of the interviews has been to gain data and information of the studied area rather than to map individual attitudes and thoughts. Most of the interviews were conducted in parallel with the literature review.

Since the number of logistic actors in the grain sector in Mälardalen is fairly limited, the information gathered through personal communication has come from a rather small group of experts.

Findings from the literature review and interviews were considered in the development of the case study alternatives, in which the utilisation of different modes of transportation were analysed.

SYSTEM DESCRIPTION

This part of study will briefly describe the current situation in the grain sector in the Uppsala / Mälardalen region regarding silo locations and grain receiving stations, along with the amount of grain handled at each location. This part will also present general information about the Swedish Farmers Supply and Crop Marketing Association, since it is the major company related to the grain industry in the region. Specifically, the system description will focus on the current situation regarding grain transportation in the Mälardalen region. Moreover, the method of transporting the grain to the silos will be mentioned. A more interesting aspect, transport between silos and a third party, will also be discussed.

Grain handling facilities in the Mälardalen region

The Swedish Farmers Supply and Crop Marketing Association (in Swedish Lantmännen) is one of the largest farming and food industry groups in Europe. The association is owned and governed by approximately 48 000 Swedish farmers and has an annual turnover of 25 billion Swedish Kronor. The grain department at the Swedish Farmers Supply and Crop Marketing handles about 2.5 – 3.0 million tonnes of grain per year. Of that amount about 1.0 – 1.2 million tonnes go for export every year. The handling takes place at 126 facilities. The yearly turnover is 3.5 billion Swedish Kronor (www.lantmannen.se, 2003).

Another grain actor mentioned in the report, Svenska Foder (Swedish Fodder), does not have silos or other grain related facilities in the Mälardalen region. However, Swedish Fodder buys grain and delivers fodder to farmers in the region. Swedish Fodder is one of the largest suppliers of animal fodder to farmers in Denmark, the Middle East, and the former Soviet Union (www.svenskafoder.se, 2003).

Additionally, there is an independent private actor in grain sector in the region. Johan Hansson Spannmåls AB in Uppsala buys grain for the production of fodder. The company also sells unprocessed grain to mills and other destinations.

However, the largest company is Lantmännen, in the wider Uppsala and Mälardalen. Lantmännen owns and operates twenty (20) silos or grain receiving facilities. Farmers that are members of the Swedish Farmers Supply and Crop and Marketing Association use these silos. The silos included in this study are those north of Lake Mälaren depicted in Figure 12:

Figure 12 Map of some silos in the northern area owned and operated by the Swedish Farmers Supply and Crop Marketing Association

The silos owned and operated by the Swedish Farmers Supply and Crop and Marketing Association differ in size between the facilities and consequently the yearly grain turn around. The geographical locations of the silos cause natural constraints on what type of transports are available for in- and out-going grain. Table 4 shows the predicted amount of goods handled at some silos in Mälardalen for 2003, by what mode of transportation it comes in and leaves the silo.

Table 4 Grain handling details at some silos of the Swedish Farmers Supply and Crop and Marketing Association in the studied region

Silo	Grain (tonnes)	Transports in by	In from	Transports out by
Bålsta	35 000	Lorry Tractor	Farms	Lorry Boat (24 000 tonnes)
Enköping	20 00-25 000	Lorry Tractor	Farms Other silos	Lorry Boat
Heby	8 600	Lorry Tractor	Farms	Lorry (to Sala and Västerås)
Norrtälje	12 000	Lorry Tractor	Farms Other silos	Lorry Boat
Sala			Farms Other silos	
Stockholm	200 000	Lorry Boat	Farms Other silos	Lorry (5.000 tonnes) Boat
Uppsala	87 000	Lorry Tractor (more than 50%)	Farms Other silos	Lorry Boat Rail
Västerås	100 000	Lorry Tractor	Farms Other silos	Lorry Boat
Vidbo	5 000	Lorry Tractor	Farms	Lorry (to Västerås and Stockholm)

Specific silo modes of transportation

Stockholm, Uppsala and Västerås host the largest silos in the Mälardalen region. All of these silos are situated so the grain can arrive, be unloaded and loaded, and depart by lorry, train or boat. However, the only silo from which railroad is used is from Uppsala. In fact, Uppsala is the only silo from which railroad is used on a more or less regular basis.

At the facility in Stockholm, lorries primarily transport the grain with boat transport being a secondary consideration. No grain is received by rail. Twenty years ago, the railroad was frequently used at the Stockholm facility. However this ended when the mills by the facility were shut down and because the need for emergency support in case of domestic crises no longer exists. The railroad tracks are still in place, but stay unused. Regarding outgoing transports, over 90 % of the grain handled at Stockholm is exported by boat. A minor amount of grain is shipped to the grain facility in Djurön. The grain dedicated for export is shipped on bigger ships to other nations, of which the Baltic States are some of them.

In the case of Uppsala, the farmers usually transport the incoming grain mainly by tractor. The company NordMills[2] in Uppsala receives grain from the silo in the same town. The two facilities are in such close proximity that the grain is transported to the mill on a conveyor belt with a capacity of 400 tonnes per day. In some cases, outgoing grain is also directly shipped for export. In other cases, the grain is transported by boat to Holmsund and Djurön (each boat with a loading capacity of 300 tonnes). Figure 13 and Figure 14 show the loading facilities at the silo in Uppsala.

Figure 13 Silo port in Uppsala

From Uppsala the grain is also transported by railroad. Each car holds approximately 60 tonnes of grain. The amount of grain transported by rail has decreased significantly compared to the situation 20 to 30 years ago. Figure 14, shows the railroad loading facility at Uppsala. The same system can also be used when loading lorries.

[2] NordMills AB is the company within the Cerealia group that is responsible for all activities regarding mills. Their facility in Uppsala handles about 100 000 tonnes of grain per year (www.nordmills.se, 2003).

Figure 14 Loading facility for train and lorry at the Uppsala silo

In Västerås, tractor and lorries transport incoming grain. Lorries sometimes transport outgoing grain, but the bulk of the grain is transported by boat. The outgoing boat-transported grain is intended for export, but some grain is shipped to Djurön, which is outside Norrköping in Östergötland. For export, the amount of grain varies from year to year. Normally, large amounts of wheat are exported and this requires ships with a loading capacity of up to 25 000 tonnes. The grain is exported to the Baltic States (direct shipment). A smaller amount is exported to southern Europe. The Västerås facility has access to railroad, but it is not used.

