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FINANCIAL AND ENVIRONMENTAL IMPACTS OF A DRY PORT TO SUPPORT TWO MAJOR FINNISH TRANSIT SEAPORTS

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ABSTRACT

Environmental problems and issues have received more and more attention during the last decades. Reasons for this are different increased external costs such as congestion, CO_2 emission, noise and accident. Transportation sector is the only sector with increasing external costs. The EU will increase its attention in decreasing the external costs of transport.

Aim of this research was to find out if a dry port solution could decrease costs of transport, especially external costs. Dry port concept is an intermodal transport system, where inland transport between seaport and dry port is performed by rail transport instead of traditional road transport. In addition, dry ports offer similar services as seaports.

Research is conducted by performing a literature review about dry port concept and costs of transport, especially external costs of transport. Financial and environmental impacts of the dry port concept are studied by comparing costs of road and rail transport by cost accounting and with a simulation model. Location of dry port is researched with different gravitational models.

Results of the literature review are that rail transport is environmentally friendlier mode of transport than road transport. In addition, cost-efficiency of the transport system can be decreased by increasing proportion of rail transport. A cost model was created to compare internal and external costs of both the road and rail transport. According to the cost model, rail transport is more inexpensive mode of transport in external and internal costs. In addition, a simulation model was created to compare conventional road transport and dry port implemented transport. Results of the model are that if only costs of freight movement are considered, the dry port implemented transport is environmentally friendlier and more cost-efficient. Results of gravitational models are that city of Kouvola is in a good position to be a dry port if only Finnish inland distribution is considered. Russian transit traffic through Finland improves location of Kouvola to be a dry port.

Keywords: Dry port, environment, external costs, seaports, intermodal transport

TIIVISTELMÄ

Ympäristöongelmat sekä -kysymykset ovat saaneet paljon huomiota edellisinä vuosikymmeninä. Syinä tähän ovat erilaiset ulkoiset kustannukset, kuten ruuhkautuminen, hiilidioksidipäästöt, äänisaasteet sekä onnettomuudet. Kuljetussektori on ainut sektori, jonka ulkoiset kustannusten määrä on noussut koko ajan. EU:n tavoite on vähentää kuljetussektorin ulkoisia kustannuksia.

Tämän tutkimuksen tavoite on tutkia, voidaanko kuivasatamakonseptin avulla vähentää kuljetuskustannuksia, erityisesti ulkoisia kustannuksia. Kuivasatamakonsepti on intermodaalinen kuljetusjärjestelmä, jossa sisämaakuljetukset sataman ja kuivasataman välillä suoritetaan rautateitse. Kuivasatama tarjoaa lisäksi samankaltaisia palveluja kuin perinteinen satama.

Tutkimus on suoritettu tekemällä kirjallisuustutkimus koskien kuivasatamakonseptia sekä kuljetuskustannuksia, erityisesti ulkoisia kustannuksia. Kuivasatamakonseptin taloudellisia sekä ympäristöllisiä vaikutuksia on tutkittu vertailemalla maantie- sekä rautatiekuljetuksen kustannuksia kustannuslaskennan sekä simulointimallin avulla. Kuivasataman sijaintia on tutkittu gravitaatiomalleilla.

Kirjallisuuskatsauksen mukaan rautatieliikenne on ympäristöystävällisempi kuljetusmuoto kuin tieliikenne. Lisäämällä rautatieliikenteen suhteellista määrää, on mahdollista kasvattaa kuljetusjärjestelmän kustannustehokkuutta. Kustannusmallin mukaan rautatieliikenne on sekä sisäisiltä että ulkoisilta kustannuksiltaan tieliikennettä halvempi kuljetusmuoto. Lisäksi kehitettiin simulointimalli, jonka avulla vertailtiin perinteistä tieliikennettä sekä kuivasatamakonseptia. Mallin tuloksena on, että kuivasatamakonseptin avulla voidaan parantaa kuljetusjärjestelmän ympäristöystävällisyyttä sekä kustannustehokkuutta, jos ainoastaan rahdin kuljetuksesta koituvat kustannukset huomioidaan. Gravitaatiomallin tuloksena Kouvolan sijainti jakelukeskuksena on hyvä. Venäjän transito-liikenteen ansiosta Kouvolan sijainti on erittäin kilpailukykyinen.

Avainsanat: Kuivasatama, ympäristö, ulkoiset kustannukset, satamat, intermodaaliset kuljetukset

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1 INTRODUCTION

1.1 Background

Problems concerning environment have received more and more attention during the last decades. Transportation sector is one of the major sources of environmental issues (Aronsson and Brodin, 2006, p.394). The volume of transportation has increased 1.5 to 2.5 times faster than the general growth of the gross domestic product (GDP). The growth of both the world merchandise exports (volume) and the GDP from year 1950 to year 2007 are illustrated in Figure 1.

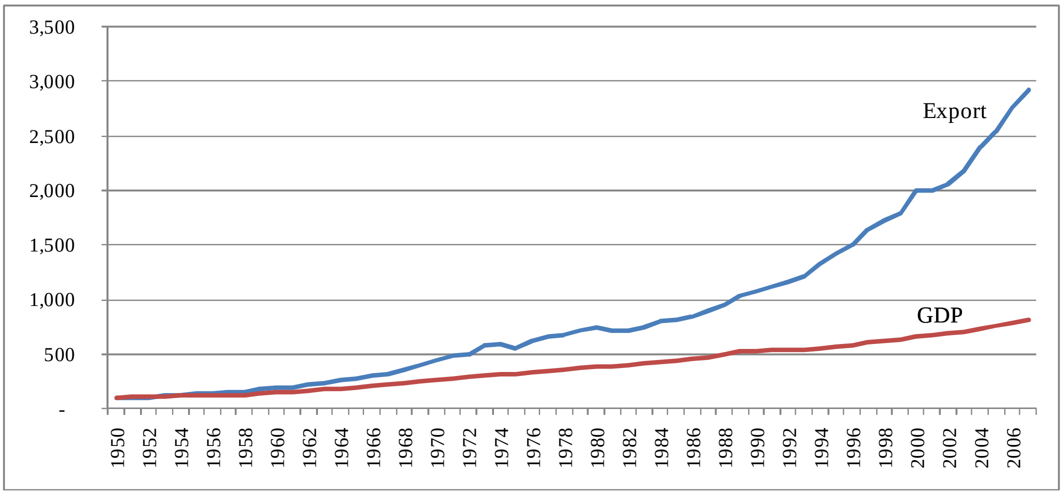

Figure 1 Indices for world economic growth (GDP) and world merchandise exports (volume), selected years. (1950 = 100)

Source: WTO (2008, p.173)

As can be seen from Figure 1, the growth of world merchandise exports has increased significantly faster than the GDP. The growth of transportation is also expected to increase faster than the GDP in the entire world in the near future.

The most important emission that contributes to the climate change is CO_2 (carbon dioxide) emission. Transportation is the only sector with increasing CO_2 emissions, while other sectors have been able to decrease or at least not to increase their CO_2 emissions (European Commission, 2009; UIC, 2009). This kind of development cannot continue, and hence the EU will increase its participation in trying to reduce emissions concerning transportation sector. In addition, the goal of the EU is also to decrease other externalities of transport (e.g. congestion, accidents and noise). (European Commission, 2001)

Inland distribution has become a very important part of globalization, seaborne transportation and freight distribution (Notteboom & Rodrigue, 2005, p.297). In the dry port concept majority of freight is transported by rail from seaport to inland intermodal terminals, which are called dry ports. Only the final leg of transportation is accomplished by road i.e. main transport type of dry port concept is rail. The dry port concept is a way to improve the capacity and cost-efficiency of a transport system; especially seaport's inland access. The dry port concept also improves transport system's environmental friendliness. The concept decreases external costs of the transport system, since railroad is environmentally friendlier transport mode than road. There are also other benefits of the dry port concept such as reduced congestions, noise and accidents at the whole transportation system. (Roso, 2009a & 2009b; Roso *et al.*, 2008)

1.2 Research problem

This research studies dry port concept and its influences on the transportation system. Main research question of this study is:

- What are the financial and environmental impacts of a dry port?

Main research question is further divided into smaller sub-questions. These sub-questions are listed below:

- What are the environmental impacts of a dry port?
- Is a transport system with a dry port solution more cost-efficient than conventional road transport?
- Is it cost-efficiently rational to use a dry port solution, if the dry port is located near seaport or seaports?
- Has city of Kouvola a good position to be a dry port?
- Is there enough warehousing capacity for a dry port implementation?

Empirical part of this research uses different research methods to answer all the sub-questions presented above. In the end of this research, an answer to the main research question is presented based on the sub-questions.

1.3 Research methodology

Although research is important in both business and academic activities, there is no consensus in the definition for research. Main reason for this is that research means different things to different people. Regardless, there appears to be agreement that research is a process of enquiry and investigation. It is systematic and methodical, and research increases knowledge. (Amaratunga *et al*. 2002)

Research can be categorized into two detached types: qualitative and quantitative. The former involves data such as words, pictures or objects, while the latter involves analysis of numerical data. Qualitative means a non-numerical data collection (Amaratunga *et al*., 2002). Quantitative research is based on a positivistic or post positivistic ideal of science. Qualitative research is instead based on an existential phenomenology and hermeneutics philosophy of science (Metsämuuronen, 2006; Todres and Wheeler, 2000).

The majority of logistics research is primarily conducted by quantitative research. There has been a lot of discussion whether or not it is sensible to choose use only other or both research types. According to Mangan *et al.* (2004) and Amaratunga *et al*. (2002), there are benefits which can result from combining qualitative and quantitative methodologies in logistics research instead of using only the other type. If both the qualitative and quantitative types are used in research, it is reasonable to choose one or the other to be the main methodology of the research (Metsämuuronen, 2006).

Majority of this master’s thesis gathered data (data for cost model, simulation model and gravitational models) is numerical, which means that the research is mostly quantitative by its nature. There are also some interviews that are conducted in qualitative form.

Trustworthiness of a research is traditionally described with terms of validity and reliability. Reliability refers to repeatability of the research i.e. if the results of the research remain alike - when the research is repeated – the research’s reliability is high and vice versa. (Metsämuuronen, 2006)

Validity refers, how well the research measures the phenomena, what it is supposed to measure. There are several types of validity that contribute to the overall validity of the research. Two main types are internal and external validity. Internal validity is the approximate truth about inferences regarding cause-effect or causal relationships. External validity concerns with the degree to which research findings can be applied to the real world. (Metsämuuronen, 2006)

Simulation data concerning starting and destination points of transport are not very valid, since they are chosen from limited data. They do not reflect real with greatest accuracy. In addition, there are not many starting and destination points used in simulation model, while in the real world there would be more starting and destination points. Transshipment costs not taken into account might skew costs of transport. Intermodal transport costs of a dry port solution would be more expensive, if transshipment costs were also included in cost calculation.

This research measures financial and environmental impacts of a dry port. Study uses cost accounting, simulation model and gravitational models to research those impacts. Results of these methods are good and in relation with literature reviewed. Internal validity is at a good level. External validity of the study is at an average or above average level. Findings of the study can be applied in Finland. They could also be applied in other countries, but the external validity would decrease, because this research is mainly focused in Finnish values (e.g. tariffs for the use of rail network). External validity for Finnish transport is good. Rail and road transport are studied with certain input values. If road or rail transport equipment’s e.g. investment costs change a lot if compared to values used in this research, then the output values might change also. This is a limitation in external validity. There is a definite relation between literature review and empirical findings.

Reliability of this research is at a good level. External costs gathered through a literature review might differ, if they are collected through different sources. There is a lot of research concerning different external costs of transport, but the results of different studies vary considerable. In this research estimates of different researches are used to improve reliability.

1.3.1 Discrete-event system simulation

Comparison of the current transport system and a transport system with implemented dry port solution is performed by discrete-event system simulation. Discrete-event system simulation is one type of simulation. Simulation imitates real-world processes e.g. manufacturing systems, public systems or transportation systems. Behavior of a system in time can be researched by developing a simulation model. The model includes assumptions regarding the operation of the system. A validated model can be further used to research varied situations i.e. changes in the system can be simulated by simulation model. Another possibility of a simulation model is to research certain system before it is built in the real-world. Data is collected from the simulation model as if a real-world system was observed. Data is further used to estimate performance of the simulated system. Because of that it is important to create the simulation as accurate as possible to imitate the real-world to avoid incorrect results. In discrete-event system simulation the state variable changes only at a discrete set of points in time (Banks *et al*., 1996)

1.3.2 Gravitational model

Gravitational model used in this research is an integer linear model. Gravitational model is completely quantitative model. It is based on numerical data concerning population of cities, distances between cities and salary classes of different countries.

Aim of the gravitational model is to compare different distribution centers and find out which one is the most inexpensive in terms of distribution costs. Model uses linear integer programming to achieve optimal location for distribution center i.e. it is an linear integer programming model (LIP-model). In linear integer programming model values of variables are restricted to integers (Sierksma, 2002, p.209). In this research the variables are restricted to be binary values.

1.4 Data collection

Data concerning dry port concept and costs of transport were collected through a literature review. Most of the references are scientific journals. Other references are conference proceedings, dissertations, EU projects and business-oriented publications.

Data regarding capacity of container warehousing was collected through interviews. They were committed with management personnel from cities of Kouvola, Lappeenranta and Hamina.

Gravitational model uses populations of 50 largest cities in Finland. Other data regarding gravitational model are distances from distribution centers to largest cities in Finland, and also to St Petersburg and Moscow. Data concerning distances and populations were gathered from various Internet sources, mainly different map services (Google Maps, 2010; ViaMichelin, 2010; Hilmola *et al.*, 2008; Ratahallintokeskus, 2009b).

Data for simulation model was gathered through literature review concerning external costs of road and rail transport. In addition, data mining concerning starting and destination points of road transport was conducted to create simulation model more accurate. Due to lack of time, data concerning starting and destination points could not completely have been included in the simulation model.

1.5 Limitations of the study

This research is limited to study intermodal container traffic. Research concerns only road and rail transport. Research does not take other freight transport modes into account. Intermodal transportation system studied in this research is mainly located at ports of Kotka and Hamina and city of Kouvola. Gravitational model used in empirical part concerns also 50 largest cities of Finland and two main transit cities St Petersburg and Moscow.

In empirical part costs of transport are being researched. Costs of transshipment at intermodal nodes are not considered i.e. only costs from movement of freight is calculated. This study calculates external costs of both road and rail transport. Other transport modes are not regarded. External costs of noise, congestion, CO_2 emissions and accidents are taken into account. Other external costs are not considered when calculating external costs.

1.6 Structure of the study

In the first Chapter backround for the study is explained. Research problem and research methodologies are discussed next. In the end the limitations and structure of this study are described.

Chapter 2 explains the theories concerning the dry port concept such as hinterland transport and inland intermodal terminal. There are also examples of two real dry ports and their benefits in the end of Chapter 2.

In Chapter 3 the internal and external costs of road and rail transport are researched through a literature review. Ways of decreasing the external costs of transport are also researched. All the external costs are also presented in monetized values so that a cost comparison between road and rail can be conducted later in empirical part of the study.

There is a discussion about research environment in Chapter 4. Background of the Mobile Port project and physical environment of the research are discussed in Chapter 4.

In Chapter 5 a cost comparison with help of a cost model between road and rail transport is conducted. In addition, the capacity of warehousing in cities of Kouvola and Lappeenranta is researched. A discrete-event simulation model is used to compare external costs of conventional road transport and dry port solution. Finally, different gravitational models are used to compare different distribution centers.

Discussion that compares results of literature review and empirical part of this study is conducted in Chapter 6. Finally, Chapter 7 summarizes conclusions of this research. In addition, avenues for further research are suggested.

2 DRY PORT CONCEPT

Dry port concept is a rather recent concept that aims at increasing cost-efficiency and environmental friendliness of transportation system. It has been researched since the late last century, although the most dry port research is conducted during the last five or ten years. Roso (2009a, b), Roso *et al.* (2008) and Woxenius *et al.* (2004) have made considerable research about the dry port concept, impacts resulting from it and factors influencing its implementation. Roso (2009b, p.308) has defined the dry port concept as:

'The dry port concept is based on a seaport directly connected by rail to inland intermodal terminals, where shippers can leave and/or collect their goods in intermodal loading units as if directly at the seaport. In addition to the transshipment that a conventional inland intermodal terminal provides, services such as storage, consolidation, depot, maintenance of containers and customs clearance are also available at dry ports.'

This definition is used in this master's thesis as the definition for the dry port concept. The performance of a dry port is measured from the quality of access to the dry port and the quality of the road-rail interface (Roso *et al.*, 2008, p.341). As container transport volume continues to grow, seaport's inland access becomes more critical factor for the seaport's competitive advantage (Roso, 2009b, p.3). One way to improve seaport's and at the same whole transportation system's competitive advantage is to improve seaport's inland access. Dry port offers similar services that are normally available at seaports.

2.1 Intermodal transport

The definition of intermodal transport has been widely discussed and researched by several authors (e.g. Hayuth, 1987; Rutten, 1998; Slack, 1996; Woxenius 1998). Rutten (1998) has defined intermodal transport as transport of goods in load-units which can be transshipped between different transport modes (e.g. road, rail, inland shipping, short-sea shipping, deep-sea shipping and air). At least two different transport modes are deployed during transportation of freight. Therefore, one or more transshipments take place between consignor and consignee. The main haulage is not carried out by road, but by rail or water. Road transportation is only used for the initial and the final legs of the freight movement (Ricci & Black, 2005, p.248). Contents of a load-unit must stay untouched during the shipping. The ability of carriers to provide the shipper with one bill of lading is also a crucial element of intermodal transport (Hayuth, 1987, p.15). Figure 2 is a simplified example of a direct road solution and a road-rail intermodal solution. In the left of Figure 2 only road transport is used whereas in the right transport between hubs is accomplished by rail.

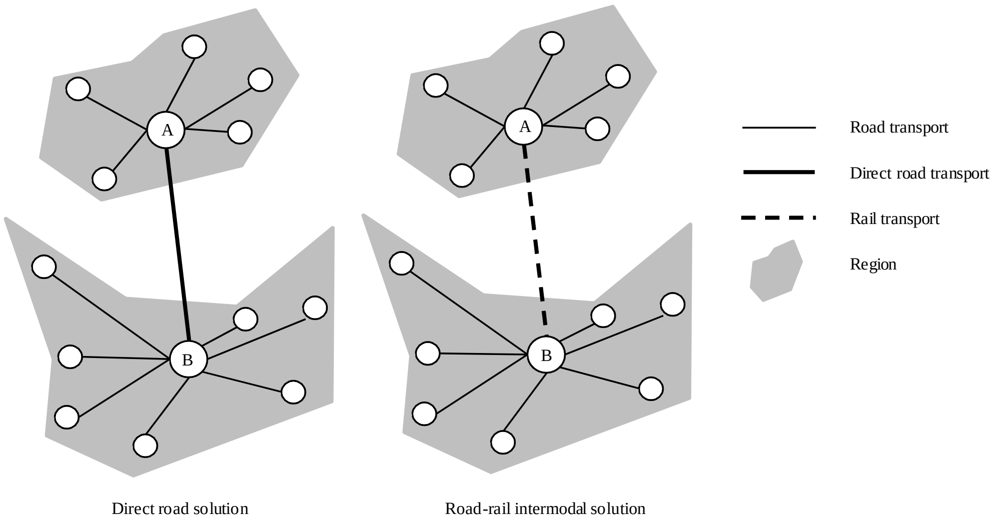

Figure 2 Direct road solution and road-rail intermodal solution.
Source: Modified from Bergqvist (2008, p.181)

The most commonly used intermodal load-units are containers, swap bodies and semi-trailers. A container is a simple steel box with standardized measures, construction strength and fastening devices. A swap body is a detachable lorry equipped with support-legs and a semi-trailer is a lorry trailer with rear wheels (Woxenius, 1998). Containers are the most commonly used standard units for unit-load concept as they are designed for easy and fast handling of freight (Vasiliauskas & Barysiené, 2008, p.311). With containerization, transshipment time at the intermodal node is reduced due to simpler and faster handling. There is no need for stuffing and stripping at the intermodal node. Damage to goods and packaging costs are also reduced since the packaging and disposal are eliminated at the intermodal node (Roso, 2009b, p.11).

Freight intermodality is increasingly considered as a major potential answer for the sustainability problems of the European transport sector. Many factors point out that the intermodality is a strategic option for European transportation. The different factors are listed below:

- road network capacity
- market globalization
- logistics rationalization
- promotion of more capable and sustainable use of land
- the environmental aspects (Ricci & Black, 2005, p.245)

In their study, Ricci and Black (2005) claim that social costs of intermodal transportation are less than of conventional road transportation.