Based on the information regarding the available infrastructure at each silo, two groups of silos may be identified:

1. The following facilities in the Mälardalen region already have or would have, with the appropriate infrastructure, the possibility to use boat or barge:
    - Bålsta
    - Enköping
    - Köping
    - Norrtälje
    - Stockholm
    - Uppsala
    - Västerås
2. The following facilities in the Mälardalen region have or would have, with the appropriate infrastructure, the possibility to use railroad:
    - (Bålsta)
    - Köping
    - Stockholm
    - Uppsala
    - Västerås

The smaller grain producers are not pleased with the recent economies of scale developments (*i.e.* decreasing the number of silos and having fewer large silos instead of many small). The Swedish Farmers Supply and Crop and Marketing Association was created by a fusion of separate companies operating in the same area of business. Because of the company mergers a number of silos were closed down. Consequently, farmers delivering by tractor would have to drive a greater distance to deposit the grain. This would prove very time consuming, especially as they have to travel the distance several times. Depending on what type of grain the farmer is going to deliver, he may have to travel a greater distance to reach the correct facility - in some cases that specific silo may not be the grain facility closest to him. This can vary from year to year. This decision in conjunction with seasonal variations makes pre transport planning difficult.

Grain transport in the Mälardalen region

There are transports occurring between the different facilities owned by Lantmännen. From smaller countryside silos, that handle a small amount of incoming grain, the product is transported to larger silos within the company. This can differ from year to year depending on the type of grain, and the transport delivery point. The type grain and its destination is the decision of the Swedish Farmers Supply and Crop and Marketing Association. This makes advance transport planning somewhat difficult. Typically, transports are not planned in advance

The harvesting season occurs approximately between the beginning of August and the middle of September. This can of course vary depending on past and prevailing weather conditions. Because of this uncertainty in nature, the amount of harvested grain can be different from year to year. It is only at the time of the harvest that an estimation of the transport requirements can be done. Normally, the transport demand is at its peak during the harvest season with a limited amount of silos and storage facilities. Yet, in advance, Lantmännen and other logistic actors in the grain community are signing contracts with different transporters to ensure that they have a means to deal with a potential sudden increase in demand for grain transports. This can include signing "what-if" emergency contracts with transporters not contracted under normal conditions. In some cases, the weather dictates the transports – a very dry and warm late summer will probably lead to many farmers simultaneously needing transport to maintain grain quality. In a normal harvesting year, 60 % of the grain is transported from the farm to a silo during the actual harvesting season (Gebresenbet & Ljungberg 2001).

In the case of grain transported from the smaller to larger silos, transportation is solely done by lorries. The primary causes are:

- The distance to the larger silos is considered to short to economically implement and alternate mode of transportation. For example, the distance from any smaller silo in the area surrounding Mälardalen, to where larger silos are located, is considered too short a distance to consider rail.
- Most silos are geographically isolated in the countryside and roads are the only infrastructure available. To first transport the grain a short distance, then re-load it onto a train or barge is considered too time consuming and not worth the effort.

As mentioned before, tractor and regular or specialised lorries transport incoming grain to the silos. Specialised lorries are seldom used for grain transports. A few old are still in use, but as to date, no known orders are in place for additional lorries specialised for grain transportation. Specialised lorries are instead more frequently used for fodder transports. In total about 50 % of the grain comes in by lorry and 50 % by tractor. The latest figure is likely to decrease if more farmers decide to use Lantmännen's pick up service. In some cases the farmer has a lorry of his own to transport the grain. It is not economically profitable for the farmers to contract an external forwarder themselves. Therefore the pick up service provided by Lantmännen, mentioned later on, that may serve several farmers, is instead more beneficiary.

As indicated, the amount of required transports can exceed the transporters capacity. In such cases the transporters use what capacity they can find. A gravel lorry or a regular lorry might be used because of a lack of specialised means of transportation. This substitution is not always officially recognized. A farmer might receive a shipment of gravel and upon delivery then may ask the driver if on the return trip he could drop off some of the farmer's grain at the local silo. In some cases, the driver may agree and subsequently receives payment from the farmer. A prerequisite for this action is that the lorry must be suitably equipped to transport grain. In this way, the farmer is not required to make the trip himself. These informal agreements are not recorded in the official statistics.

In an ideal situation the pick-ups should be done in connection with a delivery to the farmer in order to avoid empty return transports - all within an organised and official framework of operations. As Ljungberg (2000) states fodder transports are significant contributors to grain related transports that require substantial transport capacity. It is possible to co-ordinate with grain transports in the other direction. Unfortunately, this seldom occurs.

In order to cope with transport planning and to have an overall view of the grain situation the Swedish Farmers Supply and Crop and Marketing Association has developed a system to handle these types of issues. The system called "Lantmännen Direkt" is an interactive way of communicating with the farmers. The farmers can either call by phone to the association or use the Internet to announce how much grain they want to have picked up, when they want it picked up and from where. This way Lantmännen gets an overall picture of how much grain is to be picked up and where. However, in the end it is up to Lantmännen and the contracted transport partner to decide when and how much grain will be picked up. The grain might be directed to different silos dependent on the type of grain (*i.e.* barley, oats, wheat or rye). Consequently, it is a convenient method for the farmer to handle the transportation. The farmer avoids problem of transporting the grain by tractor longer distances due to the proximity of the specific types of grain and their requisite silos. The farmer can concentrate on continued harvesting or other parallel activities while a third party is conducting the transport. In order to deal with these transport requirements Lantmännen has contracts with local transporters to do the actual transporting. The transport company does all the transport planning based on the inputs from Lantmännen. The transport company has interactive communication methods (*i.e.*, GPS and combined mobile telecommunication) to guide their transport fleet. New unannounced assignments can be forwarded to the closest lorry to the pick up point within minutes of the request. During this process and dependent on the demand, the transport company can decide to subcontract other transporters, if their own transport fleet is not capable of transporting the required amount of grain. For example, in the Mälardalen region grain transports are conducted by the MLT association, which previously consisted of "free individual" transporters. MLT has approximately 50 lorries, but during harvesting season this figure almost doubles in order to cope with the increased demand. In some cases Lantmännen might contract other transporters for a shorter period of time to deal with the high demand for transports.

Since the type of lorry can vary between regular (bed with or without tipper) lorries, specialised, swap body or bulk container lorries the loading time will differ with respect to the type of lorry used. The farmers will have to pay extra if the loading time exceeds the normal stipulated loading time of about 30 minutes. The loading area must provide easy accessibility for the pick up lorry. In addition, the road to the farm and the loading area must also provide easy access to the lorries. Lantmännen regulates this when the farmers use their pick up service. Otherwise the farmer may incur extra cost for the additional handling time. If the farmers decide to transport the grain themselves, of course, there are no regulations or specifications relating to the loading area.

The use of swap body or self-discharging lorries, depicted in Figure 15, provides a new innovation in the transport of grain. The lorry can leave the bed or container at the farm and return to pick it up later. This is to some extent used when transporting grain in the Mälardalen region.

Figure 15 Self-discharging lorry fitted for handling swap bodies

However, because of the ballast weight of the bed, the transport capacity is decreased. The farmer might try to overload the bed when the driver is not present, because he wants to be able to move as much grain as possible. The driver must check this and it would be rather embarrassing for the farmer to admit that he more or less tried to unlawfully transport more grain than allowed. The farmers appreciate the flexibility of the swap body system, but from an environmental point of view this system in not preferable as it results in an empty transport in one direction. Some beds are equipped with side and backdoors for easy unloading, as depicted in Figure 8 on Page 11, but the loading time is longer if instead using regular or specialised lorries (Ljungberg 2000).