However, there are also drawbacks in intermodal concept. There has to be carriers for load-units and handling equipment has to be adapted to the load-units (Roso, 2009b, p.11). Besides that, there is a problem concerning empty container management. In general, the main concern of logistics managers' is the transportation of loaded containers. It is not rare for managers to ignore transportation of empty containers. That is not possible, because real-world container networks usually require empty containers to account for imbalances in loaded flows (Choong *et al*., 2002, p.424). Movement of empty containers also increases costs of the transportation system. Therefore, it is important to optimize the transportation of empty containers. If empty container flows are not managed carefully, the entire shipping network will operate inefficiently i.e. there is no reason to use intermodal transportation instead of unimodal (Choong *et al*., 2002, p.424). The level of complexity is higher in the intermodal transport chain than in the unimodal transport chain (Bontekoning *et al*., 2004, p.3). It is obvious, because the number of organizations organizing and controlling parts of the transport chain multiply, since the increased demand of different services. More complex level of transportation system requires more solid information flows.

2.1.1 Hinterland concept

A seaport's hinterland is the continental area of origin and destination of traffic flows through a port i.e. it is the inner region served by the port (van Klink & van den Berg, 1998, p.1). Hinterland's outline is dynamic. Its shape changes all the time due to developments in technology, economy and society. Port's hinterland can also be defined as the internal area that the seaport can serve cheaper than any other seaport i.e. port's hinterland can be delimited on the basis of generalized transport costs (van Klink & van den Berg, 1998, p.2). Figure 3 illustrates seaport and its hinterland. In Figure 3 there are also inland intermodal terminals served by the seaport. They are situated at seaport's hinterland.

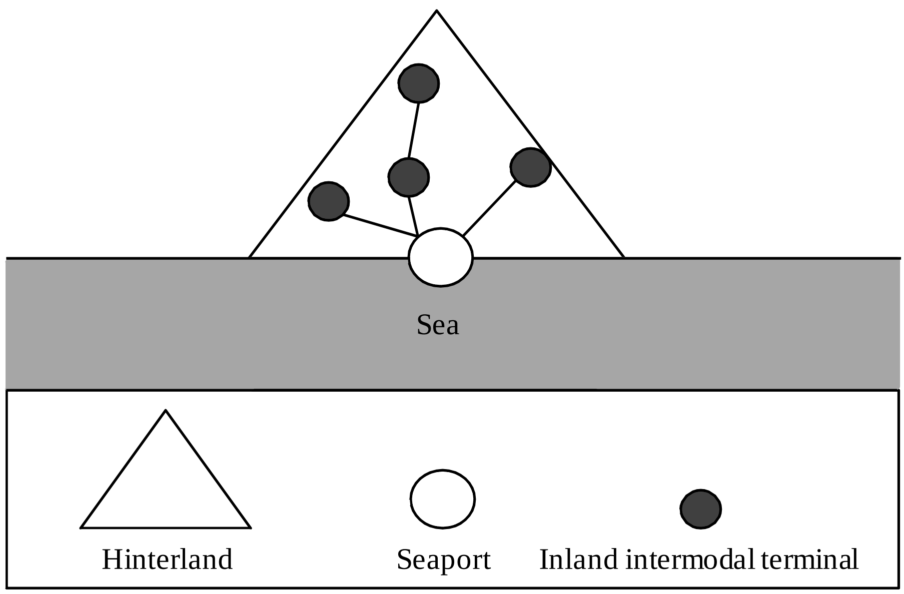

Figure 3 A graphical conceptualization of a seaport and its hinterland.
Source: Modified from Rodrigue and Notteboom (2010, p.8)

Not every seaport has its own hinterland. One such example is the Port of Singapore. It is a seaport that is connected to over 600 other ports in 123 different countries in over six continents. Port of Singapore does not have a hinterland i.e. containers are transported by a vessel to an intermediate port like Port of Singapore. Here, the containers are transshipped to another ship for its final destination. Port of Singapore does not serve hinterland. It only serves other seaports around the world. (PSA Singapore, 2010)

Since container ports have become universal links in the logistics chain, port competition has moved from competition between ports to competition between transport chains and hinterlands (Robinson, 2002). As a consequence, ports are eager to improve their transportation performance level also at their hinterland areas. This development leads to higher competition between ports' hinterlands. The competition reaches also the distant areas of hinterland not only the close areas.

2.1.2 Inland intermodal terminal

There are many definitions and terms for an inland intermodal terminal (e.g. UN ECE, 1998; Harrison *et al.*, 2002). UN ECE (1998), for example, has defined the inland intermodal terminal as an Inland Clearance Depot (ICD). Shapes and ranges of inland intermodal terminals differ greatly (Woxenius, 1998). The development of the inland intermodal terminal in the hinterland is aimed at contributing to a modal shift from road transport to rail and vice versa, and that is the characterizing activity for inland intermodal terminal. Inland intermodal terminal makes transshipments between road and rail transport possible. Inland intermodal terminal is a facility that is equipped for the transshipment and storage of load-units between road and rail. Inland intermodal terminals have access at least to both the road and rail network. They may also have access to other transport modes such as airports or inland waterways. Inland intermodal terminal can be regarded as an inland situated node in a network that improves the connectivity of the origins and destinations in a supply chain. The quality of an inland intermodal terminal can be measured by its throughput rate (Gambardella *et al.*, 2002, p.293). Modern intermodal facilities, such as inland intermodal terminals, are one of the most space needed users of land, since they need a lot of land area for warehousing of load-units (Slack, 1999, p.242).

A specific type of intermodal terminals has advanced around the need for connecting seaports to inland intermodal terminals (Roso, 2009b, p.16). An ideal inland intermodal terminal transfers a part of the activities inland away from the seaport, thus preventing a further overcrowding of limited seaport area i.e. these activities will not be performed again at seaport (Notteboom & Rodrigue, 2005, p.302). In a dry port concept the inland intermodal terminals offer other services in addition to transshipment and storage of load-units. The possible services are listed below:

- consolidation
- warehousing
- depot
- maintenance of containers
- customs clearance
- tracing and tracking of containers (Roso, 2007, p.527)

It is possible that an inland intermodal terminal has all the above services or only some of them. As it was stated earlier in this sub-chapter, the characterizing activity of an inland intermodal terminal is its ability of transshipment. Inland intermodal terminal that acts as a dry port has additional services in addition to transshipment.

2.2 Dry port implementation

The dry port concept is an intermodal transportation system. The dry port itself is an inland intermodal terminal with additional services located inland. It is directly connected by rail to seaport or in some cases two or more seaports. In a dry port concept the maximum possible amount of freight transportation is accomplished by rail between the dry port and the seaport. Only the final leg of the door-to-door transportation is carried out by road transport. In an optimal dry port implementation the whole freight transportation between seaport and dry port is carried out by rail. However, that is not usually possible due to capacity constraints of rail connection. (Roso, 2009a, b)

A flawless connection between road, rail and seaport enables fast and reliable movement of freight. The performance of a dry port is measured from the quality of access to the dry port and the quality of the road-rail interface (Roso *et al.*, 2008, p.341). The dry port offers value-creating services (e.g. consolidation, storage, depot, maintenance of containers and customs clearance) to actors which operate within the transportation system i.e. there is a whole range of administrative activities that could be moved inland with implementation of a dry port. Outsourcing activities from seaport to dry port relieves seaport, and hence seaport can concentrate in its core tasks and competencies.

Summarized main features of a dry port are listed below:

- inland intermodal terminal
- rail connection between seaport
- offers services that have traditionally been performed at seaports (Roso, 2009a, p.302)

In order to meet greater demands from shipping lines, ports are forced to respond by enlarging hinterland areas, with the creation of inland terminals such as dry ports, to enhance or sustain their relative competitiveness (Lee *et al*., 2008, p.373). As container transport volume continues to grow, seaports' inland accesses become more critical factors for the seaports' competitive advantage, because inland access easily becomes a constraint for a seaport, if it is not developed enough (Roso, 2009b, p.3).

There are differences in dry ports according to their geographical location. Woxenius *et al.* (2004) and Roso *et al*. (2008) have categorized different dry ports according to their functions and distances from the seaport. There are three different definitions for different kinds of dry ports, and they are:

- close dry port
- midrange dry port
- distant dry port

All the dry ports are located at the seaport's hinterland areas, because they serve them. It is possible that different dry ports serve more than one seaport. In that case seaports share areas of their hinterland with other seaports. There is a comparison of a conventional transport and an implemented dry port concept in Figure 4. A conventional transport is illustrated in the upper part of Figure 4. A seaport and all three types of dry ports are presented in the lower part of Figure 4.

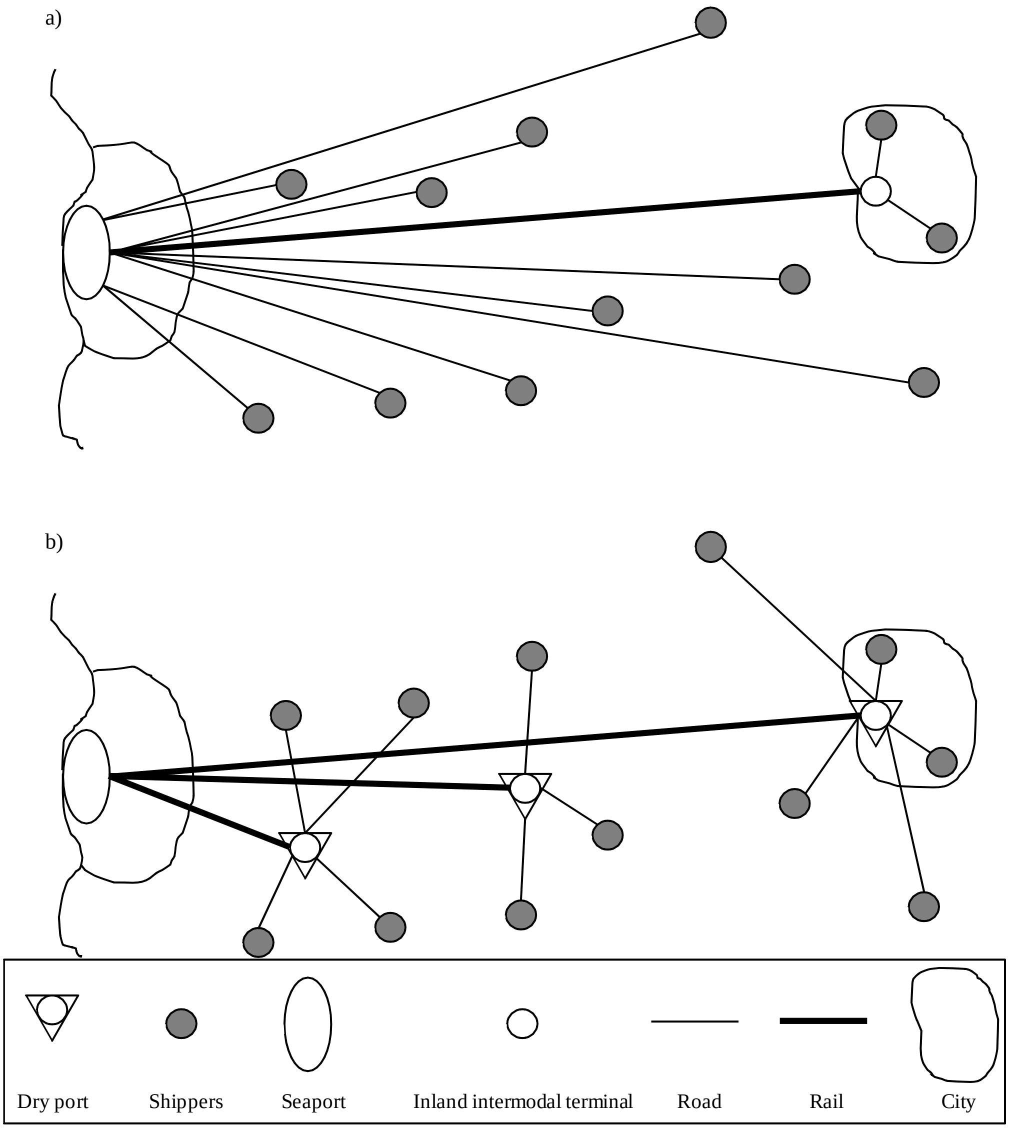

Figure 4 Comparison of a conventional transport and an implemented dry port concept.
Source: Modified from Roso (2009a, p.303)

From Figure 4 it can be seen that the distance travelled by road transport shortens, because shippers can use the nearest dry port instead of always carrying freight to seaport city. Also the number of freight connections to seaports lessens. There are 10 road connections and one rail connection to and from seaport in the upper part of Figure 4. With dry port solutions there are only three rail connections to and from seaport. Dry ports relieve the transportation system.

All dry port categories share many common benefits. There are several actors, which gain varied benefits of a dry port concept. Different actors are listed below:

- seaports
- seaport cities
- rail operators
- road operators
- shippers
- society

An implemented dry port reduces congestion at the seaports immediate closeness by modal shift from road to rail. The congestion is also reduced at the seaport cities and roads connecting cities as road transportation diminishes while transportation at rail increases. Rail operators gain more market share, because more freight is being transported by rail. Shippers gain a greater range of logistics services thanks to dry ports. For the society the dry port enables lower environmental impacts, job opportunities and regional development. The most apparent benefit from environmental perspective comes from the modal shift from road to rail, which results in less congestion and less pollution. (Woxenius *et al.*, 2004; Roso *et al.*, 2008)

Distant dry ports are located over 500 kilometers from the seaport. The main advantage of distant dry port is its capability to provide vital transportation over long distances from a strict cost perspective i.e. rail transport is more cost-efficient transportation mode than road transport especially at long distances. Part of the benefits relate to the modal shift from road to rail that results in reduced congestion and environmental impacts. Distant dry ports improve seaports' ability to offer a more efficient inland access. (Roso *et al.*, 2008; Roso 2009b)

Midrange dry ports are situated between close and distant dry ports. The distance from the seaport is approximately 100 – 500 kilometers. Midrange dry ports usually offer depot facility. All the other advantages are similar to distant dry ports. (Roso *et al.*, 2008; Roso, 2009b)

Close dry ports are located near the actual seaport. Distance between seaport and dry port is less than 100 kilometers. Close dry ports offer seaports a place for depot and also an increased terminal capacity. The close dry port offers consolidation for road transport to and from the seaport. Straight rail link between dry port and seaport relieves the seaport cities' streets. (Roso *et al*., 2008; Roso, 2009b)

Table 1 Impacts generated by dry ports for the authors of the transportation system.

	Distant	Midrange	Close
Seaports	Less congestion Expanded hinterland Interface with hinterland	Less congestion Dedicated trains Depot Interface with hinterland	Less congestion Increased capacity Depot Direct loading ship-train
Seaport cities	Less road congestion Land use opportunities	Less congestion Land use opportunities	Less road congestion Land use opportunities
Rail operators	Economies of scale Gain market share	Day trains Gain market share	Day trains Gain market share
Road operators	Less time in congested roads and terminals	Less time in congested roads and terminals	Less time in congested roads and terminals Avoiding environmental zones
Shippers	Improved seaport access "Environment marketing"	Improved seaport access "Environment marketing"	Improved seaport access
Society	Lower environmental impact Job opportunities Regional development	Lower environmental impact Job opportunities Regional development	Lower environmental impact

Source: Roso (2009b, p.47)

All the benefits of each type of dry ports regarding different actors are summarized in Table 1 above.

2.3 Examples of dry port implementation

There are real dry port implementations all over the world e.g. in Sweden and in United States. However, the amount of real dry port solutions has not grown large yet. Sweden's most important container port – the largest seaport in the Nordic countries – is the Port of Gothenburg, which is situated in the city of Gothenburg. The city is located in Southwestern Sweden by the sea of Kattegat, which is an arm of the North Sea. There are 24 daily rail shuttles that transport freight from Port of Gothenburg to different inland terminals in Sweden. Some of them can be seen as dry port implementations, while majority of them are basic inland intermodal terminals, because they lack services that dry ports are supposed to offer. Another seaport using the dry port implementation is the Port of Virginia. It is situated in the state in United States of Virginia, which is located on the Atlantic Coast of the Southern United States.

2.3.1 Dry port implementation in the Port of Gothenburg

There has been a lot of research about the dry port concept in Sweden (e.g. Roso *et al.*, 2008; Roso, 2009a,b; Woxenius *et al*. 2004). Main reasons for research are environmental aspects, need for more space for warehousing, port's capacity constraints regarding their inland access and faster and more reliable distribution of goods. Since the biggest seaports in Sweden are situated by seas inside cities, it is the most inexpensive way to extend ports with dry port implementations instead of extending the actual ports' area. If seaport is surrounded by a city, the only way to expand is to use inland intermodal terminals. There are six seaports in Sweden that transport containers. All the container seaports and transported TEUs are listed in Table 2.

Table 2 Number of TEUs transported through Swedish ports.

Port \ Year	2006	2007
Ahus	30,000	37,000
Gavle	100,000	115,000
Gothenburg	811,508	840,550
Helsingborg	230,000	300,000
Norrkoping	63,370	100,000
Stockholm	226,423	245,075

Source : Fossey *et al.* (2009, pp.63-64)

As can be seen from Table 2, Port of Gothenburg is by far the most TEUs transporting seaport in Sweden i.e. over 51 percent of the whole Swedish container traffic was being transported through Port of Gothenburg in year 2007 (Fossey *et al*., 2009, 64). During year 2006 811,508 TEUs were transported through Port of Gothenburg, while in the next year 840,550 TEUs were transported. The increase is approximately 3.6 percent in one year (Fossey *et al*., 2009, 64). According to Port of Göteborg AB (2009), Nordic commerce and industry shipped goods equivalent to 862,500 TEUs through the Port of Gothenburg in year 2008. The change compared to year 2007 is three percent.

Port of Gothenburg is not situated in the centre of city of Gothenburg, which means that there is space around Port of Gothenburg to extend its borders if needed. Financially it is more cost-efficient to use a dry port implementation and extend inland than expand seaports actual borders, because land area near city of Gothenburg is more valuable. In addition, extending with the dry port implementation moves hinterland of the Port of Gothenburg further inland, and it improves Port of Gothenburg's inland access and competitiveness at the same.

Port of Gothenburg has increased rail transport's modal share in the previous years and the goal is to increase this even more in the future. There were 24 daily shuttles transporting containers from and to Port of Gothenburg in year 2009, while there were only six daily shuttles in year 2002. The increase from year 2002 to 2009 in the number of shuttle trains was 300 percent. In year 2001 about 115,000 TEUs were transported by rail. The same number in year 2008 was almost 350,000 TEUs, which means a percentual chance of approximately 300 percent. TEUs transported through the Port of Gothenburg from year 2001 to 2008 are summarized in Figure 5. Also the rail's percentual proportion of the whole inland transportation in Port of Gothenburg is illustrated in Figure 5. (Rail services, 2010)

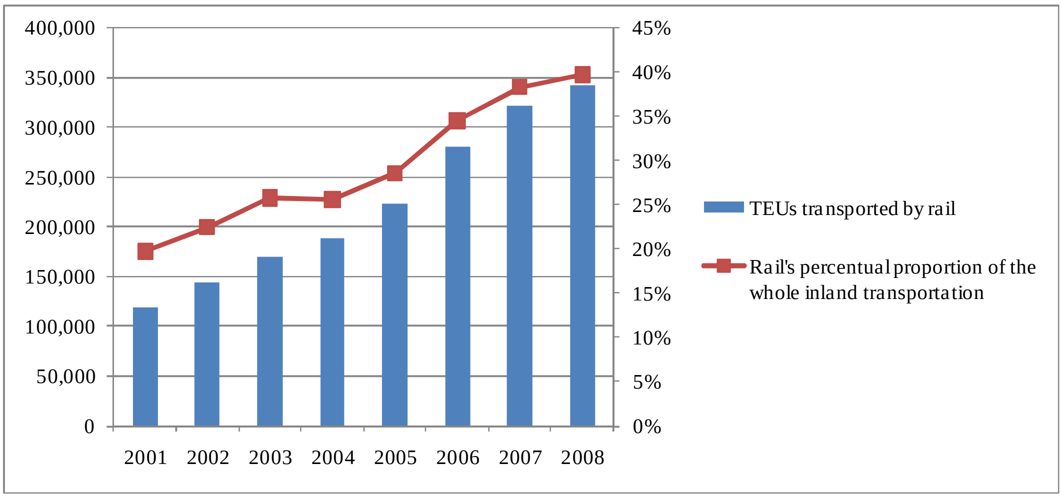

Figure 5 TEUs transported by rail through Port of Gothenburg and rail's percentual proportion of the whole inland transportation in Port of Gothenburg.

Source: Modified from Rail services (2010) and Port of Gothenburg (2010)

According to Rail services (2010), there are 26 inland intermodal terminals that serve Port of Gothenburg. There are five different types of rail freight terminals in Sweden: Intermodal Freight Centres (IFC), conventional intermodal terminals, light-combi terminals, wagon-load terminals and freeloading sites. Rail shuttle system covers 26 terminals in Sweden. The nearest terminals are the cities of Gothenburg and Uddevalla. Distance to Uddevalla is approximately 85 kilometers while distance to center of Gothenburg is a bit over two kilometers. Most of the rail shuttle terminals are located in the center of Sweden and distances are between 150 and 500 kilometers. There are brief explanations of two different Swedish terminals below.

One example is inland intermodal terminal situated in the city of Eskilstuna. The city is located a bit over hundred kilometers west from Stockholm. Distance from Port of Gothenburg to Eskilstuna is almost 400 kilometers. The Swedish warehouse of Hennes & Mauritz AB is located in Eskilstuna (Eskilstuna kommun, 2010). Majority of materials to warehouse is transported by ships to Port of Gothenburg and from there by rail to Eskilstuna.

Another example of an inland intermodal terminal for Port of Gothenburg is Nässjö. Its position – two hours by rail from Gothenburg, Stockholm and Copenhagen – has resulted in the development as a major rail junction in Sweden. Port of Gothenburg’s rail shuttle service transports hundreds of container loads daily to Nässjö’s railroad terminal. They are destined for the major central warehouses of, for example, the Jysk, IKEA and Rusta. They all are located at Nässjö. Only the final leg of the transportation is carried out by road carriages. (Rail services, 2010; Jysk, 2010)

2.3.2 Dry port implementation in the Port of Virginia

The Port of Virginia consists of four facilities: Newport News Marine Terminal, Norfolk International Terminals, Portsmouth Marine Terminal and Virginia Inland Port (VIP). All the three terminals are seaports situated by sea and all the seaports are located at Hampton Roads. VIP is located inland and it acts as a dry port implementation for the terminals by sea. It is an example of a mid-range dry port that moves interface between rail and road north-west to Front Royal over 300 kilometers from Hampton Roads. The Port of Virginia owns all the facilities including VIP. The dry port with direct rail link to sea terminal facilities offers a valuable space extension inland. The dry port creates a competitive advantage by expanding the hinterland of the Port of Virginia. It enhances seaport's access to areas outside its traditional hinterland. Number of TEUs transported through the Port of Virginia is summarized in Figure 6. (The Port of Virginia, 2010a, b, c, d)

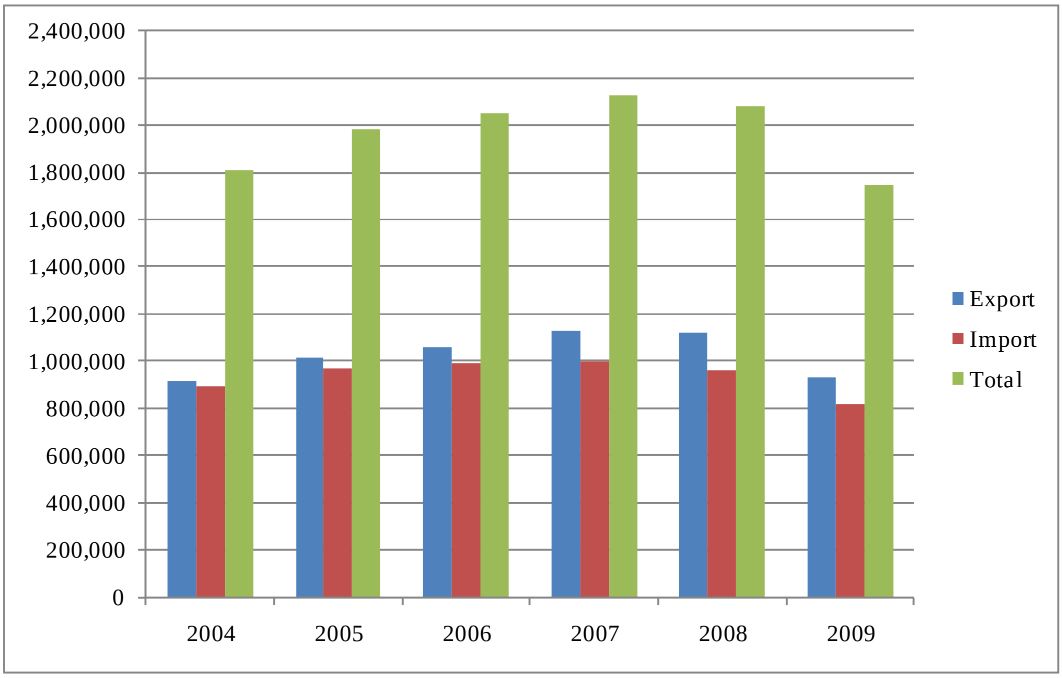

Figure 6 TEUs transported through Port of Virginia between years 2004 to 2009.
Source: The Port of Virginia (2010e)

Figure 6 shows that the container traffic through Port of Virginia has remained at least in the level of 1,800,000 TEUs per year from year 2004. Best year in TEUs transported has so far been year 2007. In that year over 2,100,000 TEUs were transported through Port of Virginia.

According to The Port of Virginia (2010e), freight is being transported by rail, road or barge inland via the Port of Virginia. The main inland destination is VIP. Inland transportation's percentual distribution among different transport modes is presented below in Table 3.

Table 3 Inland transport's percentual distribution between different transport modes in the Port of Virginia.

Transport mode	Percentual distribution
Rail	30%
Truck	66%
Barge	4%

Source: The Port of Virginia (2010e)

VIP has stimulated the attraction of some 24 warehousing and distribution centers providing a total income of 599 million dollars with approximately 56 hectares of space together with 7 000 employers. Mainly because of modal shift from road to rail, the Port of Virginia has managed to reduce its pollution level by 38 percent since year 1999. (The Port of Virginia, 2007)

3 INTERNAL AND EXTERNAL COSTS OF TRANSPORT

Transport systems have always been designed according to geographical condition, and the demand for transportation. However, currently environmental issues play a very important role as well (Roso, 2009b). Due to increasing environmental problems (such as global warming) the role will maintain its significance also in the future. One of the most considerable sources of pollution is transportation, which is the only sector with increasing greenhouse gas-emissions (UIC, 2009). That development has to change, hence the EU has pointed out that it will increase its participation in trying to decrease the level of emissions from the transportation sector (European Commission, 2001). According to Hansen (2004, pp.385-386), container transport is dominated by road transport in the hinterland of seaports. It leads to more congested road networks. Road transport produces also more impacts to environment, since it is the most polluting transportation mode, when compared to other modes of transport e.g. rail transport. The EU uses policies to encourage the use of non-road modes such as intermodalism, rail liberalization and motorways of the sea. The target is to increase rail's market share for freight sector to 20 percent by year 2020 (European Commission, 2001). Rail's market share in year 2007 was approximately 10 percent (European Commission, 2009, p.108). Modal split of different transport sectors in EU-27 countries between years 1995 and 2007 is presented in Figure 7.

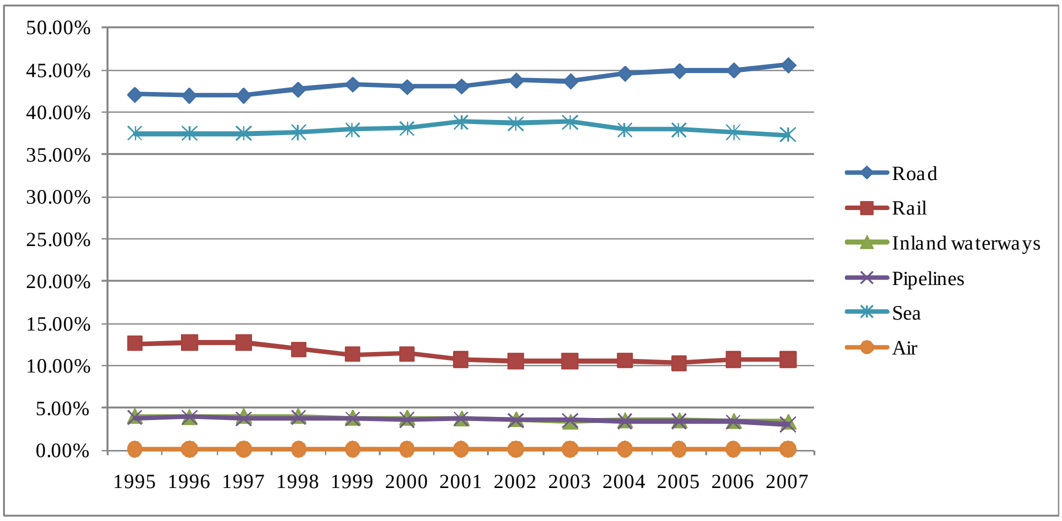

Figure 7 Modal split of different transport types in EU-27 countries.

Source: Modified from European Commission (2009, p.108)

Since rail transport is less polluting than road transport, it is environmentally sensible to shift transportation from road to rail or other environmentally friendlier mode as much as possible. Intermodal transport in general has become an important policy issue, because of its ability to be environmentally friendlier type of transportation than e.g. unimodal road transport (Ricci & Black, 2005).

Transport costs are being divided into internal and external costs. Internal costs are divided into infrastructure costs and private costs. Private costs consist of fuel, maintenance, repair, insurance, tax and depreciation costs. External costs consist of environmental costs, congestion, accidents and use of space. Environmental costs are e.g. pollution and noise. (Quinet & Vickerman, 2004)

3.1 Internal costs of transport

Internal or direct cost of transport can be seen as ‘out of the pocket’ costs i.e. money that is directly spent by government or corporation to run the transport system (Astrid *et al*., 2006, p.56). Internal costs are easy to see and explain. They are costs that a business bases its price on. Internal costs are divided into infrastructure costs and private costs. Infrastructure costs are costs that has to be paid to maintain or create infrastructure e.g. road and rail network. The private costs are e.g. fuel, maintenance, repair, insurance, tax and depreciation costs.

Internal private costs are further divided into variable and fixed costs. Variable costs depend on the utilization rate. There are also such costs that can be regarded as semi-fixed costs. They are costs that are more or less dependent on the utilization, but proportion of them is also fixed costs (Quinet & Vickerman, 2004). Fixed costs are paid yearly and the amount is the same no matter what the utilization rate is. Examples of different variable and fixed costs concerning transportation are summarized in Table 4.

Table 4 Examples of variable and fixed costs of transportation.

Variable costs	Fixed costs
Labor costs	Insurance costs
Fuel costs	Operating costs
Electricity costs	Administration costs
Tire costs	Depreciation costs
Additive costs	
Repair and maintenance costs	
Infrastructure charge costs	

Source: Quinet and Vickerman (2004) and Finnish Transport and Logistics (2010)

Repair and maintenance costs are examples of costs that can be regarded as semi-fixed instead of variable costs. These costs increase among the utilization rate, but a certain amount repair and maintenance costs are also fixed. There has to be yearly inspection concerning repair and maintenance no matter what the utilization of transport equipment is. (Quinet & Vickerman, 2004)

3.2 External costs of transport

The difference between internal and external costs is that the payer of the costs is external for the external costs. Internal costs are instead paid by the corporation or another similar source that incurs them. External costs are costs that are not included in what the business bases its prices on. Even though external costs are not included in the price of the product they must still be paid. They usually end up being paid by the society through taxes, accident compensation, medical and insurance payments and also by future generations through losses in environmental quality and natural capital. (European Commission, 2003; Forkenbrock, 2001; Schmedding, 2004)

In order to estimate the total costs, it is necessary to look at external costs simultaneously with internal costs. External costs are also being called negative externalities. A part of external costs are also called environmental costs e.g. CO_2 emissions and noise. Of all transport related external costs evaluated in the literature, accidents, CO_2 emissions, noise and congestion are the largest and most important. External – or “unpaid” – costs have only increasingly been recognized and most have either been under-valued or are considered impossible to estimate since they have no value in a market. (Astrid *et al.*, 2006)

Main goal for society is to internalize the external costs. In fact, internalizing external costs is not a new concept. Cigarettes and alcohol for example are taxed to cover their external health costs. Ideas like CO_2 taxes or other environmental taxes are trying to internalize external costs. The goal is to make external costs internal in the future so that the creator of externality pays external costs itself. By internalizing external costs, policy makers could choose transportation modes based on the true costs. Ideally, a ton-kilometer of freight would be assigned a price that would reflect the full cost including internal and external costs i.e. total costs of transport. European Commission has presented an initiative on internalizing the external costs of transport. Internalizing is divided into two elements. The first is a framework for estimating external costs of transport. Purpose of the framework is also to specify and enhance estimates that have already been researched. The second element is a strategy on how all the external costs of transport between different transport modes can be internalized correctly. (European Commission, 2008)

Transport system is a major source of external costs, although accurate estimates of their magnitudes have been difficult to obtain. Freight transport is a significant source of air pollution, CO_2 emissions, congestion, accidents and noise. Road transport mode is the major generator of negative externalities in terms of external costs (Arnold *et al.*, 2004, 255). Rail transport pollutes less and creates no congestion (depends how congestion is measured) when compared to road transportation. Rail transport is also safer mode of transport, when comparing accident rates. To charge the full cost of transportation, it is necessary to estimate as accurately as possible the magnitude of external costs (Forkenbrock, 2001, p.327). External costs of road or rail transport are generated by movement of transport equipment i.e. they are regarded as variable costs (Ricci & Black, 2005). Ranges of monetized costs for different external costs for different transport modes are quite significant. Reasons are different vehicle categories, countries and traffic situations (Schreyer *et al.*, 2004). For example, congestion costs are higher at bigger cities, which are more congested.

3.2.1 Congestion

According to Schrank and Lomax (2007), traffic congestion has increased significantly during the last two decades. Congestion can be seen as increased queues e.g. at seaport's gates or cities. Queues occur whenever instantaneous demand exceeds the capacity of the transport network e.g. road network (van Woensel *et al*., 2001, pp.209-210). Congestion increases the time individual spends at traffic. It also increases vehicle pollutions, vehicle maintenance costs, indirect health effects, accidents and stress. Infrastructure costs of road maintenance increase as well, because congested roads erode faster than roads with smooth traffic flows. Congested traffic creates more pollution, generates more noise, and consumes more energy than smooth traffic flow. Congestion is typically identified as a road-related problem, with road haulage both contributing to and suffering from congested roads and terminals i.e. main source of congestion is road transport. Predetermined timetables for rail transport prevent congestion by rail. According to Parola and Sciomachen (2005, pp.87-88), the only strategic decision to decrease congestion is to move more traffic from road to another type of transportation e.g. to rail.

According to Maibach *et al*. (2008, p.34) the proposed external costs of congestion are divided between different types of road transport modes and areas. The proposed external costs are summarized in Table 5. Costs for a passenger car are far less than for a goods vehicle. External costs of congestion are substantially lower at rural than urban areas, because fever people are affected to congestion at rural areas. In addition, congestion develops more frequently at areas with more people.

Table 5 Proposed ranges of external costs of congestion by road class and type of area (€ / vkm)

Area and road type	Passenger cars			Goods vehicles			HGV
	Min.	Centr.	Max.	Min.	Centr.	Max.	PCU
Large urban areas (> 2,000,000)							
Urban motorways	0.3	0.5	0.9	1.05	1.75	3.15	3.5
Urban collectors	0.2	0.5	1.2	0.5	1.25	3	2.5
Local streets centre	1.5	2	3	3	4	6	2
Local streets cordon	0.5	0.75	1	1	1.5	2	2
Small urban areas (< 2,000,000)							
Urban motorways	0.1	0.25	0.4	0.35	0.88	1.4	3.5
Urban collectors	0.05	0.3	0.5	0.13	0.75	1.25	2.5
Local street cordon	0.1	0.3	0.5	0.2	0.6	1	2
Rural areas							
Motorways	0	0.1	0.2	0.35	0.35	0.7	3.5
Trunk roads	0	0.05	0.15	0.13	0.13	0.23	2.5

vkm = vehicle-kilometre, HGV = Heavy Goods Vehicle, PCU = Passenger Car Unit.

Source: Maibach *et al.* (2008, p.34)

The Confederation of British Industry (CBI), for example, estimated that road congestion costs British industry approximately 15 billion pounds a year (Emmerink *et al.*, 1995, p.21). According to Maibach *et al.* (2008) road transport has by far the largest share in total external congestion costs of transport.

Congestion costs are defined according to economic welfare theory by the deadweight loss measure. It represents the costs arising from an inefficient use of the existing infrastructure. Due to that approach, congestion costs only appear for transport modes, where single users decide on the use of the infrastructure. Consequently, rail traffic is not affected by that kind of congestion. Rail transport differs from road transport significantly. Road transport is more or less random i.e. there are no strict timetables for trucks and queues can occur randomly. In rail transport the timetables are strictly predetermined. There are no queues at rail network thanks to predetermined timetables (Maibach *et al.*, 2008) i.e. rail transport creates no external congestion costs.

3.2.2 CO_2 emissions

Releasing CO_2 to the atmosphere will enhance the global warming trend (Jenkinson *et al.*, 1991). CO_2 is the most important greenhouse gas i.e. it contributes the most of all greenhouse gases to the climate change. The global warming is the driving force to decrease amount of emissions. Consequences of the global warming are various.

Some species will perish and sea levels will rise, so that some land areas and entire countries may disappear (Quinet & Vickerman, 2004). It is clear, why stopping the global warming is such an important task. According to European Commission (2008), climate change is at the moment the priority environmental problem with lots of new measures having recently been proposed by the European Commission. These include measures to limit CO_2 emissions from new cars, to apply differentiated annual circulation and registration taxes for cars based on their CO_2 emission volumes.

3.2.2.1 CO_2 emissions from transportation

Since transportation sector is one of the major sources of pollution – especially CO_2 emissions – it is considered as one of the most important subjects to reduce its volume of pollution. According to European Commission (2009) and UIC (2009), transportation is the only sector with increasing CO_2 emissions. All the other sectors have been able to decrease or at least not increase their volume of CO_2 emissions in the last twenty years. CO_2 emissions of different sectors in the EU-27 countries between years 1990 and 2006 can be seen in Figure 8.

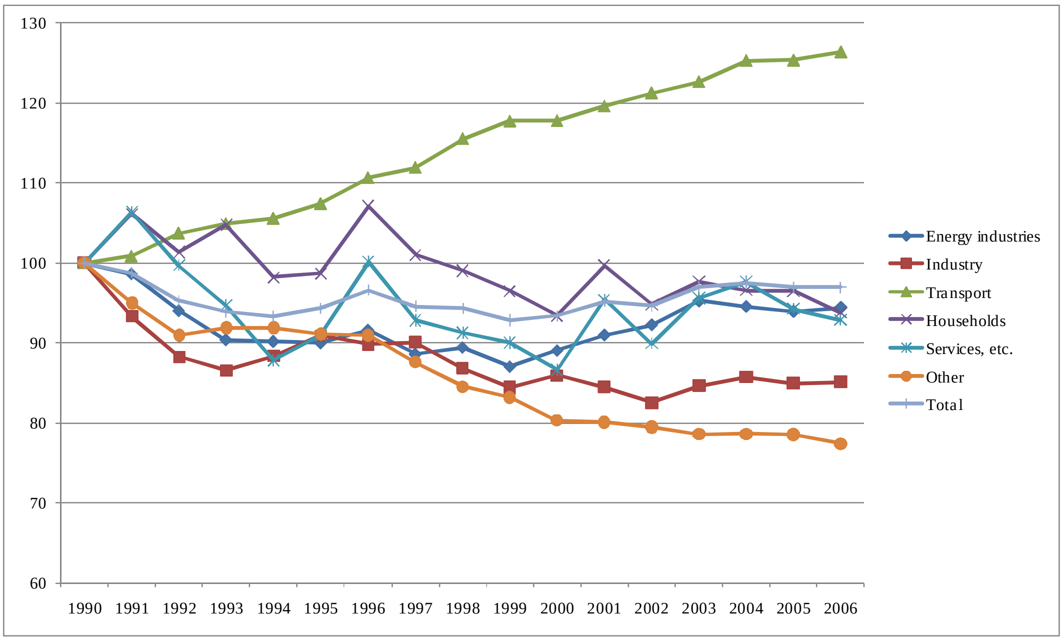

Figure 8 Indices of CO_2 emission from year 1990 to 2006 between different sectors. (1990 = 100)

Source: Modified from European Commission (2009, pp.184-185)

It can be clearly seen from Figure 8 that transportation sector has increased its amount of CO_2 emissions during the last decades. Energy industries and industry sectors instead have been able to decrease their emission volumes during the last decades.