Lately the use of timber lorries, Figure 16, has appeared as another type of lorry used for grain transportation in the Mälardalen region. Primarily timber lorries are used only during harvesting season when the transport demand is at its peak. The lorry itself can be fitted with a cargo compartment or container swap body, to hold grain. As most timber lorries are fitted with an on board crane or loading equipment, they can be self loaded and unloaded. This is a good option for farmers if they have no other means of loading the grain. However, the loading time might exceed 30 minutes and the farmer must pay accordingly, but is unavoidable if no other loading method is available. The unloading can also be time consuming if the onboard crane must be used. However this can be avoided if the loading unit fitted on the lorry is equipped with doors that can be opened.

Figure 16 Timber lorry with on board crane

When in contact with Lantmännen, the farmer can specify the type of pick up procedure and the type of lorry he desires. To the greatest possible extent, the desired lorry will do the pick up. Naturally, the farmer must pay accordingly to his specifications – loading time, amount of grain, type of pick up and the distance to the delivery point.

Once the harvesting season is over and the transport intensity is drastically reduced transports focus more on shipments to, from, and between warehouses. Normally, this begins to take place in November. At that time, transport planning becomes less complex, and the existing transport fleet can cover the needed amount of transport capacity. The Swedish Farmers Supply and Crop Marketing Association encourage the farmers to store the grain themselves at their respective farm. This is promoted by economical factors. The farmers will receive an economical advantage if he stores the grain himself. In reality, he will receive more income for the grain he supplies. This is of course lucrative for the farmer, but at the same time the farmer will have to invest in infrastructure, silos or storage facilities. In the long run, it could prove profitable for some farmers to build their own facilities, provided the conditions are right. It is a balance between the amount of grain they grow and the size of the silo required to be built. At some point there is a break-even point.

Most of the trains used for transporting grain in Mälardalen are so called system trains. A system train is a train that goes between two points and is usually fully loaded one way and empty on the other with no in between wagon switches. This results from the fact that some of the train cars used are specially built for transporting grain and nothing else and these train cars go loaded one way and then return empty to pick up more grain. There is also another type of train used and it is in this report called "car-by-car train". Such trains carry different kind of goods in different cars – grain in one, wood in one *etc.* The cars have separate destinations and are switched on and off along the way. Consequently, it takes a longer time for a single car to reach its destination when being transported in a car-by-car train than in a system train because it must be switched. In addition the cars might be re-routed in order to pass a switchyard – a time consuming activity. For large volumes of specialised cargo, (*i.e.* grain), a system train is the preferable solution.

In the case studied, diesel locomotives were used to switch cars at the endpoints while electrified locomotives were used for the actual transport. At least at some point during the transport, most likely at the industry sidetracks, diesel locomotives must be used.

Boats rather than barges do most shipments conducted by sea vessels in the Mälardalen region. This is because most of the grain transported by sea vessels is directly exported and barges would not be an option to use when transporting grain to the Baltic States or southern Europe. Instead bigger boats are loaded at the Stockholm and Västerås silo port. Smaller boats (loading capacity 300 – 600 tonnes) are used for domestic grain transportation as well as in Lake Mälaren and along its coastline. Barges are however not used in any great extent for transports between silos in the Mälardalen region. Instead, as shown, lorries are used for such transports. While boat and barge can transport a large amount of grain at a time over a long distance, those interviewed perceive this mode of transport as having some disadvantages. Because of the high material flow during and immediately after harvesting, the transport demand is very high. This affects the demand for sea transportation. There are not enough boats or barges to fulfil the requirements. The following real-life example illustrates this point:

> "Farmers bring barley by tractor to the Uppsala silo. There it is dried, processed, and prepared for the next leg of transportation. From the silo, it is transported to the port Djurön, a 200 km boat trip south of Uppsala. As grain stores begin to build up at Uppsala, fewer boats are available for transport. This is because the boats are required to transport grain from areas where boat is the only possible means of transport. For example, Gotland is an island off the east coast of Sweden, which can only use boat for transporting grain. It can take up to one week or more before the boat returns to Uppsala. During that time a lot of grain has come in to Uppsala and it must be transported out in a different way because of lack of boats. Very often lorries conduct the transport."

As a comparison, Swedish Fodder uses, to some extent, boat to transport grain to and from their sites on the east and west coast of Sweden. Each boat is self-unloading and has a loading capacity of 1 500 tonnes – 2 000 tonnes. According to a representative from Svenska Foder one of the major conditions for using boat is that the corresponding transport distance on road must be at least 300 kilometres. Otherwise it would not be economically a viable mode of transport. The handling costs and the costs to and from the ports are mentioned to be a disadvantage.

Emission data comparison

Given the information in Table 3, an emission data comparison can be conducted as shown in Table 5. The two modes are compared to the emissions from a lorry.

Table 5 Emission comparisons – tonne/km, lorry used as index (measured in grams)

Mode of transportation	CO_2	SO_2	NO_X
Boat	-17	+0.54	+0.25
Rail (diesel)	-30	-0.001	-0.12

The most environmentally friendly mode of transport is rail. When transporting a relatively large amount of goods a long distance, boat is a better alternative than lorries. The CO_2 level is reduced when using both rail and when using barge. Thus, using any other mode of transportation than lorry would reduce the contribution to global warming (the green house effect). As previously mentioned, this is one of the environmental goals the UN and EU are trying to achieve.

The biggest disadvantage using boat and barge are the SO2 emissions. Scrubbing the exhaust with seawater can reduce sulphur oxide emissions. Because of the natural alkalinity of seawater, SO_2, in the exhaust can be dissolved in seawater then discharged into the sea. If the boats are not fitted with such equipment from the beginning, it may be impossible to install later because of lack of space. Perhaps the main reason for the high SO_2 emission by boat and barge is due to the fact that they often are run on very low quality of diesel. Often they run on the "left over diesel" once the road-based vehicles have received their diesel. The SO_2 emissions would be reduced if boats and barges were using the same quality diesel as lorries.

Methods of decreasing NO_X emissions are by reducing the peak combustion temperature and pressure. This, however, generally increases the formation of other species (particulate, CO, and HC) and the fuel consumption due to the decreased thermal efficiency of the engine (generally, 10 % nitrogen oxides reduction causes 1 % increase in consumption) (Transport Research Laboratory, 1999).

CASE STUDY – LAKE MÄLAREN

Current system

The feasibility case will study the grain transportation situation between two silos in the region. Especially one intermodal alternative route will be studied, namely Uppsala to Stockholm. The assumption is that the Stockholm silo and the Stockholm port will serve as a hub and point of export for the silo facilities surrounding Lake Mälaren, to a greater extent than used for today. Figure 17 shows the route to from Uppsala to Stockholm both by land and water.

Figure 17 Map of land and waterway between Uppsala and Stockholm

Since the aim of the study has not been to conduct thorough economical study of the affects of intermodal transportation, the case studied will mainly take the three previously mentioned environmental factors into consideration. In addition, a time analysis will be conducted from which some economical conclusions may be found.

Most transports from the silos above are, as previously described, conducted by lorries. The lorries go straight from silo to silo without pickups along the route. Road transports may instead be shifted to waterway or railroad transportation. One obvious limiting factor for using the waterways in Lake Mälaren is that it is covered by ice for about four months every year (December – March). For heavy-duty vehicles, the fleet used on long-distance goods transport usually consists of new vehicles. As they become older, they are sold, or used for shorter distance transport within the same company.

The distance on land and water between the silos and Stockholm are shown in Table 6:

Table 6 Distances between silos (kilometres)

From:	To:	By road:	By rail:	By water:
Uppsala	Stockholm	69	66	82

Intermodal alternative

The intermodal alternatives consist of using barges of the same type as used in The Netherlands or railroad. It is assumed that such barges can be bought or leased for the period of time desired to use them. Natural constraints in ports of the specific silos limit the length of the barges to 70 metres and the depth to 3.5 metres (the case in Uppsala silo port). That would mean that a set of two barges is capable of transporting about 1 000 tonnes of grain. However, at that time the barges are not fully loaded since the depth in the harbour limits the loading capacity.

In the intermodal alternative the barges would move in a set route and set timetable between the silos. The suggestion is to use to move straight from the Uppsala silo to the Stockholm silo either by barge or railroad. Once in Stockholm the grain may be cross-loaded to another mode of transport or stored in the Stockholm silo.

Results

The results show the difference in emissions when transporting the amount of grain equivalent to one set of barge (1 000 tonnes) both by road, rail, and water. It is assumed that 1 000 tonnes is picked up at the Uppsala silo and transported straight to the Stockholm silo.

In the current system 25 lorries are required for the task, while in the intermodal case only one trip either by barge, or rail, would be sufficient.

Table 7 Total amount of emissions by mode of transport between Uppsala and Stockholm when transporting 1 000 tonnes, measured in kilos

Mode of transport	CO_2	SO_2	NO_X
Lorry[b]	3 312	0.69	28.98
Barge[a, b]	2 542	54.94	44.28
Rail[b]	74.48[c]	$93*10^{-5}$ [c]	23.76 [c]

[a] Transport Research Laboratory (1999).
[b] www.ntm.a.se, accessed 5th of September 2003
[c] Not including electricity production

The data used for barges are primarily based on emission rates for tug and fishing boats at moderate activity. The emission rates were calculated using the known fuel consumption per working day, assuming that that one roundtrip between Uppsala and Stockholm is possible in one working day. The data found at www.ntm.a.se was used as reference to ensure that the calculated emission data was not completely out of range.

In the case of rail, the total electric consumption is 50 kWh.

The data in Table 7 can be broken down more in detail to show the emissions trip. This is depicted in Table 8.

Table 8 Emissions in the current and intermodal systems, measured in kilos / trip

Mode of transport	CO_2	SO_2	NO_X
Lorry	132.48	0.028	1.16
Barge	2 542	54.94	44.28
Rail	74.48	93*10-5	23.76

Another interesting aspect is to calculate the time required, since increased time often means increased cost, from point A to B in segments including loading, transport, and unloading. By doing it is possible to identify in what segments an intermodal alternative would be most beneficiary from a time-cost point of view.

Table 9 Time factor by mode of transport when loading 1 000 tonnes

Loading	Lorry	Barge	Rail
Theoretical capacity	160 t / h	500 t / h	160 t / h
Capacity per unit	40 t / 15 min	500 t / h	50 t / 18.75 min
Required time 1000 t	6.25 h	2 h	6.25 h

The barges can theoretically load 650 tonnes per unit but because of the shallow water in Uppsala silo port each barge may only load 500 tonnes.

Table 10 Time factor by mode of transport when transporting 1 000 tonnes

Transport	Lorry	Barge	Rail
Required time 1000 t	31.36 h	8.86 h	1.32 h

For lorry, requiring 25 trips to transport 1 000 tonnes, the transport was divided in two parts. On the first part, between Uppsala and Stockholm travelling on the highway, the average speed was assumed to be 80 km/h. For the second part, downtown Stockholm, the average speed differs but in total, the distance inside Stockholm almost requires the same time as the transport between the two cities (Upplandstransport, 2nd of April 2004).

For barges, requiring only one trip to transport 1 000 tonnes, according to Peter Belin (1st of December 2003) the average speed is about 5 knots.

Finally, for railroad, also requiring only one trip, the average speed was assumed to be 50 km/h (industry side tracks included).

Table 11 Time factor by mode of transport when unloading 1 000 tonnes

Unloading	Lorry	Barge	Rail
Theoretical capacity	480 t / h	250 t / h	480 t / h
Capacity per unit	40 t / 5 min	500 t / 2 h	50 t / 6.25 min
Required time 1000 t	2 h	4 h	2 h

Figure 18 shows the analysis for the current used system and the intermodal alternative in the case of Uppsala to Stockholm, based on the data depicted in Table 9 - Table 11.

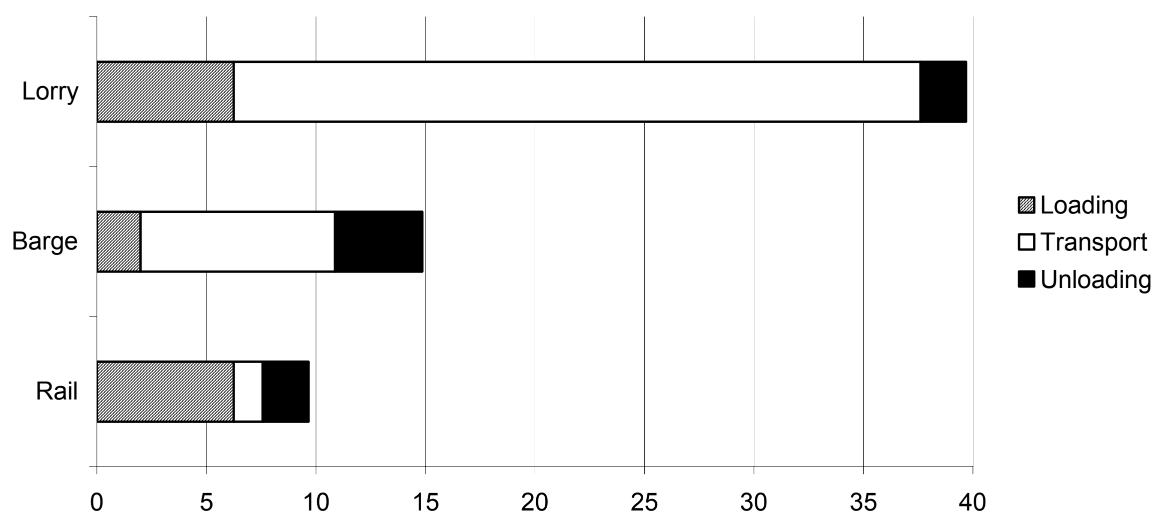

Figure 18 Relative time analysis for transports Uppsala – Stockholm, measured in hours per 1 000 tonne of transported grain

DISCUSSION

The first issue that must be discussed is how intermodal transports should be defined. There are many definitions, each related to particular perspectives and the topics of discussion. In the case of grain transportation, the definition must be set early on to eliminate any potential confusion. Grain has been found to be a typical bulk commodity by nature in the aspect of its obvious consistency. If you decide that an intermodal transport must include transportation in one and the same cargo unit, it would limit the use of the term.