In year 2006 the EU-27 countries emitted total of 4,258 million tons of CO_2 emissions (European Commission, 2009). Transportation sector emitted total of 969 million tons CO_2 emissions, which is over 20 percent of the total CO_2 emission amount. However, energy industry and industry sectors are the largest emitters at the moment energy industry being largest with 37 percent share. CO_2 emissions' distribution among different sectors is represented in Figure 9.

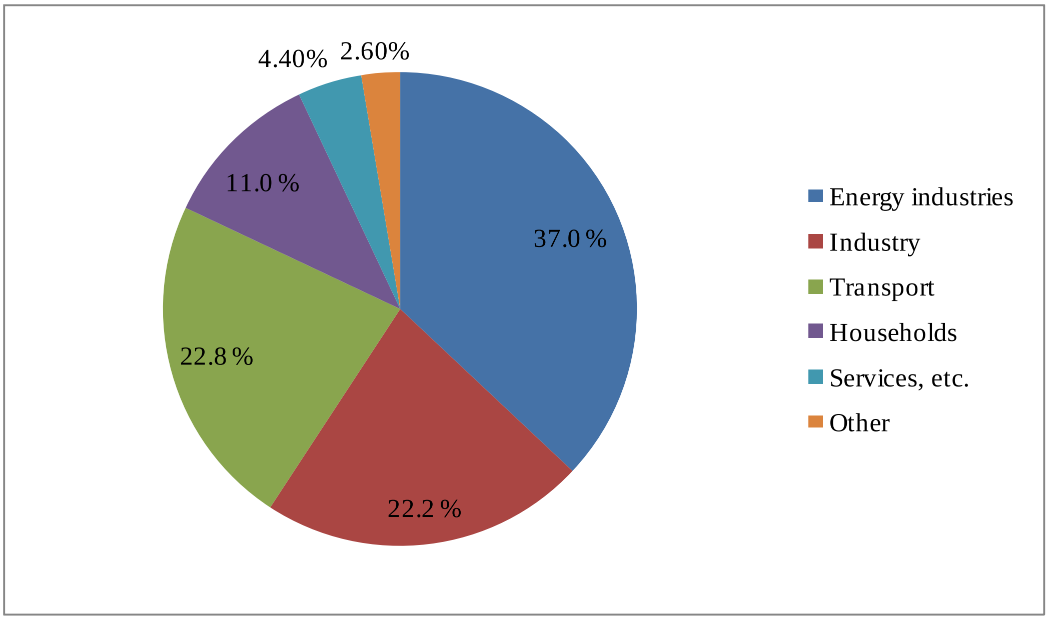

Figure 9 Total CO2 emissions by sectors in EU-27 countries.
Source: Modified from European Commission (2009, pp.184-185)

In year 2006 road transportation created 902 million tons of CO_2 emission. That is approximately 93 percent of the whole transportation sector's CO_2 emission, if only domestic aviation and navigation are considered. In the same year railways' CO_2 emissions were 7.8 million tons. That is less than a percent of the whole transportation sector's CO_2 greenhouse gas amount. Figure 10 summarizes CO_2 emissions' distribution between different transport modes.

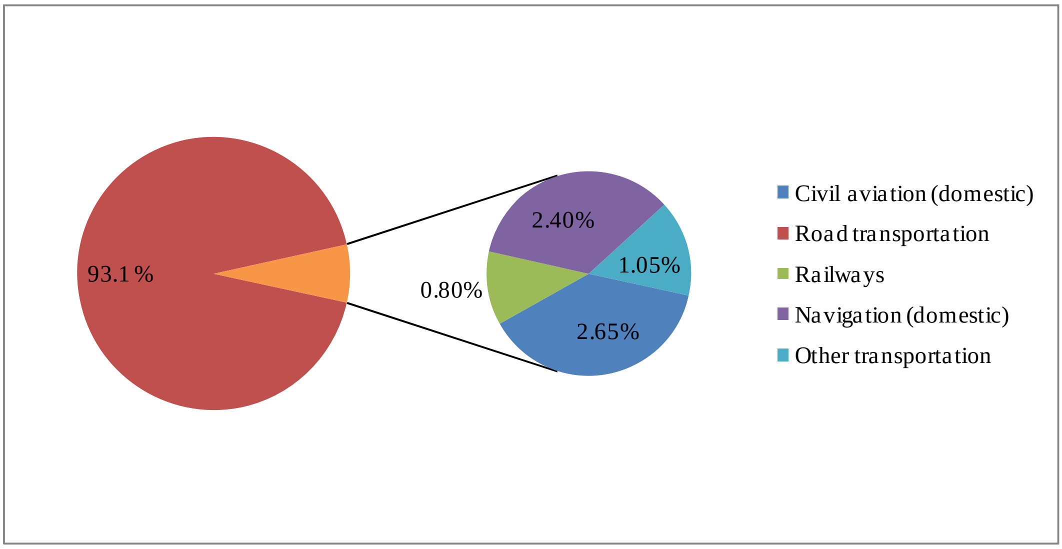

Figure 10 CO_2 emissions by different transport modes.

Source: Modified from European Commission (2009, pp.193-194)

There are differences in the quantities of CO_2 emissions between different transport modes. According to van Wee *et al.* (2005), the average factors for CO_2 emissions from transport of goods by road are 300 percent higher than by rail. Average unit emissions of CO_2 of a container train in Finland in year 2007 were 6.7 grams per ton-kilometer, while semi trailer combination's emissions were 44 grams per ton-kilometer (LIPASTO, 2009). According to LIPASTO (2009), CO_2 emissions from a full trailer combination is over six times higher than from an electric container train. Table 6 summarizes the unit emissions of CO_2 of electric container train and full trailer combination.

Table 6 CO2 emission amounts of electric container train and full trailer combination.

Vehicle type \ CO_2 emissions	[g/km]	[g/tkm]
Electric container train	4,656	6.7
Semi trailer combination	1,100	44

Source: Modified from LIPASTO (2009)

The key variable that affects the amount of CO_2 emissions from rail transport is its engine type. Diesel engine pollutes more than an electric engine. Electric train has no direct emissions, while emissions from diesel train are direct (European Environment Agency, 2008). It is generally accepted that not only the direct emissions of diesel locomotives but also the indirect emissions have to be included in the CO_2

calculation, when calculating the emissions of rail (UIC, 2009). According to UIC (2009), railroads account for less than 3 percent of European CO_2 emissions.

3.2.2.2 External costs of CO_2 emissions

Due to the global scale of the damage caused, there is no difference how and where in Europe or in the whole world the emissions of greenhouse gases take place. That is why Bickel *et al*. (2006) recommends using same values in all countries. According to Bickel *et al*. (2006), median estimate valuation of CO_2 emissions is 4 Euros per ton, and the mean valuation is 25 Euros per ton. These estimates are based on different researches. According to Maibach *et al*. (2008) the equilibrium price of the European trading system within the second period (2008-2012) is a possible reference value for relatively short term view. The value is roughly 20 to 25 Euros per ton of CO_2. There are many different external cost values used to measure the costs of CO_2 emissions. Maibach *et al*. (2008) estimate that the development of the avoidance costs in the least cost path towards the year 2050 are going to increase gradually to a value of about 65 Euros per ton of CO_2 emission. However, in this master's thesis the external cost factors based on damage costs are being used. External costs are slightly higher than avoidance costs. Recommended values for the external costs of CO_2 emissions are summarized in Table 7.

Table 7 Recommended values for the external costs of climate change (€ / ton of CO2), expressed as single values for a central estimate and lower and upper values.

Year of application	Lower value	Central value	Upper value
2010	7	25	45
2020	17	40	70
2030	22	55	100
2040	22	70	135
2050	20	85	180

Source: Maibach *et al*. (2008, p.80)

Recommended values for external costs of climate change have been chosen on the basis of the following considerations. For the short term (2010 and 2020) values are based basically on different avoidance goals such as Kyoto-protocol. For the longer term (2030-2050) the recommended values are based on damage costs, because there are no agreed policy goals available yet.

3.2.3 Noise

Noise is irritating even in rural areas where fever people live and work. Even if the level of noise is low, noise can affect people and their lives, especially when they need to concentrate or rest. Noise can affect sleep, which impact on the general state of health and also in the rate of accidents. The impact of noise is hard to measure (Quinet & Vickerman, 2004). Though, noise has an impact on residential property values (Forkenbrock, 2001). In their study, Maibach *et al*. (2008) have calculated marginal cost values per vehicle kilometer for different network types for road and rail traffic relating noise. The marginal costs are summarized from other studies that research costs for externalities. Marginal costs are summarized in Table 8.

Table 8 Unit values for marginal costs for different network types (€ct / vkm) for road and rail traffic.

	Time of day	Urban	Suburban	Rural
Car	Day	0.76	0.12	0.01
	Night	1.39	0.22	0.03
MC	Day	1.53	0.24	0.03
	Night	2.78	0.44	0.05
Bus	Day	3.81	0.59	0.07
	Night	6.95	1.10	0.13
LGV	Day	3.81	0.59	0.07
	Night	6.95	1.10	0.13
HGV	Day	7.01	1.10	0.13
	Night	12.78	2.00	0.23
Passenger train	Day	23.65	20.61	2.57
	Night	77.99	34.40	4.29
Freight train	Day	41.93	40.06	5.00
	Night	171.06	67.71	8.45

Source: Modified from Maibach *et al*. (2008, p.69)

External noise costs of different transport modes differ significantly. External noise costs for freight trains are at urban areas 40–170 cents per vehicle kilometer depending whether it is day or night, while same costs for heavy goods vehicle are between 7 and 13 cents per vehicle kilometer. Overall costs of rail transport is not necessary more expensive when comparing external costs of noise, because one train can transport considerable greater amount of freight than one lorry.

3.2.4 Accidents

Traffic accidents fit in to the most noticeable and important negative impacts of transport (Bickel *et al.* 2006). Table 9 summarizes fatalities by road and rail transport at EU-15 countries in recent years.

Table 9 Road and rail fatalities at EU-15 countries.

Transport mode \ year	1990	2000	2001	2005	2006	2007
Road	55,888	41,421	40,266	31,379	29,514	28,238
Rail	165	117	75	51	36	54

Source: Modified from European Commission (2009, p.173-178)

According to European Commission (2009), there were 28,238 road fatalities and 54 rail fatalities in year 2007 in EU-15 countries. The difference is significant. Earlier in Chapter 3 it was mentioned that rail transport's share of total transportation is approximately 10 percent. If both the fatalities and rail transport's share of total transportation are compared with road transportation, rail transport creates substantially less accidents. Modal shift from road to rail would decrease the amount of accidents and fatalities significantly. Estimated external accident values for Finland are presented in Table 10.

Table 10 External accident costs for road and rail transport. (€ / km)

Urban roads	Motorways	Other roads	Rail
0.0875	0.0025	0.0221	0.0200

Source: Modified from Maibach *et al.* (2008, p.44)

External accident cost values for road transport are researched more than same values for rail transport. External accident cost value of 0.0200 Euros per kilometer for rail transport is a rough estimate created by Maibach *et al.* (2008), while external costs for road are more accurate and researched.

3.2.5 Land use

Carbon sink is a natural or artificial pool that accumulates and supplies some carbon-containing substance for an imprecise period of time. Main natural carbon sinks are oceans and organisms that use photosynthesis e.g. forests and plants. Every square meter of green land stores certain amount carbon. When forests are being transformed to roads, rails, cities or other urban forms, the carbon is released back to air, and natural carbon sequestration is reduced. Total carbon sink is also reduced at the same i.e. less carbon or CO_2 can be absorbed by land. That is why it is important to measure land area that is lost when new roads or railroads are being constructed.

There is a lot of research concerning the amount of CO_2 that a square meter of land area e.g. forest can absorb from air. According to Liski *et al*. (2006), the estimate for net ecosystem production (NEP) is 0.099 kg C/m^2/year. On the other hand, the same study suggests that young and vigorously growing forests' NEP value could be 0.23 to 0.31 kg C/m^2/year. Research of Valentini *et al*. (2000) supports previous NEP-values as net ecosystem exchange (NEE) in Finland is 0.245 kg C/m^2/year. Both NEP and NEE values are alike i.e. they measure same subject. Ilvesniemi *et al*. (2009, p.743) have used 0.242 C kg/m^2/year as NEE value in their study. According to Heijari (2010), 237 grams of coal (C) can be converted to 1,000 grams of CO_2.

3.3 Ways to reduce external costs of transport

There are many ways to relieve negative environmental impacts created by transportation. One way is to reduce the amount of transportation. Another way is to create current transportation modes environmentally friendlier e.g. to improve environmental friendliness of road transportation. One way is to transport freight by environmentally friendlier and safer transportation mode.

By internalizing firstly the most important and largest external costs (congestion, CO_2 emission, noise and accident costs) it would be easier to choose the most inexpensive and environmentally friendliest transport mode. Main economic instruments for internalizing different external costs are taxes, tolls, tariffs and emission trading. Different external costs have certain features, which require the use of appropriate instruments. Some external costs are local, and they have effect on infrastructure and their impact vary according to time and place. E.g. congestion, noise and accidents are these kinds of externalities. Climate change mainly occurring through CO_2 emissions is a global problem. (European Commission, 2008)

3.3.1 Tolls and tariffs

Main idea of different tolls and tariffs is to reduce transportation or encourage modal shift to environmentally friendlier modes of transportation. Tolls are higher for more polluting transportation modes than for less polluting modes.

London implemented congestion charging scheme (CCS) in February 2003. CCS has measurably reduced traffic flows in central London. Main results of CCS are reduced pollution and congestion. CCS reduced use of private cars by 29 percent, while it increased the use of busses by 20 percent and taxis by 13 percent. CCS reduced overall vehicle kilometers in London, and that results in increased speed of traffic flow. Smoother traffic flow results in reduced CO_2 emissions. The overall decrease of CO_2 emissions is 19.5 percent. A similar system has been implemented also in Singapore. There is an electronic road pricing (ERP) technology used in Singapore. It has decreased personal road traffic significantly, which has led in cleaner and less polluted air and less congestion. (Beevers & Carslaw, 2005; Goh, 2002)

3.3.2 Natural gas

Compressed natural gas is a cleaner alternative to other automobile fuels such as gasoline and diesel. According to EIA (1998), natural gas' CO_2 emissions are 117,000 Pounds per Billion Btu (British Termal Unit) of Energy, when oil's emissions are 164,000 Pounds per Billion Btu of Energy. Figure 11 represents CO_2 emissions from natural gas and oil.

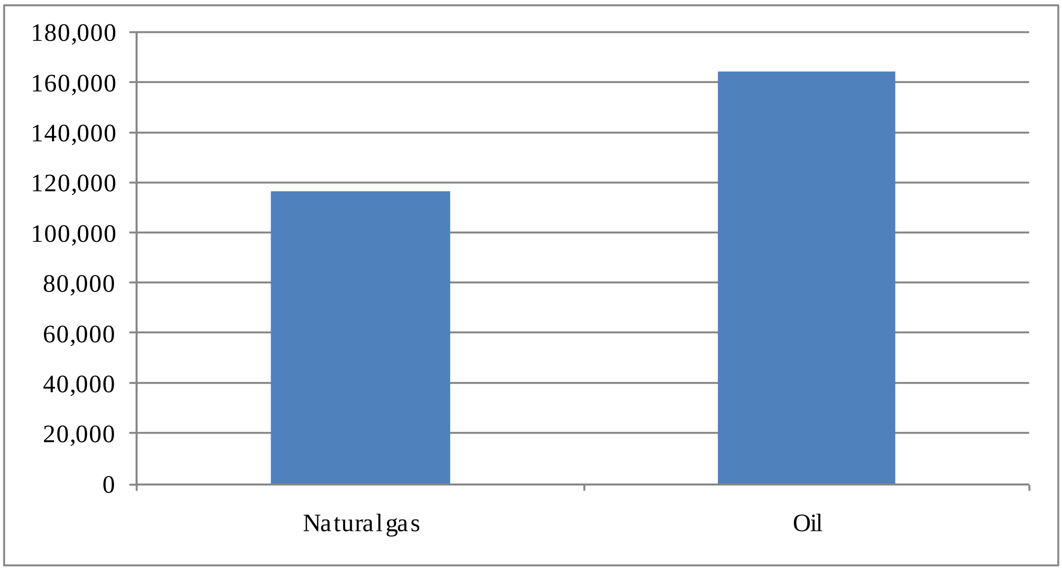

Figure 11 CO2 emissions of natural gas and oil as Pounds per Billion Btu of Energy.
Source: Modified from EIA (1998)

Natural gas engines reduce CO_2 emissions by over 25 percent when compared to traditional gasoline and diesel. The energy efficiency is generally equal to that of gasoline engines, but lower than modern diesel engines. In near future it is possible to use natural gas as the main energy source for road transport. This will make road transport environmentally friendlier mode of transport. Difference between environmentally friendlier transport modes reduces. (NaturalGas.org, 2004)

3.3.3 Modal shift

Although transport is a major contributor to many external costs, there are ways to increase environmental friendliness, while increasing total amount of transportation. A reasonable way is the modal shift from road to rail. Road transport accounts for the majority of external costs from transport, so it is rational to use an environmentally friendlier mode of transport. That way it is possible to reduce the overall external costs of the whole transportation system. The rail transport is much environmentally friendlier than road traffic i.e. CO_2 emissions costs and noise costs are much lower when using rail (van Wee *et al.*, 2005; LIPASTO, 2009; European Commission, 2009). Major reason for rail being less polluting is its main energy source, which is electricity. In Finland the source of energy used at electric trains is hydro power (VR, 2010a). 83 percent of train-kilometers are carried out by electric trains in Finland

(VR, 2010b). Nonetheless, diesel engine trains pollute less than road transport in general i.e. modal shift from road to diesel engine trains also lessens environmental impacts caused by transportation sector. According to Padilha and Hilmola (2010), modal shift from road to rail in Finland when transporting eastbound transit traffic from ports of Kotka and Hamina could decrease CO_2 emissions by 70 to 80 percent. Difference can be as high as over 90 percent if only electric trains are used for eastbound transit traffic. Conclusion of the same study (Padilha & Hilmola, 2010) is that CO_2 emissions decrease significantly at very long distances despite indirect routes of railway.

3.3.3.1 Marco Polo program

European Union has launched a program called Marco Polo that relates to modal shift. Marco Polo program runs from year 2007 to 2013. The aim of the program is to shift freight transport from road to sea, rail and inland waterways i.e. reduce road transport by modal shift to another transport mode with decreased external costs. The program helps to reduce traffic congestion and CO_2 emissions on Europe’s roads and promotes environmentally friendly transport modes. The aim is to free European roads of an annual volume of 20 billion ton-kilometers of freight. That translates into substantial environmental, societal and economical benefits. (European Communities, 2009)

Marco Polo program motivates logistic companies to move freight transport from road to environmentally friendlier modes with grants. They cover periods of two to five years. Program’s budget for grants is about 60 billion Euros. So far more than 400 companies have benefited from funding. Another motivator to participate in Marco Polo program is that successful participation in Marco Polo program enhances company’s green credentials. (European Communities, 2009)

3.3.3.2 Modal shift in Port of Gothenburg

Port of Gothenburg has moved a lot of transportation from road to rail. The number of TEUs transported by rail can be seen in Figure 5 earlier in this study. Modal share of rail transport has increased year after year in. In year 2002 Port of Gothenburg used 6 daily rail shuttles, while in year 2009 it used 24 daily rail shuttles. Modal shift at Port of Gothenburg has lead to less fuel consumption and therefore decreased CO_2 emissions. Saved fuel and CO_2 quantities are summarized in Table 11. (Rail services, 2010)

Table 11 Environmental benefits of rail in Port of Gothenburg.

Environmental impact factor	Difference between train and lorry
Fuel, diesel	19,800,000 litres
CO_2	48,000 tonnes

Source: Modified from Rail services (2010)

Electrifying rails and using electric trains instead of diesel trains is an efficient way to reduce emissions by rail. However, rail is environmentally friendlier transport mode than road even when diesel locomotives are used. Electricity used at Swedish electric trains is created from hydro power.

3.3.4 Double-stack rail concept

Container traffic, besides the impressive growth, also covers a vast hinterland for each port which calls for a transport infrastructure capable of providing sufficient capacity for fast and cost-efficient service. One way to improve rail capacity from and to seaport is to use double-stack concept.

The concept of a double-stack rail was born in United States after the deregulation of the railroads in the early 1980s (Hayuth, 1987, p.29). The concept concerns containerized intermodal transport. There are two containers one upon the other in the double-stack concept. The capacity of a double-stack train in North America is 55 percent more than the capacity of a as long single-stack train (Raghu, 2009). Shipping companies can extend the economies of scale by using double-stack trains that are able to carry over 400 TEUs per train (Hayuth, 1987, p.29). The shipping lines can achieve better utilization of equipment and rolling stock by concentrating at higher volumes of traffic. According to Hayuth (1987, p.29), double-stack trains can save up to 30 to 40 percent in transport costs per container, when compared with conventional trains. According to Richardson (1989, p.22) there is also another benefit of the double-stack concept and that is less damage to transported freight. Articulated platforms eliminate the slack movement natural in conventional train couplings so damage is reduced compared to conventional train. Corollary of this is that less time is consumed in administrative efforts spent on damage claims.

3.3.4.1 The National Gateway project

The National Gateway project will clear existing rail routes for double-stack trains in United States. Purpose of project is to maximize the use of double-stack trains. The National Gateway is a plan to create a more efficient rail route linking Mid-Atlantic ports with Midwestern markets in the United States, improving the flow of rail traffic between these regions by increasing the use of intermodal double-stack cars. It has been counted that the project will reduce highway maintenance costs by converting over 14 billion highway miles to rail. The modal shift from road to rail reduces almost 20 million tons of CO_2 emissions a year. In the same, fuel consumption reduces by over 7.5 million liters. One double-stack train can carry the load of more than 280 lorries in the United States. The National Gateway Project frees room for approximately 1,100 cars and drastically reduces the congestion on the roads. (National Gateway, 2007)

3.3.4.2 Double-stack concept in Europe and India

Double-stack concept has not yet been used in European countries. Main reasons lie in geography, network characteristics and demand patterns (Vassallo & Fagan, 2005; Hayuth, 1987, pp.31-32). The electrification of most tracks in Europe and many low bridges and tunnels do not allow easy clearance required by the double-stack cars. In Scandinavia, specifically in Finland, there aren’t that many tunnels. Finland has more favorable conditions in this respect. According to Vassallo and Fagan (2005), the United States has three times the land area of the European Union, and that result in longer shipment distances that favor rail, because rail transport’s cost–efficiency compared to road transport increases with longer distances. Other explanations of Europe’s and United States’ rail share differences stated in Vassallo and Fagan’s (2005) research are:

- Coastline of the United States is shorter than in Europe.
- Commodity mix in United States favors railroads.
- There are many political disadvantages of railroads in Europe.
- There are less harbors in United States.

All the above reasons slow down the development of rail infrastructure in Europe when compared to development in United States.

Indian Railways (IR) suffers from severe constraint. Load restrictions reduce the payload per unit of transport. This affects throughput, cost of haulage and detention at terminals. Lower speeds of freight trains increase transit time. Because of that freight rates for high rated cargo are consequently higher compared to road transport. According to Raghu (2009), trials in India have confirmed the feasibility of operating double-stack container trains on electrified railroads. That is a major breakthrough, because before it was thought that double-stack trains can operate only with diesel locomotives.

3.3.5 Dry port implementation

In dry port concept the maximum amount of transportation between seaport and consignor or consignee is carried out by rail. This way most of the transportation is performed by more environmental friendly transportation mode i.e. rail transportation is much environmentally friendlier type of transport than road transport. Road transportation also strains roads, seaport cities and cities' surroundings. Modal shift to rail transport in dry port concept eases road congestion. One train can transport considerable higher amounts of freight than one truck i.e. same amount of freight by road takes numerous trucks. In many countries e.g. in United States trains can transport considerable larger amounts of freight, because in United States railroad companies are allowed to use longer trains and double-stack concept. The more freight transport is moved by rail the less there is congestion on the roads. Less congestion also results in shorter queues and waiting times at seaport's gates. That reduces the risk of road accidents. Congested traffic also pollutes more than a smooth traffic flow. In that way reduction in congestion also reduces CO_2 emissions. Not maintaining a predetermined schedule for the arrival of trucks at a busy seaport terminal has been shown to be the major cause of congestion at the terminal (Roso, 2009b). This is easy to fix by modal shift to rail, because rail transport has always predetermined schedule. (Roso, 2009a, b, 2007; Roso *et al.*, 2008)

4 RESEARCH ENVIRONMENT

4.1 Background of the research

This master's thesis is part of Mobile Port project. The main goal of the Mobile Port project is to create an information center for two major transit seaports in Finland. Information center gathers and shares data and information needed for actors within transportation system. It improves information flows between seaport and all the actors that are connected to seaport. Benefits of the information center are decreased accident risks, decreased congestion and decreased emissions. The Mobile Port project is divided into five different work packages. The different packages are:

- WP1: Process descriptions and environmental impacts
- WP2: Processes of seaport and process description
- WP3: Case: Developing Kouvola to be a dry port
- WP4: Mobile communication
- WP5: Piloting an information center for Port of Kotka

This master's thesis concerns work package three (WP3). Aim of this study is to measure monetized environmental impacts of a dry port implementation and to research if it is financially profitable to use a dry port implementation near two major transit seaports of Finland.

4.2 Physical environment of the research

Figure 12 illustrates container ship routes through Finnish seaports. Only Finnish seaports and seaports connected to them are shown in Figure 12. It is possible that more than one container vessel travels between certain route e.g. there are more than just one container ship route between ports of Helsinki and Kotka. Those routes are illustrated with thicker lines.

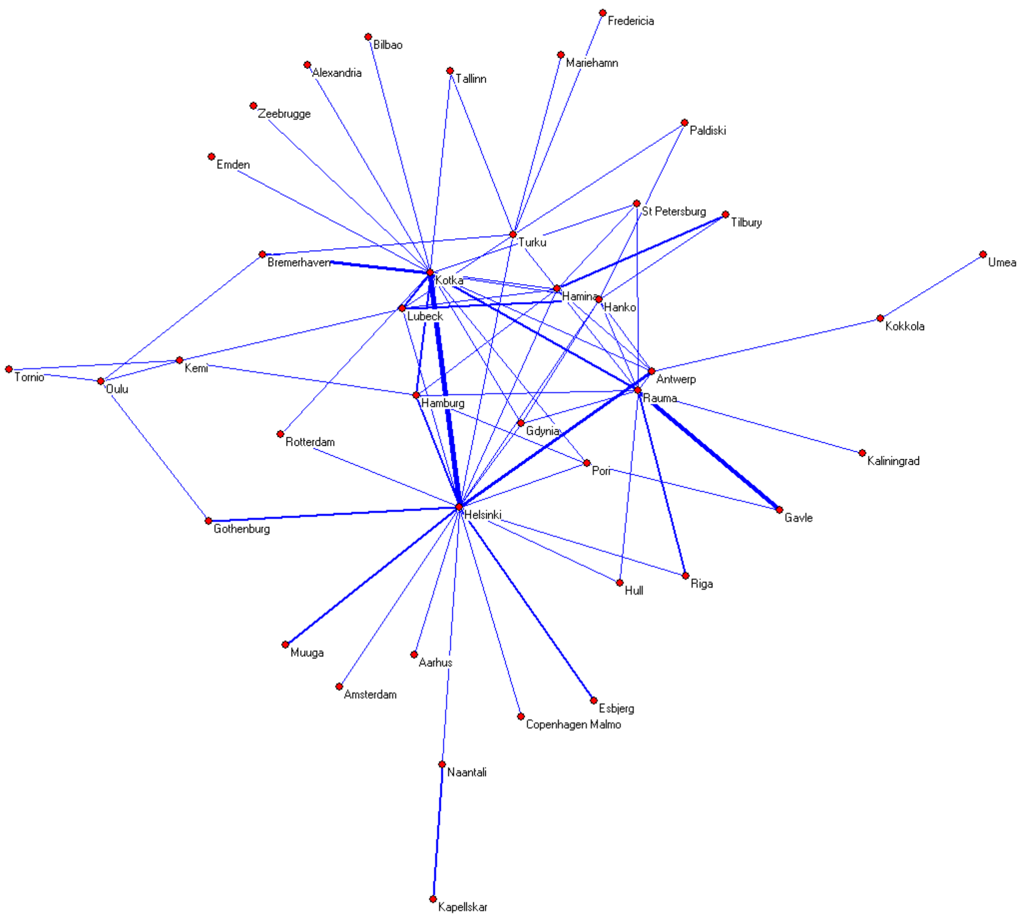

Figure 12 Container ship connections with Finnish seaports.
Source: Fossey *et al*. (2009)

Seaports with most container ship connections are located in the middle of the Figure 12, while seaports with least connections are located in the edge of Figure 12. As can be seen from Figure 12, major container seaports of Finland are Kotka, Hamina, Rauma, Helsinki, Hanko and Turku, when comparing the amount of container ship connections with other seaports. Ports of Kokkola, Kemi, Oulu, Tornio and Naantali have only few container ship connections with other ports. This master's thesis is limited to Port of Kotka and Port of Hamina. Also city of Kouvola is part of this research's physical environment.

4.2.1 Port of Kotka

City of Kotka is located in the southern Finland by the Gulf of Finland. Port of Kotka consists of five different terminals, and the terminals are:

- City terminal,
- Hietanen,
- Hietanen South,
- Mussalo Harbor Area and
- Sunila Quay.

Container terminal of Mussalo was completed in year 2001. Mussalo terminal is the one that focuses on container transshipment and transportation. Because of that, it is part of the research environment. Mussalo port and logistics area currently encompasses 500 hectares of which the capacity for containers is annually 1,000,000 TEUs. There is a total of 275,000 square meters of heated and unheated warehouses for the containerization, handling and intermediate storage of export and import. Many warehouses have a direct rail connection to inland destinations. Mussalo container terminal has a 1,436 meters long quay. There are eight berths available in the Mussalo container terminal, and the draught is 10 – 12 meters deep. There are seven container cranes and one mobile crane operating in the Mussalo container terminal. The container terminal has been designed for an annual volume of one million TEUs.

Container traffic of Port of Kotka has grown steadily from year 1998 to 2008. In year 2008 traffic of TEUs through Port of Kotka was 627,769, which is so far Port of Kotka's record. TEUs transported through Port of Kotka between years 2000 and 2009 are summarized in Figure 13.

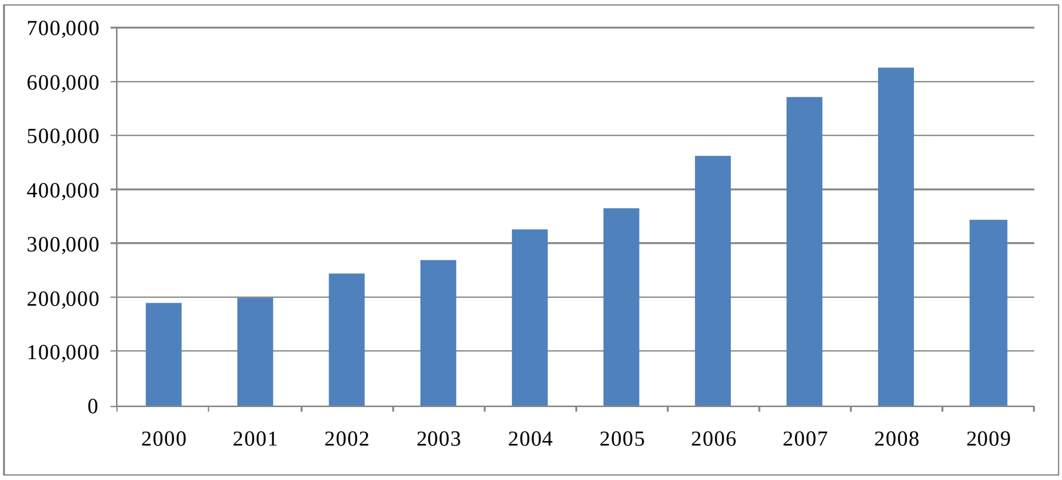

Figure 13 TEUs transported through Port of Kotka in years 2000 to 2009.
Source: Finnish Port Association (2010)

As can be seen from Figure 13, the amount of TEUs transported through Port of Kotka collapsed in year 2009 to number of 345,939 TEUs. That is almost 45 percent reduction if compared to TEUs transported in year 2008. In year 2008 Mussalo was the biggest seaport, when comparing the amount of TEUs transported in Finland. In year 2009 Port of Helsinki transported 357,209 TEUs, which is 11,270 TEUs more than Port of Kotka. In year 2009 Port of Helsinki was the biggest container seaport, while Port of Kotka was still the second largest.

4.2.2 Port of Hamina

The Port of Hamina is the most eastern seaport in Finland. It is situated only a bit more than 20 kilometers east from Port of Kotka. The Russian border lies 35 kilometers east from Port of Hamina. Due to its location near of Russian border, the Port of Hamina has developed an expertise in transit traffic to the markets of Russia. The port features an efficient container terminal and a liquid terminal specializing in the storage and handling of liquids.

Container capacity of Port of Hamina is 500,000 TEUs a year and length of quay is 610 meters. The capacity will be expanded in year 2010, and the total terminal will have 1,000 meters quay and 60 hectares of operating area at the container terminal. There are 7 RoRo-ramps, 3 berths for tankers and a LPG pier, where the draught is from 7 to 10 meters in the Port of Hamina. There are 3 units of wide span SSG-cranes and 8 mobile cranes in the seaport. Container terminal's throughput in number of TEUs from year 2000 to 2009 is summarized in Figure 14 below.

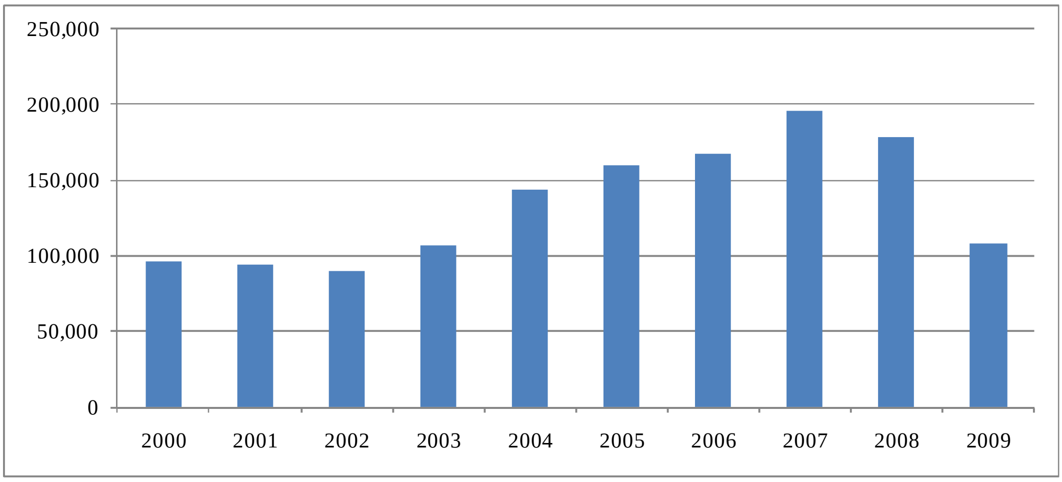

Figure 14 TEUs transported through Port of Hamina in years 2000 to 2009.
Source: Finnish Port Association (2010)

It can be seen in Figure 14 that the throughput of containers in Port of Hamina has increased quite equally until year 2007. In years 2008 and 2009 the throughput of containers has decreased almost 50 percent if compared to year 2007.

Since both seaports (Kotka and Hamina) operate in this master's thesis' research environment and they are increasing their collaboration, it is reasonable to merge both ports' throughput in one single figure. The whole throughput of both seaports can be seen in Figure 15.

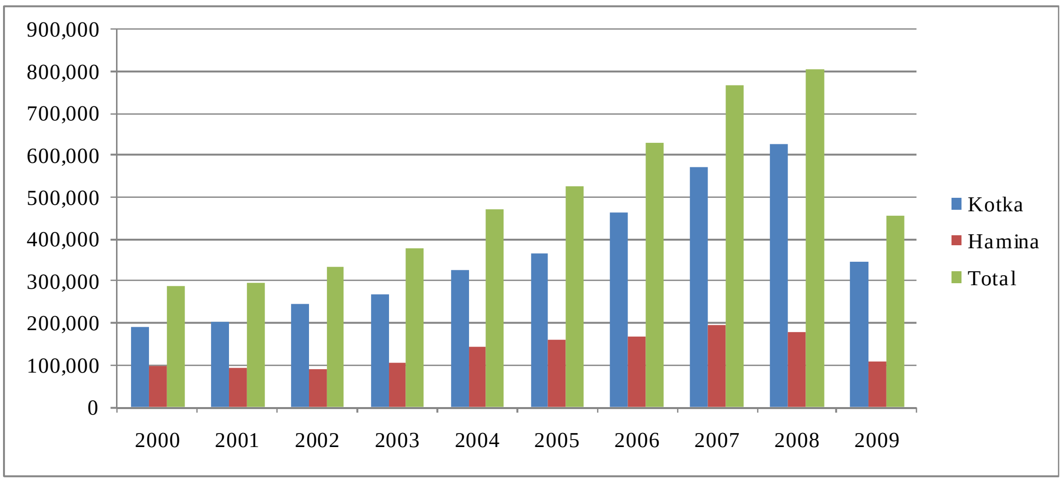

Figure 15 Total TEUs transported through ports of Kotka and Hamina in years 2000 to 2009.
Source: Finnish Port Association (2010)

It can be seen in Figure 15, that there has been a dramatic decrease of throughput of TEUs through seaports of Kotka and Hamina. Main reason for the decrease is the decline of economic prosperity. Figure 16 summarizes the transit traffic through ports of Kotka and Hamina in years 2000 to 2009.

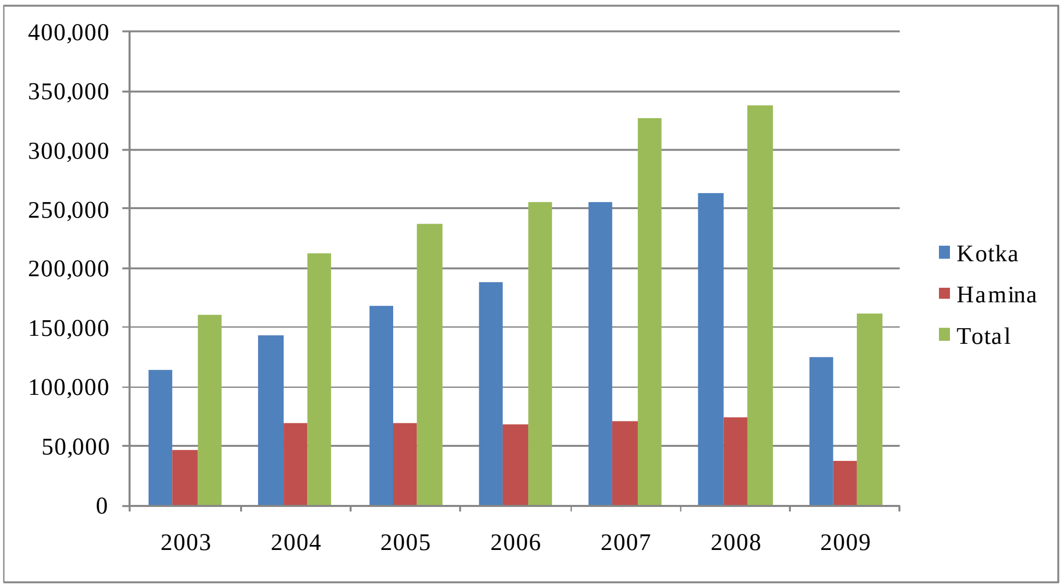

Figure 16 Transit traffic in TEUs through ports of Kotka and Hamina in years 2000 to 2009.
Source: Finnish Port Association (2010)

In his study, Lorentz (2007) has found out that there is a strong correlation between Russian GDP and crude oil export value. Fundamental driver of Russian GDP and of all oil related and originating investments, consumer and federal expenditures, as well as income from export, is the value of crude oil exports. According to Lorentz (2007), a quite accurate forecast of Russian GDP can be done based on the Russian crude oil export value. A sensitivity analysis results were that a 10 percent increase in international oil prices is associated with a 3.8 percent growth in the level of Russian GDP.

Development of transport volumes in the future is not easy to predict. However, in his study Lorentz (2007) stated that in the late 90's crisis, there was a similar drop in transport volumes followed by a recovery to pre-crisis level in three to four years. Based on that, we can expect a related recovery in year 2012 or 2013.