If one were to transport grain in a container the required ballast weight of the container would result in less grain being transported, making the transportation economically unprofitable. Another solution is to transport grain in sacks. The ballast weight is low, however the handling process would prove time consuming and also expensive in relation to the profit an intermodal solution would offer.

Hence, the feasible solution found during the study is to switch modes of transportation of the grain as it is – as a bulk commodity. This can be accomplished between pipeline, barge, rail or motor carriers.

Analysis of the case study results

The case study results revealed that for all emissions, the train clearly is the least polluting form of transport. The amount of pollution caused by inland cargo ships is also quite high. The main reasons for this are that no legislative action has yet been undertaken on ship emissions, whereas tough restrictions have already been applied to lorries. Also, the fuel used (maritime diesel for ships) causes the emission indices per amount of energy consumed to be higher. If the barges use more environmentally friendly diesel the level of SO_2 will most likely decrease significantly. The variables change over time due to implementation of new technology and regulations, and also considering fleet rotation. In terms of the CO_2 emission rate, if using barge it is reduced by 23 % compared to lorry when transporting 1 000 tonnes of grain between Uppsala and Stockholm. If using rail, the same figure is 98 %. In terms of SO_2, it is significantly increased for barge, and in the case of rail significantly reduced compared to lorry. In terms of NO_X, it is also drastically increased for barge, while in the case for rail it is reduced by 17 % compared to lorry.

The time analysis showed that lorry requires more than double the time transport the amount compared to barge and more than four times compared to rail. When using rail instead of lorry to transport 1 000 tonnes of grain between Uppsala and Stockholm the transport time, loading, and unloading included, is reduced by nearly 76 %. When using barge the same figure is 63 % compared to lorry. Other time consuming factors must also be taken into account for all modes of transportation. Others factors include such things as traffic or track congestion, engine failure, traffic accidents, bad weather, construction work *etc*. The number of trips required should be multiplied with these factors, making lorry significantly more vulnerable to other factors compared to the two other modes. Depending on what average speed is set for the transport some other factors can be included in a decreased average speed. Loading and unloading for lorries and railroad are the same. The major differences lie in the transport time. The emissions in the results fall under the series transports. As a consequence the emissions do not include engine idling when loading and unloading. If they did the rates for lorry would increase. This could be studied in future research. Since time very often means money, the analysis shows that time is a disadvantage when it come to lorries. Perhaps the time can persuade companies switch mode of transport instead of only referring to the environmental benefits when promoting intermodal transportation.

The case study showed that railroad is the most environmentally friendly mode of transportation. Barge must not be discarded because of the high SO_2 and NO_X emissions.

Required time for transport and other factors must be taken into consideration. The quality of diesel has already been mentioned but it remains more or less an economical issue – low sulphur-content diesel is more expensive. One way to reduce NO_X emissions is to use the Humid Air Motor (HAM), a method in which the intake air is dampened, thus reducing the combustion temperature and the creation of NO_X.

To promote other modes of transportation than lorry the transport operators should pay for every transported kilometre, with reduced cost for low fuel consuming and optimised loaded lorries. By doing so, the market itself would increase the efficiency in the transport sector, reduce the emissions, lower the costs for the consumer, and promote intermodal transportation.

Intermodal transportation

Handling process

Shifting a single cargo unit with the right equipment, *e.g.* a container, is a flexible, simple and fast solution. Large quantities can be moved at the same time. When transporting a bulk commodity, loading, unloading and shifting modes can be time consuming activities. Specifically, loading may make one dependent on a conveyor belt or pipeline. These modes of loading offer limited transport capacity when moving the grain from the storage location to the actual means of transportation. In a similar sense, unloading and shifting between the modes consumes an equal amount of time despite the fact that some modes of transportation are self-unloading, *e.g.* some barges that have on-board cranes.

However, grain is a bulk commodity and it is loaded onto any mode of transportation in the same basic manner (*i.e.* through some kind of pipeline, conveyor belt, or funnel). Consequently, the loading time should not make a difference when choosing mode of transportation. Thus, loading time is not an economical factor (time-cost) to be considered when choosing a mode of transportation. Regardless of the mode of transportation, loading is done in the same way. Since the different modes vary in capacity per loading unit, it obviously does not take the same amount of time. However, the relative loading time compared to the transported amount stays the same. Figure 14 illustrated that lorries and railroad cars could be loaded at the same location, thus offering good possibilities for intermodal transportation. The silos equipped with railroad sidetracks all have functioning loading systems to load the cars.

Unloading, lorries and trains are easy and fast. Both have doors or hatches that can be opened. Again in this case, it should not affect the choice of mode of transportation. However, when using barge or boat the unloading process can be different. Either the boat has an on board crane or the port of de-embarkation has means of unloading the grain. Other means of unloading a barge or boat is by a suction device or to use some kind of screw-type device. In a sense, the unloading process can be seen as a time consuming activity, but compared to the large amount of grain that can be transported it is cheap. The unloading process should not be seen as a limiting factor when using boat or barge.

In conclusion, the respective loading times should not dictate the mode of transport to be used.

Investments in infrastructure and appropriate means of transportation

In order to have a well functioning intermodal transport system it is necessary to have the appropriate infrastructure (*i.e.* accessibility to roads, railway lines and waterways; storages or other facilities). Some of these conditions may already be fulfilled and others can be fulfilled after investments. However, industries today seem reluctant to mainly invest in railway lines. This choice does not promote intermodal transportation. Individual corporate investments in waterways are very seldom made today and are not seen as an investment alternative. More likely, the corporate interests would lie in the port facilities. Therefore, already existing sites located close to railway lines or waterways offer a good opportunity to conduct intermodal transportation. Usually, between sites that handle small amounts of grain, the mode of choice is by road. In contrast, the major shipments should be done using intermodal transportation between those facilities capable of offering multiple methods of transportation.

One way to encourage companies to conduct intermodal transportation is for the government to subsidise infrastructure investments leading to intermodal transportation.