4.2.3 City of Kouvola

City of Kouvola has been chosen to be part of the physical environment, because it is assumed to have a very good location to be a distribution center for both the road and rail network. Significant amounts of Russian transit traffic flows through city of Kouvola. There are also logistics companies, which are situated in Kouvola that operate at Russian markets (Oksanova & Hilmola, 2009). These kinds of subsidiaries usually transport electronics (e.g. televisions). As it was researched in the literature review, the Port of Gothenburg has established many rail connections to inland intermodal terminals of which some can be regarded as real dry ports. Port of Gothenburg has been able to decrease externalities by increasing use of rail transport instead of road transport. This study is trying to find out, if same kind of development would be possible also in Finland. City of Kouvola has been chosen to be the researched, if it could act as a dry port. Also the near city Lappeenranta is chosen to be in a minor part of this study, because it is situated between city of Kouvola and Russian border. It would be possible to expand hinterland of ports of Kotka and Hamin also with city of Lappeenranta. City of Lappeenranta would be a midrange dry port for ports of Kotka and Hamina. Ports of Kotka and Hamina could expand their hinterland and competitiveness with help of Kouvola and Lappeenranta.

Kouvola is situated a bit over 55 kilometers north from Port of Kotka. There is a rail connection between Port of Kotka and city of Kouvola. In fact, Port of Kotka's only rail connection to inland goes through city of Kouvola. The distance from Port of Hamina is approximately same, since ports of Kotka and Hamina are situated near each other. The city is in the center of many important rail connections to other locations of Finland or Russia. Almost all transit traffic by rail from and to Russia goes through Kouvola. Lappeenranta is located approximately 90 kilometers east from Kouvola.

4.2.4 Road and rail network

Road and rail network for transit traffic to and from Russia differs in distances quite a lot. This is due to historical reason concerning the construction of railroad in Finland. When freight is transported from Finnish seaports to Russia by rail, it is first transported approximately 60 kilometers north to city of Kouvola. Rail network continues east from city of Kouvola to Russian border. Mainly used border crossing point to and from Russia is situated at Vainikkala, when transporting freight by rail. Other border crossing points at Russian border are Imatra and Niirala. Border crossing points of Vainikkala, Imatra and Niirala, city of Kouvola, ports of Kotka and Hamina and railway connections between them can be seen in Figure 17 below.

Figure 17 Railway connections and border crossing points in Southern and South-Eastern Finland.
Source: Modified from Ratahallintokeskus (2009a, p.21)

As Figure 17 illustrates, freight transportation by rail is not optimal, if most direct connection is the optimal route i.e. railway makes considerable indirect route from ports of Kotka and Hamina through city of Kouvola to Russian border. Distance from Port of Kotka to Vainikkala by rail is approximately 144 kilometers. Vainikkala is by far the most used border crossing point. Same trend continues at Russia, if freight is transported all the way to Moscow. Freight trains carry freight through city of Vologda, which is located some hundreds of kilometers northeast from Moscow. That indirect route extends rail route from Finnish border to Russia by more than 400 kilometers, if compared to a direct road route from Finnish border to Moscow.

Road network instead does not make such an indirect route as rail. This is a significant advantage in distance, if road transport is used. Shorter distance allows faster transportation to Russian border from ports of Kotka and Hamina. Road network from ports of Kotka and Hamina leads almost directly to border of Russia. Most used border crossing point for road is Vaalimaa. Other border crossing points are Nuijamaa and Imatra. According to Posti (2009), 60 percent of road transit transport is accomplished through Vaalimaa. The distance from Port of Kotka to Vaalimaa is a bit over 60 kilometers. From Port of Hamina the distance is approximately 40 kilometers. Distance from ports of Kotka and Hamina by road directly to Russian border is much shorter (84 kilometers) than when using rail transport that goes through Kouvola and Vainikkala. Road connection from border crossing point to Moscow is considerable shorter than rail connection. Road connection to Moscow is fairly straight, whereas rail connection does a broad indirect route. Table 12 summarizes road and railway distances from ports of Kotka and Hamina to Russian cities of St Petersburg and Moscow.

Table 12 Road and rail network distances between ports of Kotka and Hamina and St Petersburg and Moscow.

	Road distance	Railway distance
Kotka - St Petersburg	265	323
Kotka - Moscow	973	1,409
Hamina - St Petersburg	240	321
Hamina - Moscow	948	1,407

Source: Hilmola *et al.* (2008) and ViaMichelin (2010)

It can be seen in Table 12 that road distance is much shorter than railway distance. The difference in distance is emphasized when comparing distances from Finnish ports to Moscow. Road distance from Kotka to Moscow is a bit less than 1,000 kilometers, while distance by rail between same cities is about 1,400 kilometers. 40 percent longer distance by rail can be explained by a substantial indirect route that railway makes through Vologda when its goal is Moscow. Although rail transport pollutes less than road transport, the difference between road and rail distances decreases the positive environmental effects from rail transportation. But still rail transport would be environmentally friendlier mode of transport even to Moscow, as external costs of rail transport are over 90 percent less than same costs of road transport i.e. distance by rail could be 10 times longer than by road and still both transport modes would create the same amount of external costs. A more direct rail route from ports of Kotka and Hamina would increase rail transport’s cost-efficient and environmental friendliness in transit traffic more.

5 EMPIRICAL PART

Aim of this study is to research, if it is financially and environmentally rational to use city of Kouvola as a dry port solution for ports of Kotka and Hamina. Empirical part starts by comparing costs of road and rail transport. Cost comparison is accomplished by using a cost model. Costs are divided into internal and external costs. The cost model uses different input values concerning internal and external costs of road and rail transport to calculate internal and external costs for both transport modes. Purpose of the cost comparison is to find out, which transport mode is financially and environmentally more rational to use to carry freight from and to ports of Kotka and Hamina. Different possibilities to decrease costs of transport are analyzed. In current transportation system most of the freight transport is being accomplished by road transport from and to ports of Kotka and Hamina. Modal share of rail transport is very low. Costs of transforming green land area to road infrastructure between cities Kouvola and Kotka are also studied. Potential warehousing capacity of Kouvola and Lappeenranta were researched. As well, possibility to expand warehousing areas if needed was studied. Next, conventional road transport and transport of a dry port solution is compared with a discrete-event simulation model. Finally, gravitational models are used to compare three different distribution center locations in Finland. Different scenarios are created for both the road and rail transport.

5.1 Costs of transport

In this sub-chapter total costs of road transport and rail transport are being calculated based on parameter values defined later in this chapter. Costs of both road and rail transport are divided into internal and external costs. The external costs measure environmental friendliness of transport mode. Total costs of both road and rail are further converted to costs per kilometer and costs per ton-kilometer to allow better comparison.

Different external costs used in this research to estimate external costs of road and rail transport are summarized in Table 13. All the values in Table 13 are presented in

Euros per kilometer. Congestion costs for rail transport are set to zero, because strict timetable system prevents congestion at rail network.

Table 13 External cost values used in this research. (€ / km)

			Road	Rail
Congestion	Urban motorways		0.35	0
	Urban collectors		0.13	0
	Local street cordon		0.2	0
CO2 emissions			0.0275	0.1164
Noise	Urban	Day	0.0701	0.4193
		Night	0.1278	1.7106
	Suburban	Day	0.011	0.4006
		Night	0.02	0.6771
	Rural	Day	0.0013	0.05
		Night	0.0023	0.0845
Accidents	Urban roads		0.0875	
	Motorways		0.0025	
	Other roads		0.0221	
	Railroad			0.02

All the external values above in Table 13 are gathered through a literature review. Some of the values e.g. CO_2 emission costs are converted to Euros per kilometer from average CO_2 emissions of truck and rail and from cost of one to ton of CO_2. Costs of road congestion are the minimum values from literature review. Those values are used because traffic congestion is a bigger problem in larger cities that have bigger population than cities in Finland. It is assumed that only costs of moving transportation equipment or rolling stock are concerned. Costs of transshipment at intermodal nodes are not considered.

5.1.1 Road transport

Yearly costs of road transport consist of internal and external costs. Internal costs in this research are further divided into variable and fixed costs. Variable costs used with cost model to calculate total internal variable costs of road transport are:

- salary costs including social costs such as holiday bonus
- daily benefits of travelling

- accommodation costs
- fuel costs
- tire costs
- additive costs
- repair and maintenance costs

Fixed costs used with cost model calculate total internal fixed costs of road transport are:

- insurance costs
- operating costs including taxes and inspections
- administration costs
- capital costs
- depreciation costs

Part of fixed costs are based on transport equipment's procurement costs i.e. fixed costs are higher, if stock's procurement costs increase. Because of that also procurement costs including maintenance time, percentage of interest, driving kilometers per year, driving hours per year and overall mass of stock are also defined and used as input data in cost model.

External costs of both the road and rail transport that are calculated in this research with cost model are:

- CO_2 emission costs
- congestion costs
- noise costs
- accident costs

There are also other possible external costs such as air pollution costs, nature costs, soil and water pollution costs. In this research only those external costs were chosen that are rather specifically studied to get costs as accurate as possible. When other external costs are studied more carefully, then they can be also calculated to study all the external costs of transport.

Parameter values used for road transport in this research are summarized in Table 13 below. Values for both the road and rail transport are gathered from various sources (e.g. Finnish Transport Agency, 2010; Finnish Transport and Logistics, 2010; Sahin *et al.*, 2009). They are estimates i.e. different types of lorries have differences in their internal and external costs. With values presented in Table 14, cost model calculates output values regarding internal and external costs of road transport.

Table 14 Parameters used to calculate costs of road transport.

Parameters	Values	
Transport equipment's procurement costs	70,000	euros
Period of amortization	8	years
Interest rate	10	%
Driving kilometers per year	80,000	kilometers
Overall weight of transport equipment	42	tons
Driving hours per year	3,600	hours
Hourly work costs	13.5	euros / hour
Number of drivers	2	
Consumption of fuel	35	liters / 100 kilometers
Price of fuel	0.83	euros / liter
Consumption of additive	1.8	liters / 100 kilometers
Price of additive	0.65	euros / liter
Duration of tyres	130,000	kilometers
Price of tire set	5,000	euros
Repair and maintenance costs per year	8,000	euros
Incurance costs per year	5,000	euros
Operating costs per year	1,300	euros
Administrarion costs per year	3,700	euros
CO2 emission costs	0.0275	euros / kilometer
Congestion costs	0.13 - 0.35	euros / kilometer
Noise costs	0.0013 - 0.1278	euros / kilometer
Accident costs	0.0025 - 0.0875	euros / kilometer

Differences in congestion, noise and accident costs are consequence of different costs at dissimilar environments. All these costs are higher at urban areas and lower at rural areas.

All variable, fixed and external costs calculated with parameters represented in Table 14 above can be seen in Table 15 below. Costs are arranged by total costs per year, costs per vehicle kilometer and costs per ton-kilometer. Costs are transformed to costs per ton-kilometers to allow better comparison between road and rail transport.

Table 15 Variable, fixed and external costs of road transport.

Total costs per year:	
Variable costs	106,761 euros
Fixed costs	39,871 euros
External costs	23,390 euros
Variable and fixed costs altogether	146,632 euros
All costs altogether	170,021 euros
Costs / kilometer:	
Variable costs / kilometer	1.3345 euros / kilometer
Fixed costs / kilometer	0.4984 euros / kilometer
External costs / kilometer	0.2924 euros / kilometer
Variable and fixed costs altogether / kilometer	1.8329 euros / kilometer
All costs altogether / kilometer	2.1253 euros / kilometer
Costs / ton-kilometer:	
Variable costs / ton-kilometer	0.0318 euros / ton-kilometer
Fixed costs / ton-kilometer	0.0119 euros / ton-kilometer
External costs / ton-kilometer	0.0070 euros / ton-kilometer
Variable and fixed costs altogether / ton-kilometer	0.0436 euros / ton-kilometer
All costs altogether / ton-kilometer	0.0506 euros / ton-kilometer

As from Table 15 can be seen, road transport’s most considerable costs are variable costs. This is mainly due to rather low procurement costs when compared to e.g. variable salary and fuel costs. Low procurement costs causes low yearly capital and depreciation costs when compared to e.g. salary costs. Fixed costs are almost twice as much as external costs. Percentual distribution of variable, fixed and external costs are summarized in Figure 18.

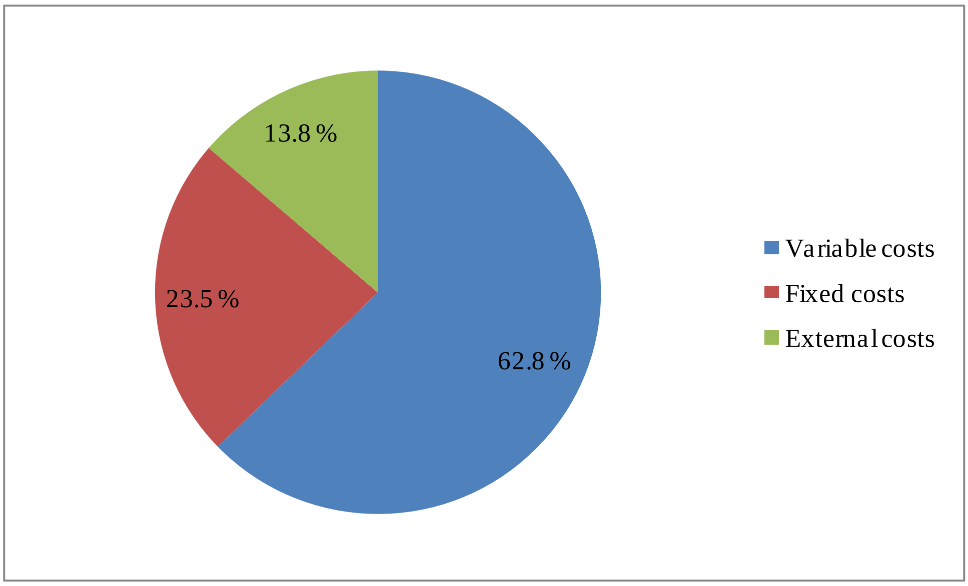

Figure 18 Percentual distribution of variable, fixed and external costs of road transport.

Variable costs are circa 63 percent of all costs of road transport. It means that most costs of road transport are due to salaries and fuel costs. Fixed costs are a bit over 23 percent. These costs increase if transport equipment's procurement price increases. Fixed costs can be decreased by using used transportation equipment. External costs are approximately 14 percent of all road transport costs. The amount of external costs is fairly high. Almost 15 percent of total road transport costs consist of noise, CO_2 emission, congestion and accident costs. By lowering external costs, road transport could be environmentally friendlier and overall more inexpensive mode of transport.

5.1.2 Rail transport

Parameter values used to calculate variable, fixed and external costs of rail transport are summarized in Table 16.

Table 16 Parameters used to calculate costs of rail transport.

Parameters	Values	
Price of locomotive	3,000,000	euros
Number of locomotives	3	
Price of wagon	80,000	euros
Number of wagons	80	
Transport equipment's procurement costs altogether	15,400,000	euros
Period of amortization	20	years
Interest rate	10	%
Driving kilometers per year	250,000	kilometers
Overall weight of transport equipment	3310	tons
Utilization rate	60	%
Driving hours per year	6,000	hours
Hourly work costs	27.7	euros / hour
Consumption on electricity	0.0046 - 0.0107	kWh / ton-kilometer
Tariffs from using rail network:		
Basic charge	0.00135	euros / ton-kilometer
Tax for electrified train	0.0005	euros / ton-kilometer
Tax for diesel train	0.001	euros / ton-kilometer
Repair and maintenance costs per year	1,540,000	euros
Incurance costs per year	118,000	euros
CO2 emission costs	0.1164	euros / kilometer
Congestion costs	0	euros / kilometer
Noise costs	0.05 - 1.7106	euros / kilometer
Accident costs	0.02	euros / kilometer

Procurement costs of rail transport are considerable higher than the same costs for road transport. Reason is that wagons and locomotives for rail transport are very expensive. Another reason is that there is no sense in e.g. getting only one locomotive and one wagon. In this research it is assumed that procurement costs consist of three locomotives and 80 wagons. Price of rolling stock compared to price of road transport in the previous chapter is significantly higher. In this case procurement costs of rolling stock are 15,400,000 Euros while, procurement costs of road transport are 70,000 Euros.

Electricity consumption of rail transport per ton-kilometer decreases, if the weight of train increases i.e. a more heavy train consumes less electricity per ton-kilometer, while lighter train consumes more electricity per ton-kilometer. In this research it is assumed that rail transport creates no congestion costs.

Table 17 summarizes calculated variable, fixed and external costs of rail transport by cost model. All costs are arranged by total costs per year, costs per vehicle kilometer and costs per ton-kilometer. Costs are divided all the way to costs per ton-kilometer to allow better comparison between road and rail transport's internal and external costs.

Table 17 Variable, fixed and external costs of rail transport.

Total costs per year:	
Variable costs	2,411,275 euros
Fixed costs	4,118,878 euros
External costs	165,775 euros
Variable and fixed costs altogether	6,530,153 euros
All costs altogether	6,695,928 euros
Costs / kilometer:	
Variable costs / kilometer	9.6451 euros / kilometer
Fixed costs / kilometer	16.4755 euros / kilometer
External costs / kilometer	0.6631 euros / kilometer
Variable and fixed costs altogether / kilometer	26.1206 euros / kilometer
All costs altogether / kilometer	26.7837 euros / kilometer
Costs / ton-kilometer:	
Variable costs / ton-kilometer	0.0097 euros / ton-kilometer
Fixed costs / ton-kilometer	0.0166 euros / ton-kilometer
External costs / ton-kilometer	0.0007 euros / ton-kilometer
Variable and fixed costs altogether / ton-kilometer	0.0263 euros / ton-kilometer
All costs altogether / ton-kilometer	0.0270 euros / ton-kilometer

Because of significant procurement costs, the fixed costs of rail transport are most substantial costs when compared to variable and external costs. The external costs of rail transport are minor. Considerable proportion of variable costs consists of maintenance and repair costs. The percentual distribution of different costs of rail transport is illustrated in Figure 19.

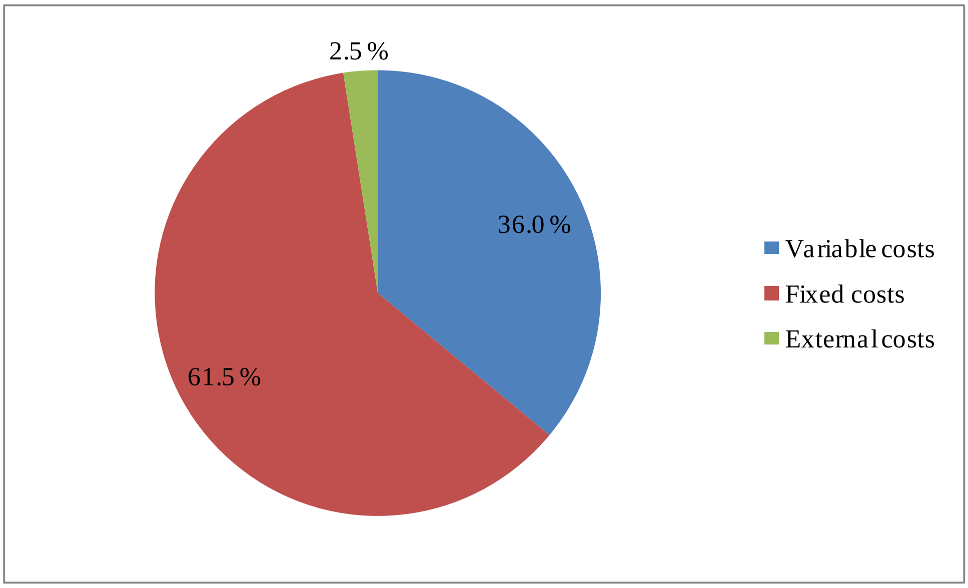

Figure 19 Percentual distribution of variable, fixed and external costs of rail transport.

About 62 percent of all costs of rail transport are fixed costs. Variable costs are around 36 percent of total rail transport costs, while external costs are only a bit over two percent. Environmental friendliness in terms of accident costs, noise costs, congestion costs and CO_2 emission costs are very low. As it was earlier stated, main reason for high fixed costs is the procurement costs of rolling stock and traction. Salaries are considerable lower, if compared to fixed costs. In rail transport salaries play very small role. That is totally opposite in road transport. Maintenance and repair costs increase variable costs.

5.1.3 Sensitivity analysis

Firstly, a sensitivity analysis concerning investment costs is made. Procurement costs of road and rail are halved. Results of sensitivity analysis for road transport are presented in Table 18 below.

Table 18 Sensitivity analysis for road transport.

Costs / ton-kilometer:	
Variable costs / ton-kilometer	0.0318 -> 0.0318 euros / ton-kilometer
Fixed costs / ton-kilometer	0.0119 -> 0.0086 euros / ton-kilometer
External costs / ton-kilometer	0.0070 -> 0.0070 euros / ton-kilometer
Variable and fixed costs altogether / ton-kilometer	0.0436 -> 0.0404 euros / ton-kilometer
All costs altogether / ton-kilometer	0.0506 -> 0.0473 euros / ton-kilometer

It can be seen from Table 18 that change in procurement costs affect only fixed costs of road transport. Procurement costs affect different fixed costs e.g. depreciation costs, insurance costs and capital costs. There is also a possibility that repair and maintenance costs increase, if transportation equipment needs more maintenance due to its lower quality. Decrease in all costs together per ton-kilometer is not very high. Percentual decrease is circa 6.5 percents, while the decrease in procurement costs is from 70,000 Euros to 35,000 Euros.

Results of sensitivity analysis concerning procurement costs for rail transport are presented in Table 19. Procurement costs of rail transport decrease from 15,400,000 Euros to 7,700,000 Euros.

Table 19 Sensitivity analysis for rail transport.

Costs / ton-kilometer:	
Variable costs / ton-kilometer	0.0097 -> 0.0097 euros / ton-kilometer
Fixed costs / ton-kilometer	0.0166 -> 0.0096 euros / ton-kilometer
External costs / ton-kilometer	0.0007 -> 0.0007 euros / ton-kilometer
Variable and fixed costs altogether / ton-kilometer	0.0263 -> 0.0193 euros / ton-kilometer
All costs altogether / ton-kilometer	0.0270 -> 0.0200 euros / ton-kilometer

Decrease in procurement costs of rolling stock affects only fixed costs of rail transport. Percentual decrease on all costs together per ton-kilometer is approximately 26 percent. Higher decrease in rail transport’s costs originates from rail transport’s higher fixed costs mainly due to procurement costs of rolling stock.

Second sensitivity analysis concerns only rail transport. It tests how the costs of rail transport behave if double-stack trains or longer trains are used. With double-stack train concept or longer trains between ports of Kotka and Hamina and city of Kouvola the capacity of one train could be significantly more. Double-stack train concept is widely used in United States and it is very cost-efficient concept. Double-stack concept leads to decreased costs per ton-kilometer, because there would be no need for more salary for driver. Also lesser amount of container wagons would be enough to transport the same amount of cargo than before.

Cost model was used to see what happens, if same rolling stock could transport 100 percent more containers i.e. the amount of wagons rise from 80 to 160. This kind of change can be achieved e.g. with double stack train. Change in costs per ton-kilometer is summarized in Table 20.

Table 20 Double-stack train's effect on costs of rail transport.

Costs / ton-kilometer:	
Variable costs / ton-kilometer	0.0097 -> 0.0084 euros / ton-kilometer
Fixed costs / ton-kilometer	0.0166 -> 0.0123 euros / ton-kilometer
External costs / ton-kilometer	0.0007 -> 0.0006 euros / ton-kilometer
Variable and fixed costs altogether / ton-kilometer	0.0263 -> 0.0207 euros / ton-kilometer
All costs altogether / ton-kilometer	0.0270 -> 0.0213 euros / ton-kilometer

Both the variable and fixed costs decrease. Also the external costs decrease slightly. Cost-efficiency of the rail transport increases with double-stack concept. This is due to more freight can be transported with same rolling stock and same salary costs. Percentual decrease in all costs altogether is a bit over 20 percent. Cost-efficiency of rail transport would increase significantly. Problem concerning double-stack train in Finland is that implementing the concept might be expensive. Double-stack train couldn't probably operate at present rail network in Finland, because electrification system might be so low that double-stack train doesn't have enough space. Infrastructure costs regarding the implementation of the double-stack concept could rise very high. Same kind of capacity increase could also be accomplished with longer trains. At the moment the length of train is restricted. If the length of train in Finland could be increased, then cost-efficiency of trains would increase same way as it would increase by double-stack concept.

5.1.4 Cost comparison of road and rail transport

Since procurement costs of road transport and rail transport differ significantly, there is no sense in comparing total costs per year or costs per vehicle kilometer. Also the difference in weight between a truck and train is so huge that total costs per year differ radically. Reasonable way to compare road and rail transport is to compare their costs per ton-kilometer. Figure 20 illustrates comparison of variable, fixed and external costs per ton-kilometer between road and rail transport. Also the internal costs (variable and fixed costs altogether) and total costs of both transport modes can be seen in Figure 20.

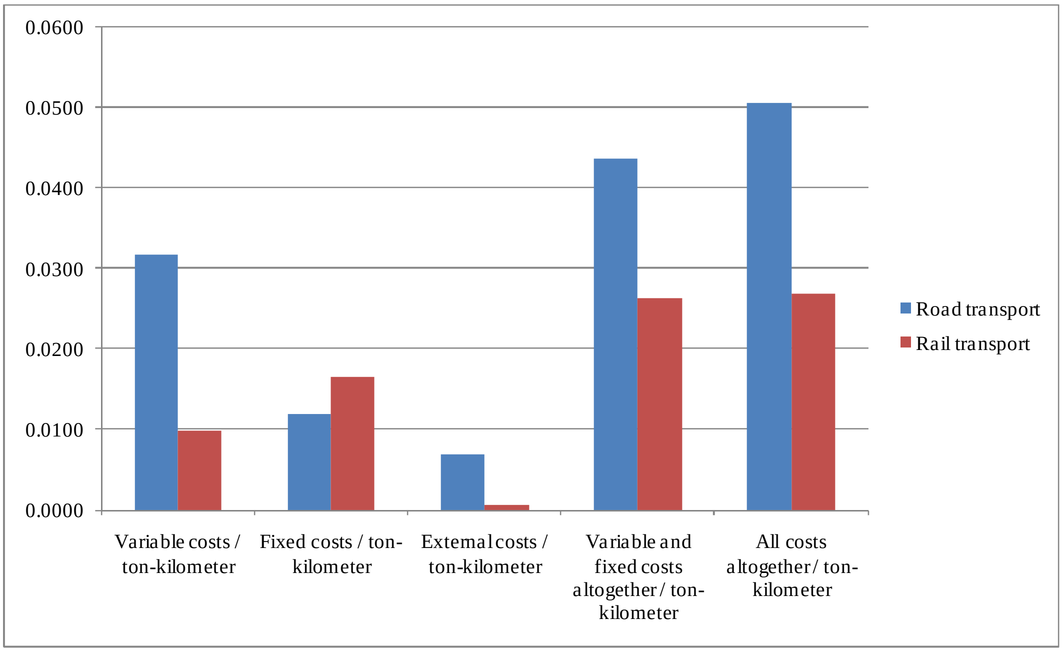

Figure 20 Road and rail transport's costs per ton-kilometer.

Figure 20 shows that rail transport's costs per ton-kilometer are significantly lower than road transports. The most substantial differences are in variable and external costs in rail transport's favor. Fixed costs of rail transport are a bit higher than the same costs of road transport. Variable costs per ton-kilometer for road transport are slightly more than 0.0300 Euros per ton-kilometer, while same costs for rail transport are approximately 0.0100 Euros per ton-kilometer. The external costs per ton-kilometer for road transport is 0.0071 Euros as the same figure for rail transport is 0.0007 Euros. External costs per ton-kilometer for road transport are circa 10 times higher than external costs for rail transport. Result of this comparison is that rail transport pollutes far less than road transport. Rail transport is also in other environmental terms (noise, congestion and accidents) friendlier. Also variable and fixed costs altogether (internal costs) of rail transport are lower than road transport. All costs (variable, fixed and external) altogether for road transport is a bit more than 0.0500 Euros per ton-kilometer. Same figure for rail transport is a bit less than 0.0300. The difference is significant. If infrastructure costs and transshipment costs of transport are not taken into account, the rail transport is more inexpensive and environmentally friendlier mode of transport than road transport.

5.2 Land use

If same trend continues and road transport maintains or increases its market share transporting freight from and to ports of Kotka and Hamina, it can be assumed that road between ports and city of Kouvola needs to be expanded. Road between port of Kotka and city of Kouvola is one of the most congested roads in Finland. Infrastructure costs itself will be significantly higher. There will also be other costs concerning land use.

Costs occurred from land use are calculated by defining green area needed for expanding the present road between Kotka and Kouvola. Size of the green area needed to expand the present road depends on how significant the expansion will be. Width of the current road is approximately 10.5 meters and the road has two lanes, one for both directions. With current or increased traffic optimal road between Port of Kotka and city of Kouvola would be a motorway that includes four lanes, two for both directions. Width of such motorway would be approximately 30 to 38 meters. Length of the road that needs expansion between cities of Kotka and Kouvola is approximately 39 kilometers. If current road will be expanded to motorway, it will consume a bit over 108 hectares of green land area. That can be further converted to costs per year caused by lost green land that could have absorbed CO_2. Costs are slightly more than 25,000 Euros per year. These costs can be avoided by increasing the use of rail transport to ease the congested road between cities of Kotka and Kouvola. By using more rail transport, there is no need for road expansion. Or at least a smaller expansion would certainly be enough. Costs of land area above and two other options if expansions are smaller are summarized in Table 21.

Table 21 Costs of loss of green land area.

Type of the road expansion	Costs per year
Narrow trunk-road with four lanes	6,600
Narrow motorway with four lanes	16,000
Wide motorway with four lanes	25,500

Maximum costs of lost land area are 25,500 Euros per year. These costs occur, if current road is structured to a wide motorway with four lanes. Expansion could be smaller, but road will get congested easier in the future. If road is constructed to a narrow motorway with four lanes, it would cost 16,000 Euros a year through lost CO_2 emission absorption. Same cost per year would be 6,600 Euros if present road is structured to a narrow trunk-road with four lanes.

5.3 Warehousing capacity

A dry port solution needs plenty of space for storage of containers and other load-units. Because of that it is necessary to know, whether or not there is warehousing capacity at city of Kouvola. City of Lappeenranta was also researched regarding warehousing capacity, because location of Lappeenranta could be potential for a dry port solution or for expanding dry port from Kouvola to Lappeenranta. Kouvola and Lappeenranta both have a large potential warehousing capacity i.e. in both cities there are many hectares of empty container warehousing space, and there are also large potential land areas that can be constructed to container warehousing areas, if needed.

Kouvola has prepared itself for possible increasing container traffic in the near future. The main logistical area of Kouvola is situated at Tykkimäki. It is located three to four kilometers east from the center of Kouvola. In Tykkimäki there are already privately owned container warehouses. There is also a construction of about 20 hectares of land space for more container storage warehouse in Tykkimäki. Logistic area at Tykkimäki has both the road and rail connection. If that area is not enough in the future, then there is also another potential land area of 13 hectares in Tykkimäki that can be constructed to a warehousing area if needed. There are also other possible land areas in Kouvola, where it can expand its container warehousing areas. They lie at Inkeroinen, Kaipiainen and Lehtomäki. If rail intermodal container transport to Kouvola increases, there is enough warehousing area and potential expanding area.

There is a lot of potential warehousing capacity at the city of Lappeenranta. Main logistical area of Lappeenranta is its inland harbor of Mustola. It is connected to Russia with Saimaa canal. In addition, Mustola has road and rail connection. At the moment the container traffic through Mustola is very minor, because traffic itself has diminished considerably. There is approximately 200 hectares of feasible space for container warehousing if needed at Mustola. At the moment container fields are used for warehousing of tires, but if container traffic through Mustola increases, space for container storage area can be released quickly for containers.

5.4 Marco Polo program

Finnish companies are also eligible for funding from Marco Polo program. It is a good opportunity to increase modal share of rail transport and also gain extra funding from that. Also empty intermodal transport units are taken into account, if these are shifted off the road. It means that it does not matter whether the containers are full or empty. They are still eligible for funding. Only international routes are supported i.e. national routes inside Finland are not eligible for Marco Polo program funding. Funding for corporation shifting freight transport off the road is based on ton-kilometers. The whole budget of the project is 450 million Euros. If a Finnish company can increase environmental and social benefits by approximately 14 million Euros with modal shift, then the grant of Marco Polo program would be 1.5 million Euros.

5.5 Discrete-event system simulation model

Discrete-event system simulation model used to compare present transport system with a dry port implemented transport system is created by Lauri Lättilä. Model is made by discrete-event simulation software called AnyLogic. Software is created by XJ Technology. Model uses the internal and external costs of road and rail transport calculated earlier in this research. Purpose of the simulation is to find out if dry port solution is environmentally friendlier than conventional road transport system. A data collection for simulation model was accomplished, but due to time limits collected data is not included completely in the simulation model represented in this research. The mostly used connections are included in the simulation model.

5.5.1 Data collection

Critical data for simulation model is data concerning routes of trucks. Data regarding starting and destination points of trucks that transfer freight to or from ports of Kotka or Hamina were not easy to find. First, administrative staff of both ports was contacted. They didn’t have data regarding starting and destination points of road transport. After that local haulers were contacted regarding the same data. They had a small quantity of data concerning starting points of some trucks, but not all. The data was not very reliable, since it was informal text written by truck haulers. Next, Statistics Finland was contacted and asked if they had data of road transport and their routes from and to ports of Kotka and Hamina. They had some data regarding this situation, but they didn’t have permission to deliver data, because the data was not reliable, since they had so little of it. Finally, Finnish Transport Agency was contacted regarding data. They had a data collection concerning trucks and their routes all over Finland. Their survey was conducted by Statistics Finland during years 2006 to 2008. It contains over 13,000 route connections in Finland or Finnish borders. From ports of Kotka and Hamina study includes almost 1,000 different connections. All those connections are truck connections from and to ports of Kotka and Hamina between other cities in Finland and Finnish borders. Since the survey has been made during years 2006 to 2008 and there are only about 1,000 connections, the data cannot be concerned very reliable. In the real life the number of connections from and to ports of Kotka and Hamina is significantly higher.

Problem with the data gathered from this study is that it contains only 74 routes that are connected to ports of Kotka and Hamina between years 2006 and 2008. All the other connections are from cities of Kotka and Hamina, not from seaports. To increase reliability and validity of this study, all connections are taken into account when defining starting and destination points of road transport. Now all road connections from and to Hamina and Kotka are included in the data that will be used in simulation model in the future. This also decreases reliability and validity of this research, because now data contains also other transport types than intermodal container movement e.g. trucks transporting oil and cars. But since this is the only data available concerning road transport’s starting and destination points in Finland, this is the most reliable way available to gather data for the simulation model.

Table 22 below summarizes the most operated route connections of road transport from and to cities of Hamina and Kotka. Road connections to ports of Hamina and Kotka are also presented in the Table 22.

Table 22 Road connections from and to cities and ports of Hamina and Kotka.

Route	Number of connections	Percentual share
Kotka - Hamina	25	3.37 %
Kouvola - Kotka	24	3.24 %
Kotka - Kouvola	21	2.83 %
Port of Kotka - Kotka	20	2.70 %
Kotka - Lappeenranta	18	2.43 %
Kotka - Pyhtää	17	2.29 %
Hamina - Kotka	16	2.16 %
Lappeenranta - Kotka	14	1.89 %
Pyhtää - Kotka	14	1.89 %
Hamina - Lappeenranta	13	1.75 %
Kotka - Helsinki	12	1.62 %
Anjalankoski - Kotka	11	1.48 %
Helsinki - Kotka	11	1.48 %
Kuusankoski - Kotka	11	1.48 %
Lappeenranta - Hamina	11	1.48 %
Porvoo - Kotka	11	1.48 %
Port of Hamina - Hamina	10	1.35 %
Kotka - Anjalankoski	10	1.35 %
Kotka - Port of Kotka	10	1.35 %
Kotka - Porvoo	10	1.35 %
Hamina - Anjalankoski	9	1.21 %
Port of Hamina - Kotka	9	1.21 %
Heinola - Kotka	9	1.21 %
Kotka - Kuusankoski	9	1.21 %
Kotka - Valkeala	8	1.08 %
Kotka - Vantaa	8	1.08 %
Valkeala - Kotka	8	1.08 %
Virolahti - Hamina	8	1.08 %
Lohja - Hamina	7	0.94 %
Hamina - Port of Kotka	6	0.81 %
Hamina - Virolahti	6	0.81 %
Joutseno - Kotka	6	0.81 %
Port of Kotka - Hamina	6	0.81 %
Kuusankoski - Hamina	6	0.81 %
Luumäki - Hamina	6	0.81 %
Hamina - Eno	5	0.67 %
Hamina - Imatra	5	0.67 %
Hamina - Miehikkälä	5	0.67 %
Imatra - Hamina	5	0.67 %
Kotka - Virolahti	5	0.67 %
Vantaa - Hamina	5	0.67 %
Vantaa - Kotka	5	0.67 %
Hamina - Lohja	4	0.54 %
Hamina - Pyhtää	4	0.54 %
Hamina - Valkeala	4	0.54 %
Harjavalta - Hamina	4	0.54 %
Harjavalta - Kotka	4	0.54 %
Heinola - Hamina	4	0.54 %
Kotka - Port of Hamina	4	0.54 %
Kotka - Heinola	4	0.54 %
Kotka - Joutseno	4	0.54 %
Kotka - Siilinjärvi	4	0.54 %

There are also other road connections from and to cities and ports of Hamina and Kotka. They are not shown in Table 22 above to save space. These connections were supposed to be included in the simulation model, but due to time restrictions they were not able to be included completely in the current simulation model. Connections to chosen cities are taken into account in the simulation model. Most probably all the connections above shown in Table 22 will be included in the simulation model in the future to improve model's accuracy and through that also the validity of the simulation model.

5.5.2 Results of discrete-event simulation model

Discrete-event simulation was created to compare costs and CO_2 emissions of conventional road transport and of dry port solution. Three different results of the simulation model are included in this research. First scenario uses connections presented in Table 22. Percentual distribution to chosen cities is based on the amount of connections between port and chosen cities. Second scenario distributes freight to cities near the dry port implementation, which is in this case city of Kouvola. Third scenario distributes to more distant cities. There is a comparison of a conventional road transport and transport with dry port implementation in both simulation models. Connections and their percentual distribution to chosen cities for first scenario are shown in Table 23.

Table 23 Connections used in simulation model's first scenario.

Consignee or Consignor	Number of connections	Percentual share	Number of trucks
Anjalankoski	33	10.8%	108
Heinola	20	6.5%	65
Hollola	1	0.3%	3
Hyvinkää	1	0.3%	3
Hämeenlinna	1	0.3%	3
Iisalmi	2	0.7%	7
Imatra	14	4.6%	46
Joutseno	12	3.9%	39
Jyväskylä	6	2.0%	20
Jämsä	2	0.7%	7
Kemi	2	0.7%	7
Kokkola	1	0.3%	3
Kouvola	50	16.3%	163
Kuopio	1	0.3%	3
Kuusankoski	29	9.5%	95
Lahti	9	2.9%	29
Lappeenranta	56	18.3%	183
Luumäki	8	2.6%	26
Mikkeli	12	3.9%	39
Oulu	3	1.0%	10
Pori	4	1.3%	13
Rauma	2	0.7%	7
Riihimäki	3	1.0%	10
Rovaniemi	1	0.3%	3
Seinäjoki	1	0.3%	3
Tampere	6	2.0%	20
Valkeala	23	7.5%	75
Varkaus	3	1.0%	10
Total	306	100.0%	1000

In first scenario it is assumed that 1,000 trucks carry freight between ports and chosen cities. Trucks are divided between different routes according to number of connections. Route between Kouvola and ports of Hamina and Kotka is the most used one. That’s why number of trucks between that route is the largest. Conventional transport uses only road transport. Freight traffic to and from chosen cities is accomplished by trucks from Port of Kotka. Dry port implemented transport is performed differently. Freight from Port of Kotka is first transported by rail to city of Kouvola and vice versa. Freight from and to city of Kouvola from chosen cities is carried out by road transport. It is assumed that idle time at port of Kotka is 30 minutes and idle time at dry port of Kouvola is 15 minutes. Weight of the cargo is assumed to be 20 tons. Figure 21 shows CO_2 emissions of a traditional road transport and implemented dry port transport with chosen cities according to data received from Finnish Transport Agency.