Regardless, practical implementation of intermodal transportation is not easy to achieve. The chain of command in companies, like the Swedish Farmers Supply and Crop Marketing Association, will need to work hard to produce a long-term vision and commitment among the farmers, industries, and freight forwarders. Moreover, companies and freight forwarders will sometimes be required to invest in order to save. For example, it may be necessary for industry to invest in the electrification of industry sidetracks. The question remains as to who will pay for this infrastructure improvement. There are many options: Banverket (the Swedish state owned company responsible for railroad infrastructure), the customer, the industry on which the track is situated, the public or a joint payment.

Today most railway stations and railway facilities; ports and port facilities are well established and the infrastructure already exists. Making improvements that will encourage intermodal transportation may present logistic problems in the existing infrastructure. New constructions with specifications that fulfil the requirements for intermodal transportation are very expensive. Re-construction and adjustments to the existing infrastructure may offer the best and most cost effective solution to suit those requirements needed to conduct intermodal transportation. The physical layout of the existing silos, ports and railway stations can cause problems if they are to be adapted to service grain transportation. Unfortunately, it is not always possible to adjust the infrastructure to meet the requirements. This is continues to be an impediment to intermodal transportation.

Possible future scenario

Using intermodal transportation between central silos in different regions is an interesting alternative. The following example illustrates the possibilities of introducing intermodal grain transportation between different geographical regions in Sweden

Figure 20 a, and b show the geographical areas of interest: Mälardalen, Västergötland, and Östergötland. All three regions are major grain producers in which the same grain handling company operates – Lantmännen. This would make intermodal transportation within the company between these regions possible. In Östergötland lies a port, Djurön outside Norrköping, used for exporting grain. It is operated by the Lantmännen and is the largest single grain export facility in Europe. The facility can store up to 250 000 tonnes of grain and accommodate ships that load as much as 65 000 – 70 000 tonnes (www.norrkoping-port.se, 2003). The distance between Uppsala and Djurön, is about 250 kilometres by water.

There is a good railroad network between the regions. The problem is that the tracks are very busy because it is shared both by passenger and goods traffic. Passenger traffic primarily occurs during day, forcing the majority goods transports to take place during night.

The distance between central grain stations in different regions is about 300 km by land. This is the minimum distance considered to be optimal for the use of rail when compared to cost of road transport. By implementing intermodal grain transportation a hub-and-spoke methodology would evolve between regions. In turn, the main hub can transport the collected amount to other facilities.

Figure 19 depicts a possible hub-and-spoke system within, and between the three regions.

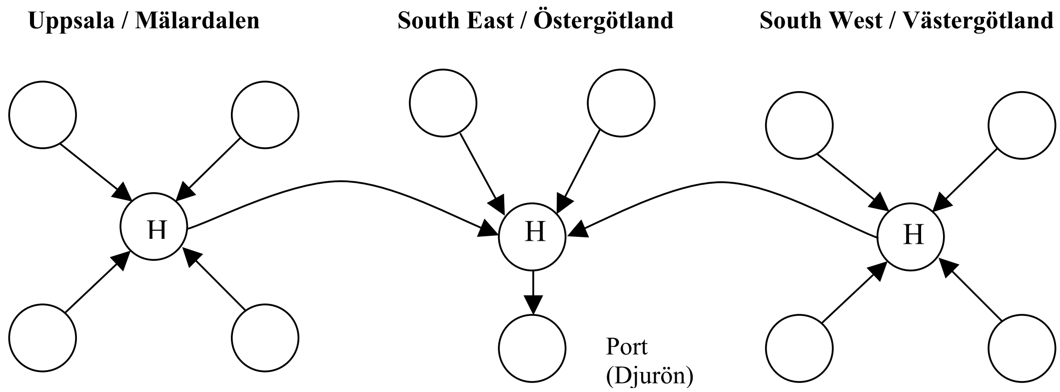

Figure 19 Possible grain hub-and-spoke system

When using the waterways from both regions, the barges must pass one or several water locks. The waterways in Västergötland mainly consist of canals, where the size of the canals and water locks limit the size of the barge and in turn the amount of potential transported grain. However, this does not limit the use of barges, only the size.

Going from Mälardalen to Östergötland, one is not as dependent on canals. Instead, the barges move on lakes and along the waters of the coastline. Figure 20 a, and b illustrate both the possible waterways and railways from the two different regions.

Figure 20 a)

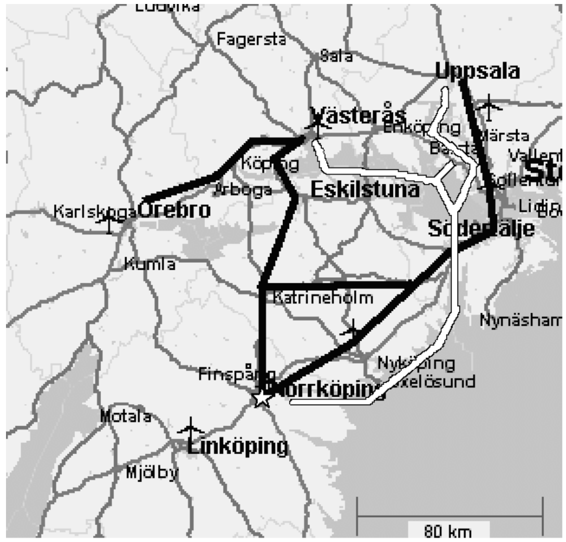

Figure 20 b)

Figure 20 Rail- (black) and boat (white) transport from a) Västergötland and b) Mälardalen to Östergötland

These are just visions of possible future developments, and further studies must be conducted before coming to any feasible and reliable conclusion. However, it can be anticipated that in the case depicted in Figure 20 a, barge is not a feasible solution since the waterway connecting the silos in the south west of Sweden to Djurön is too small to move on with the size barges needed to be used. In the case depicted in Figure 20 b, one would have to travel in coastal waters in order to get to Djurön from Lake Mälaren. Depending on the weather it would not be possible to travel this distance when using barge – a mid-sized boat would have to be used instead.

Attitudes to changes

At the low levels the agricultural transport sector is practical work primarily based on experience and inherited knowledge rather than theoretical studies. Though it was not the primary purpose of the study, the interviews conducted with staff revealed scepticism towards logistics solutions imposed from higher order, especially if those who want to impose such solutions lack credibility due to limited practical experience. The theoretical part of intermodal logistics must be bridged with practical applications and examples from successful intermodal solutions.

Personnel involved on low levels meant that transports have been executed without problem "for all times", so why change it? If there is no imminent necessity, the result will be a lack of willingness to change the already functioning system. Today, tractors and lorries conduct transports from farms. Intermodal transportation is not likely to occur at that stage. Ljungberg (2000) stated that in order to reduce environmental impact of grain transports one of the most important thing is to co-ordinate the transports and to optimise the routes.

Generally, the bottom-up approach for introducing intermodal grain transportation must be based on the operational benefits gained in time, money, and equipment. In contrast, the top – down approach for introducing grain transportation is based on economies of scale, co-operation between logistic actors, environmental aspects, rationalisation, and the optimisation of the supply chain. Different levels in the grain logistic chain have different ways of looking at intermodal transportation and the accompanying benefits. Intermodal transportation requires a broad overall picture and system perspective. Therefore, the guidance and initiative to implement such a system can only come from top-down. This is due to the fact that there is no necessity for intermodal transportation at the lower levels. However, for successful implementation, all levels must support the decision. Also on the detailed level the solutions must be satisfactory in reality. The prerequisites are will, trust, education, and authority.

Another possible disadvantage or important factor that must be taken into consideration is hygiene. This may not directly impact intermodal transportation, but it does affect its applicability. Grain is a bulk commodity, which is easiest transported as it is. When conducting intermodal transportation one must switch one or more modes of transportation, thus exposing the grain to different environments and cargo units. It is very important for the cargo units to be clean. If not, groceries may be polluted and that could negatively influence the possibilities to introduce intermodal transportation. Thus, a lack of hygiene can threaten the institutionalisation of intermodal transportation. However, when in contact with logistic actors in the grain industry, the hygiene issue is not considered a limiting factor for intermodal transportation. Already today grain is shifted between different environments and storage areas. The risk lies more in if the water content is too high for a longer period of time. Mitigations are done through sufficient drying and ventilation.

Also mentioned, as a hinder, more to the will than to the possibility, is distance. The longer the transported distance, the more beneficial intermodal transportation would become. Among those interviewed, some stated that the studied region (Uppsala / Mälardalen) is itself geographically too small to economically institute intermodal transportation. The distances between the farms and grain silos are too short to make use of any other modes of transport other than road transport. It is not economically feasible.

Hard factors are elements that can be measured: profit, investments, savings and costs, pollution, and time. Soft factors are subjective elements that can only be measured with great difficulty: trust, responsibility, will, understanding, and independence based on company cultural and background. When using an intermodal transport chain one must trust the different components of the chain and believe that everything will work as planned especially when there is more than one mode involved and perhaps different transporters. By nature, there is a risk that something could go wrong in the transport chain. Timings and cross docking between the modes must be as exact as possible. This feeling must be empirically overcome by showing those who hesitate that the systems can work effectively. Trust is an important factor particularly if you are dependent on more than one freight forwarder to conduct your transport. Basically, as long as one does not use one's own transport chain, both will and trust seem to decrease in favour for your own well-established and functioning transport system. Some examples are risks associated with a lack of resources, limited insight and control, and the risk of something going wrong without the possibility to do anything about it. Both company cultural background and personal background sometimes limit the will to change a functioning system and to delegate and rely on others. Hard factors tend to attract more interest from company officials than soft factors since they are economically measurable. Thus, hard factors are seen to be more important when it comes to intermodal grain transportation. Soft factors take a secondary position.

In the case of railroad transport, it is not the grain industry and logistic layout that limit its use. In the Mälardalen region, there are many possibilities to conduct intermodal transportation. As found during this study, there are the following possibilities:

- Between silos in Mälardalen and different regions offering such infrastructure possibilities
- Between silos and industries (mills *etc.*) offering such infrastructure possibilities

As previously stated, from Uppsala the grain is partially transported by railroad. The question has been raised as to why the Uppsala silo is the only facility to use railroad. Silos at Stockholm and Västerås have access to railroad. This implies that the grain industry and logistic community could use railroads. The preference for other modes of transportation is a common railroad phenomenon experienced throughout railroad logistic community for the past 20 years. After the 60's in Sweden, many industry sidetracks were forgotten or eliminated. Those interviewed perceived railroad as a complicated method of transporting goods. Cars must be switched, return transports were often empty, cars must be booked in advance locally or from abroad[3], and sidetracks must be maintained. These activities incur cost and the cost-benefit analysis resulted in a decision to use other modes of transport. Ultimately, the end-user pays for the transport. For instance, a loaf of bread costs money, to make the bread costs money, and to get that grain to the bakery costs money. In this case, it is the bakery that actually pays for the transport. If the bakery finds the transport too expensive another solution will be sought. The grain industry in conjunction with other companies choose the lorry for its flexibility and low price.

Regarding railroad transportation, the overall situation of goods transport must change in order for the grain logistic community to once again implement the use of railroad. Current price politics could be improved to encourage railroad traffic. It is currently too complicated and expensive to use railroad in the unique case of grain transportation. There are many ways to encourage railroad transport. One could increase the tax on transports by road, lower the prices for switching and renting railroad cars, and for using the track. The PPP, polluter pays principle, is a system that can be introduced. If a transporter uses vehicles that emit a significant amount of pollution, then he must pay accordingly. This will promote modes of transport that are environmentally friendly. The maintenance of industry sidetracks could be a shared responsibility by Banverket and the industry that owns it.

CONCLUDING REMARKS

Having found that grain is best suitable for being transported as a bulk commodity, the following conclusions may be drawn from the report regarding the intermodal and grain sector as a whole and, in specific, the case study:

- After having studied, and mapped the flow of grain in the Uppsala / Mälardalen region, it is evident that the current locations of the silos in the area offer possibilities for intermodal transportation.
- It is possible to introduce intermodal grain transportation in the Uppsala / Mälardalen region using already existing infrastructure. The infrastructure does not hinder the implementation – interoperability between the modes already exists.
- In terms of the CO_2 emission rate, if using barge it is reduced by 23 % compared to lorry when transporting 1 000 tonnes of grain between Uppsala and Stockholm. If using rail, the same figure is 98 %. In terms of SO_2, it is significantly increased for barge, and in the case of rail significantly reduced compared to lorry. In terms of NO_X, it is also drastically increased for barge, while in the case for rail it is reduced by 17 % compared to lorry.
- Railroad is the most environmental friendly mode of transportation in the system studied.
- When using rail instead of lorry to transport 1 000 tonnes of grain between Uppsala and Stockholm the transport time, loading, and unloading included, is reduced by nearly 76 %. When using barge the same figure is 63 % compared to lorry.
- The loading and unloading process and time for barge and rail are not limiting for intermodal transportation.
- In all, it must be cheaper and easier to use railroad transportation if railroad is to become competitive to road transportation.

[3] as the case in Mälardalen where grain cars from Germany were brought in during the harvesting season some 20 – 30 years ago

- Economical measures, like the Polluter Pays Principle, and governmental subsidies, can be taken to promote intermodal transportation.

FURTHER STUDIES AND RECOMMENDATIONS

As a next stage of a scientific study, the work may be further expanded and cover a wider area. The best step would be to cover a larger geographical area, perhaps the whole of Sweden. By covering a larger geographical area it is possible to determine if there are any intermodal alternatives between sites located at greater distance from each other than studied in this report. Additionally, a larger geographical area would introduce economies of scale and it would be possible to see what benefits the freight forwarder can make. The same applies to environmental aspects though the benefits cannot directly be attributed to a single body, but rather to the society as a whole.

This study is primarily theoretical. The next step is a trial run of intermodal transportation in the region studied. Based on the current study, it is recommended that the major freight forwarders be investigated rather than the small transporters.

As a recommendation, the grain logistic community on all levels should be educated in the benefits of intermodal logistics. A suggestion for improvement would be to regularly arrange a logistic seminar for as many of those involved grain logistic actors as possible. The purpose of the seminar would be to show the participants the benefits of intermodal transportation and for the grain logistic actors to get acquainted. The ultimate aim is to improve inter-company relationships and to obtain the knowledge in what areas different companies may co-operate and consequently save or earn money.

Further economic studies could be conducted on how intermodal transportation can be introduced in the agricultural sector. It would not necessarily have to be focused on grain or even agriculture. This study indicates that many different logistic sectors suffer from the same challenges such as complications to using railroad and conservative thinking.

REFERENCES

Banverket (2001). *Marknadsanalys för godstrafik*.

Bloomberg, D & LeMay, S & Hanna, J (2002). *Logistics*. Prentice Hall.

Brewer, A & Button, J & Hensher, D (2001). *Handbook of logistics and supply-chain management*. Pergamon. 1st edition.

Coyle, J & Bardi, E & Langley, J (1992). *Management of Business Logistics*. West Publishing. 5th edition.

Coyle, J & Bardi, E & Novack, R (2000). *Transportation*. South-Western College Publishing. 5th edition.

DeWitt, W & Clinger, J (1999). *Intermodal freight transportation*. Committee on Intermodal Freight Transport, Transportation Research Board, Washington D.C.

Gebresenbet, G & Oostra, H (1997). *Environmental impact of goods transport – with special emphasis on agricultural and related products*. Report 219, Department of Agricultural Engineering, Swedish University of Agricultural Sciences, Uppsala.

Gebresenbet, G (1999). *Agricultural goods transport and environment*. Report 235, Department of Agricultural Engineering, Swedish University of Agricultural Sciences, Uppsala.

Gebresenbet, G & Ljungberg, D (2001). *Samordnad godstransport inom lantbrukssektorn – för att främja ett uthålligt transportsystem*. VINNOVA Report VR 2001:14.

Godstransportdelegationen (2001). *SOU 2001:61*.

Hayuth, Y (1987). *Intermodality: Concept and practice*. Lloyds of London Press.

Ljungberg, D (2000). *Possibilities to reduce environmental impact of grain transports through coordination and optimisation*., Department of Agricultural Engineering, Swedish University of Agricultural Sciences, Uppsala. Institutionsmeddelande 2000:4

Ljungberg, D & Gebresenbet, G & Eriksson, H (2002). *SAMTRA – samordning av gods-transporter*. Report 249, Department of Agricultural Engineering, Swedish University of Agricultural Sciences, Uppsala

Lumsden, K (1998). *Logistikens grunder*. Studentlitteratur.

Microsoft (1996). *Microsoft® Encarta® 97 Encyclopedia*. De Luxe Version on CD ROM. © 1993 – 1996 Microsoft Corporation.

OECD, Organisation for Economic Co-operation and Development, (2002). *Benchmarking Intermodal Freight Transport*.

Ottosson, T & Svensson, S (1982). *Samordningsmöjligheter inom jordbrukets utomgårds-transporter*. Chalmers University of Technology, Department of Transportation and Logistics, Gothenburg.

Pewe, U (1993). *Lönsam logistik*. Förlags AB Industrilitteratur. 1st and 2nd edition.

Pimentel, D & Pimentel, M (1996). *Food, energy and society*. University. Press of Colorado. Revised edition.

SCB, Statistiska Centralbyrån, (2002). *Yearbook of Agricultural statistics 2002 – including food statistics*.

SEPA, Swedish Environmental Protection Agency, (1999). *A sustainable food supply chain*. Report 4966.

SIKA, Statens Institut för kommunikationsanalys, (2000). *Prognos för godstransporter 2010*. Report 2000:7.

SIKA, Statens Institut för kommunikationsanalys, (2003). *Transporter och kommunikationer – SIKA:s årsbok 2003*.

SIKA & SCB, (1999). *Varutransporter på väg avseende kvartal och år 1998*.

Sjögren, S (1996). *Effektiva kombiterminaler – en tillämpning av DEA*. Gothenburg University: BAS, Gothenburg.

Storhagen, N et al. (1999). *Godstransporter och logistik: kunskapsläge och forskningsbehov*. Transportforskningsberedningen (TFB), KFB. Studentlitteratur.

SNRA, Swedish National Road Administration (2001). *Lasta lagligt 2001*. Vägverket.

Thor, C & Kirkendall, E (1982). *Energy Conservation*. Extension Engineering, Kansas State University.

Transport Research Laboratory (1999). *Methodology for calculating transport emissions and energy consumption*. Project Report SE/491/98, Crowthorne, United Kingdom.

U.S Department of Transportation (1994). *Environmental Advantages of Inland Barge Transportation.*

Woxenius, J (1993). *Enhetslaster – teknik, ekonomi och historia*. Meddelande 58, Chalmers University of Technology, Department of Transportation and Logistics, Gothenburg.

Woxenius, J (1998). *Development of small-scale intermodal freight transportation in an systems context*. Doctoral thesis, Report 34, Chalmers University of Technology, Department of Transportation and Logistics, Gothenburg.

Internet

BMH Marine AB, www.bmhmarine.se, accessed 23rd of December 2003.

NordMills AB. www.nordmills.se, accessed 23rd of October 2003.

Norrköping Port and Stevedoring, Norrköpings Hamn och Stuveri AB, www.norrkoping-port.se/nhs_eng/spannmal.asp, accessed 11th of September 2003.

SCB, Statistics Sweden. Statistiska Centralbyrån. www.scb.se, accessed 11th of July 2003.

Swedish Board of Agriculture. Jordbruksverket. www.jordbruksverket.se, accessed 20th of August 2003.

Swedish Fodder. Svenska Foder, www.svenskafoder.se, accessed 4th of March 2003.

The network for transport and environment. Nätverket för transporter och miljön. www.ntm.a.se, accessed 5th of September 2003.

The Swedish Farmers Supply and Crop Marketing Association. Lantmännen. www.lantmannen.se, accessed 10th of October 2003.

Interviews

Belin Peter. Belins Bogsering & Sjötransporter, +46 18 10 23 32. 1st of December 2003.

Falk Johan. Regional Co-ordinator, Lantmännen, +46 171 266 61. 5th of September 2003.

Hult Bertil. Chief of Logistics, Svenska Foder. +46 510 828 23. 4th of March 2003.

Persson Henrik. Farm Foreman. +46 13 13 06 58. 3rd of October 2003.

Upplandstransport. +46 17 28 00. 2nd of April 2004.

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