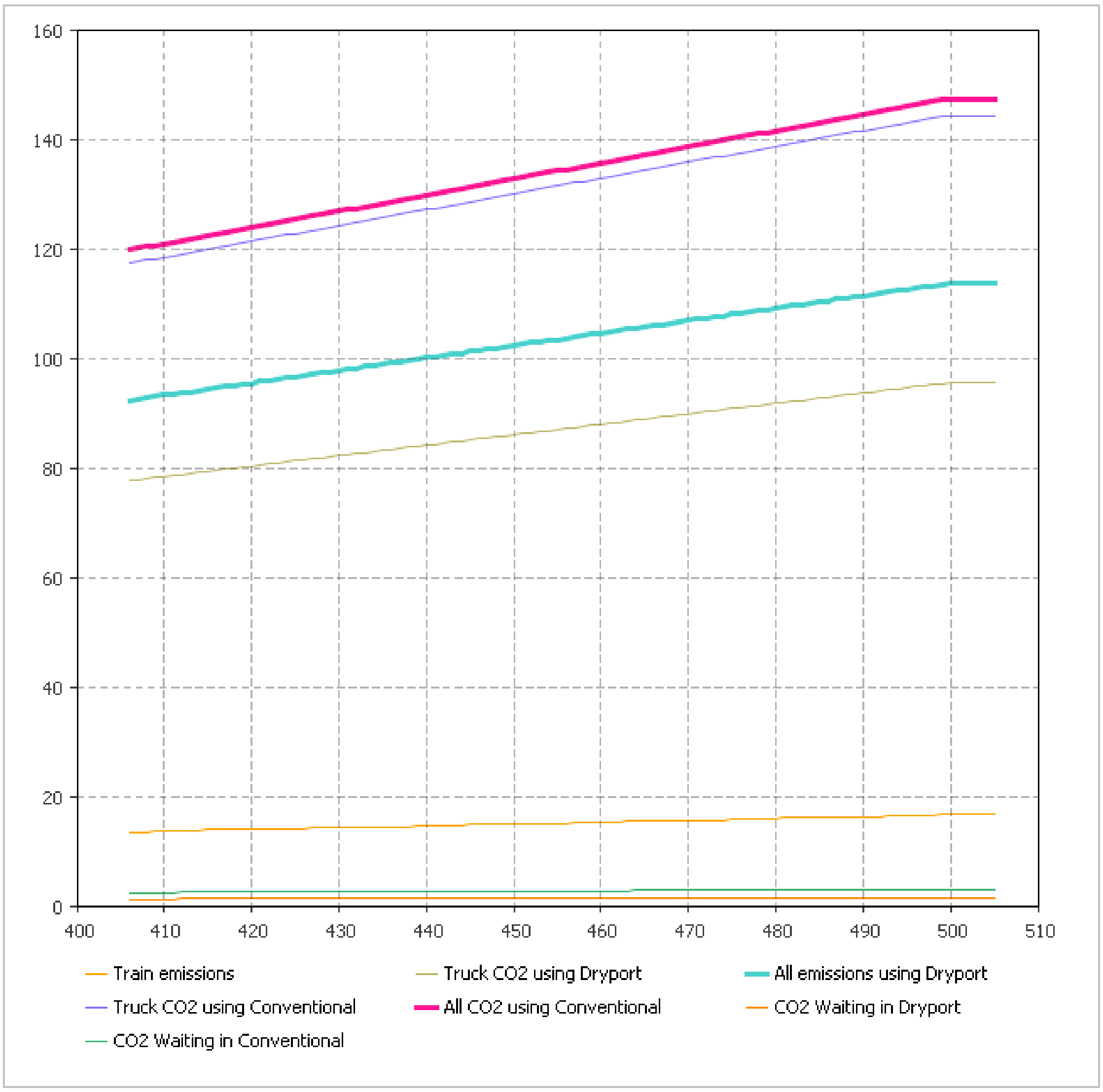

Figure 21 Comparison of conventional road transport and dry port solution with chosen cities in terms of CO_2 emissions (tons) and time (hours).

Y-axis describes cumulatively CO_2 emission amounts of traditional and dry port implemented transport. Red line that describes total CO_2 emissions of the traditional transport is straight in the end. That is because model has to wait for the last train of the dry port implementation. Figure 21 shows that the dry port solution could lower CO_2 emissions of the current transport system. The Red line shows the amount of CO_2 emissions of conventional road transport, whereas the blue line shows CO_2 emissions of the dry port implemented transport system. Percentual difference in CO_2 emissions in the first scenario is 23 percent. Reason for decreased CO_2 emissions is rail transport's ability to create lesser amount of emissions. Simulation model also calculates internal and external costs of transport based on the values calculated in Chapter 5.1. Costs of conventional road transport and dry port implemented transport in the first scenario are summarized in Table 24.

Table 24 Costs of conventional and dry port implemented transport with chosen cities (Euros).

		Conventional road transport	Dry port implemented transport
Road transport	External costs	29,500	19,500
	Internal costs	184,000	121,500
Rail transport	External costs		1,300
	Internal costs		47,500
	Total costs	**213,500**	**189,800**

As can be seen from Table 24 the total costs of dry port implemented transport system are lower than costs of conventional road transport. In addition, external costs of dry port implemented transport system are lower. They could be lowered more with more increased use of rail transport.

In second model freight is transported to cities near Kouvola. Cities are Lahti, Hämeenlinna, Mikkeli, Lappeenranta and Kouvola. Distances to chosen cities by road from Port of Kotka are approximately 120, 194, 158, 110 and 59 kilometers respectively. Figure 22 summarizes the results of the second model.

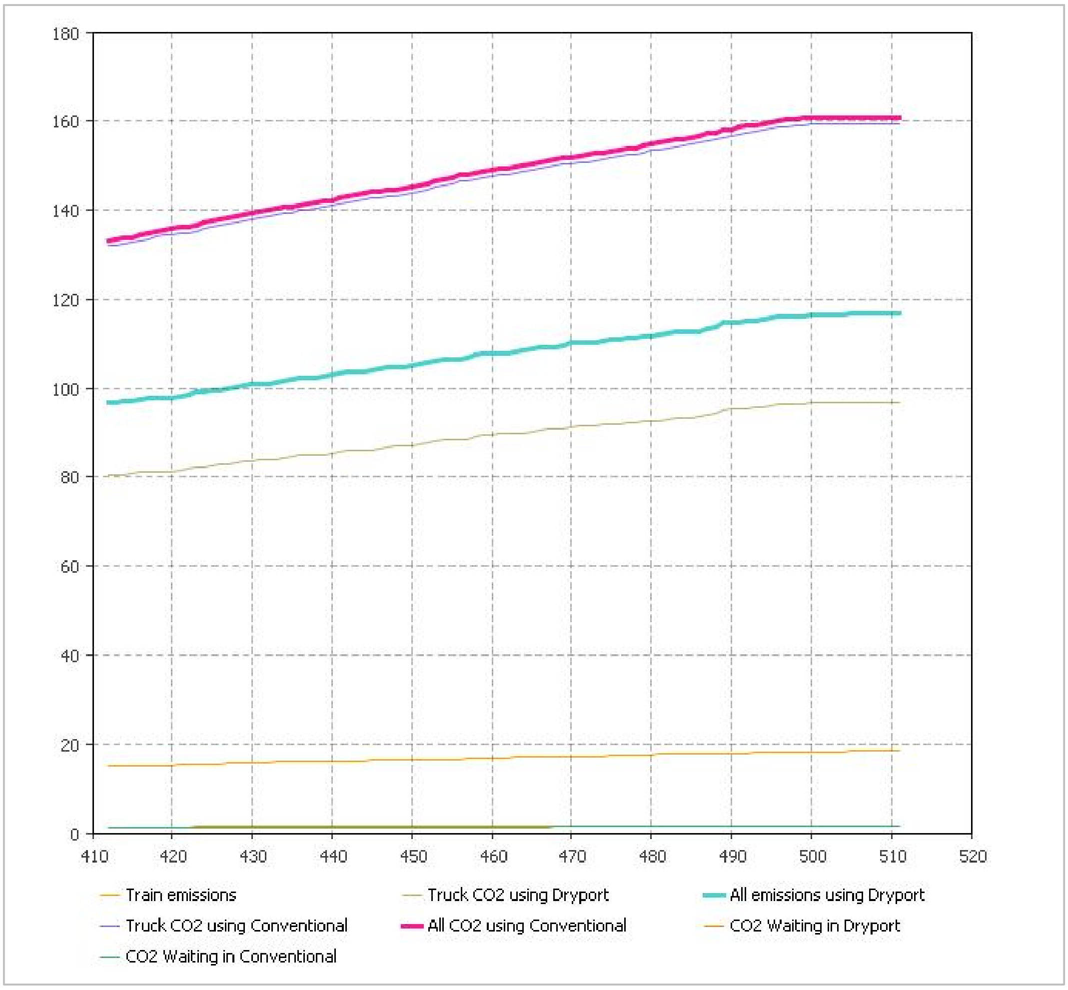

Figure 22 Comparison of conventional road transport and dry port solution with near cities in terms of CO_2 emissions (tons) and time (hours).

As can be seen from Figure 22, dry port solution decreases the amount CO_2 emissions of transport. Percentual difference in CO_2 emissions between conventional road transport and dry port implemented transport is 28 percent. Reason for significant difference is rail transport's ability to be environmentally friendlier mode of transport than road transport. Table 25 summarizes differences of internal and external costs between traditional and dry port implemented transport.

Table 25 Costs of conventional and dry port implemented transport with near cities (Euros).

		Conventional road transport	Dry port implemented transport
Road transport	External costs	33,000	20,000
	Internal costs	203,000	123,000
Rail transport	External costs		1,400
	Internal costs		52,000
	Total costs	**236,000**	**196,400**

Results of Table 25 are that dry port implemented transport system could decrease costs with near cities from 196,400 to 236,000 Euros. In addition, external costs of transport would decrease from 33,000 to 21,400 Euros. Decrease in total costs would be circa 17 percent, and decrease in external costs would be approximately 35 percent. Decrease in both the internal and external costs would be significant with the dry port implementation.

In Figure 23 results of distribution between different cities are illustrated. Now cities are farther than in the previous results shown in Figure 22. Chosen cities are Tampere, Jyväskylä, Joensuu and Kuopio. Distances to those cities from Port of Kotka are circa 274, 246, 342 and 319 kilometers respectively.

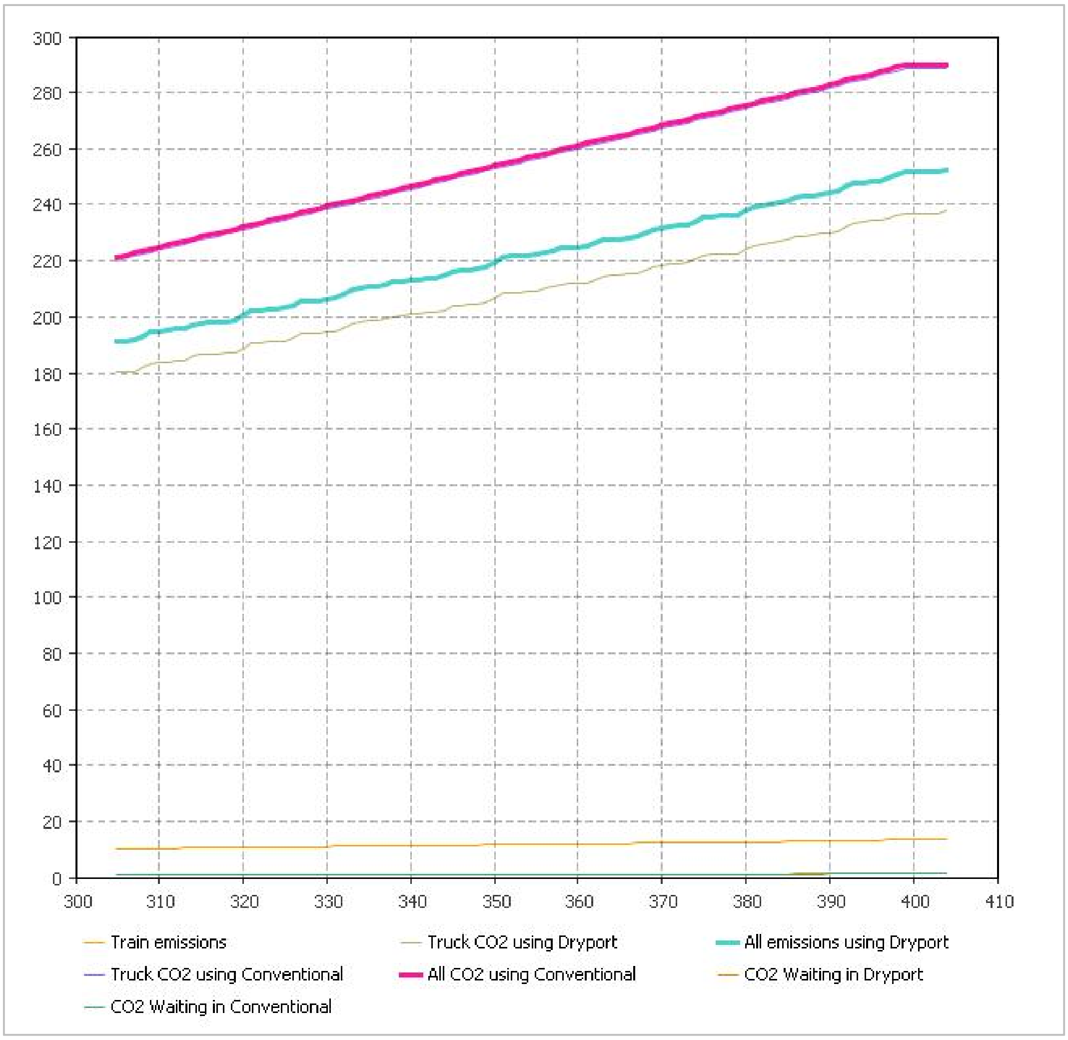

Figure 23 Comparison of conventional road transport and dry port solution with farther cities in terms of CO_2 emissions (tons) and time (hours).

Result in this scenario differs a bit if compared to previous scenario. This time difference in CO_2 emissions created by conventional road transport and dry port implemented transport system is smaller. Percentual difference of CO_2 emissions is 13 percent. Dry port implemented transport system maintains its ability to be environmentally friendlier transport system. Results show that if rail transport's percentual proportion increases, the amount of CO_2 emissions of transport system decrease compared to conventional road transport and vice versa i.e. dry port solution improves environmental friendliness of a transport system the more the larger the share of rail transport is. If rail transport was used to transport freight all the way to chosen cities in previous scenarios, the volume of CO_2 emissions of the whole transport system would have decreased significantly more. Internal and external costs of both the traditional and dry port implemented transport system are summarized in Table 26.

Table 26 Costs of conventional and dry port implemented transport with farther cities (Euros).

		Conventional road transport	Dry port implemented transport
Road transport	External costs	59,000	49,000
	Internal costs	368,000	303,000
Rail transport	External costs		1,000
	Internal costs		38,000
	Total costs	**427,000**	**391,000**

With farther cities the percentual decrease in both the internal and external costs of transport with the dry port implementation would be smaller. Percentual decrease in total transport costs would be a bit over eight percent, and the decrease in external costs would be 18 percent. Result is that rail's proportion of the whole transportation is important. With larger proportion the internal and external costs can be decreased more.

5.6 Gravitation models

During the research different gravitation models concerning distribution costs of transport for different distribution locations were created. Purpose of the gravitational models is to compare different distribution centers and their costs. Models consist of 50 biggest cities in Finland. Some of the models also take St Petersburg and Moscow into account, since they are important transit cities for Russian transit traffic going through Finland. Cities of Kouvola, Kotka and Vantaa are chosen to be three different distribution centers for road transport, which are compared together. Kouvola is chosen because researching its ability to be a dry port is the main purpose of this research. Kotka is chosen because it is a large and important Finnish port closely connected to Kouvola. Vantaa is researched because it is assumed to be in relatively favorable location to be a distribution center in Finland. Many companies have their main warehouses situated in Vantaa. Kouvola, Kotka and Kerava are chosen to be distribution centers for rail transport. Vantaa is replaced with Kerava, because Vantaa does not have a direct rail link from Port of Vuosaari. Kerava is used as a distribution center for rail transport, because it has a straight rail link and it is situated near city of Vantaa.

Distances by road and rail from Kouvola, Kotka, Kerava and Vantaa to 50 biggest cities in Finland were researched. Distances of road and rail network were gathered from various sources (Google Maps, 2010; ViaMichelin, 2010; Hilmola *et al.*, 2008; Ratahallintokeskus, 2009b). All the road and rail distances can be seen in Appendix 2 and 3. Also populations of the 50 largest cities in Finland were studied (Population Register Center, 2010). Populations of 50 biggest cities in Finland can be seen in Appendix 2.

All the gravitational models are not shown in the empirical text part of this research to save space. Only the results of the most of the models are shown in the text. All the gravitational models are included in the appendices 4-19 though.

5.6.1 Road transport

The first model itself is quite straightforward. Only input data concerned in this gravitational model are distances between distribution hub cities and largest cities in Finland and population of the largest cities. Distance of hub city and largest cities are multiplied with population of largest cities. Hub with least value is assumed to be the most cost-efficient city to be a distribution center. In Table 27 below distribution of Finland is considered to be managed through only one distribution city.

Table 27 Distribution costs of road transport in Finnish inland transportation.

	Kouvola	Kotka	Vantaa
Helsinki	80,591,310	77,671,335	11,679,900
Espoo	36,948,945	35,970,165	7,340,850
Tampere	44,868,316	57,990,182	36,825,882
Vantaa	25,369,984	24,775,375	0
Turku	52,364,070	51,658,830	30,325,320
Oulu	74,428,386	81,257,957	83,348,642
Jyväskylä	25,560,553	31,918,254	33,734,740
Lahti	6,263,364	12,122,640	9,496,068
Kuopio	24,741,021	29,559,497	34,655,962
Kouvola	0	5,202,325	11,286,400
Pori	25,189,136	30,657,830	20,631,891
Joensuu	23,280,960	24,881,526	30,992,778
Lappeenranta	6,329,752	7,912,190	15,536,664
Hämeenlinna	8,980,065	12,904,686	6,452,343
Rovaniemi	45,366,253	48,302,774	49,141,780
Vaasa	25,645,724	31,923,892	24,757,304
Seinäjoki	20,640,897	25,157,880	20,297,835
Salo	13,622,392	13,402,676	6,756,267
Kotka	3,232,964	0	6,849,500
Mikkeli	5,212,826	7,697,444	10,717,960
Porvoo	4,231,941	4,037,369	2,091,649
Kokkola	20,102,000	22,356,000	22,724,000
Hyvinkää	5,845,119	6,524,784	2,038,995
Rauma	13,200,984	15,109,560	10,298,358
Nurmijärvi	5,869,680	6,147,300	1,308,780
Lohja	7,485,620	7,328,028	2,560,870
Järvenpää	4,993,332	4,799,792	928,992
Kajaani	16,642,230	18,631,646	20,697,578
Tuusula	4,745,136	4,561,216	588,544
Kirkkonummi	6,285,052	6,102,347	1,680,886
Kerava	4,242,000	4,106,256	475,104
Nokia	7,047,488	8,903,746	5,851,932
Kaarina	9,048,438	8,925,330	5,201,313
Ylöjärvi	6,971,349	8,721,731	5,794,368
Raasepori	6,906,284	6,790,212	3,104,926
Imatra	3,438,480	4,097,522	7,106,192
Riihimäki	3,518,415	4,519,590	1,859,325
Kangasala	4,878,630	6,561,900	5,392,170
Vihti	4,691,232	5,054,244	1,675,440
Savonlinna	5,798,078	7,351,630	8,905,182
Sastamala	5,997,600	7,515,360	5,042,880
Raisio	7,308,400	7,187,400	4,283,400
Varkaus	4,447,838	5,640,042	7,038,589
Jämsä	4,079,582	5,340,127	4,904,666
Kemi	14,421,990	15,529,635	15,846,105
Raahe	11,781,098	12,884,872	13,200,236
Tornio	14,906,136	16,028,586	16,342,872
Iisalmi	7,764,050	8,917,566	10,137,631
Hollola	1,528,170	2,772,537	2,117,607
Hamina	1,181,620	558,584	2,964,792
Total costs	767,994,890	853,972,370	642,991,468
Percent per least costs	119%	133%	100%

As can be seen in Table 27, total distribution costs are the lowest when all the distribution is managed through Vantaa. If only Kouvola is used then the distribution costs are 19 percent higher than in case of Vantaa. Distribution through only Kotka is 33 percent more expensive than through Vantaa. If all the distribution to 50 largest cities in Finland is done through one city, Vantaa is in better location than Kouvola or Kotka. Kouvola has better location, if Kouvola and Kotka are compared.

In Table 28 same kind of model is presented. Difference between model in Table 28 and Table 27 is that all the distribution centers are used together in second gravitational model. Model uses linear integer programming when choosing which distribution center distributes to which cities. Purpose of the model is to decrease total distribution costs by using different distribution centers instead of using only one.

Table 28 Linear integer program model of road transport in Finnish inland distribution.

	Kouvola	Kotka	Vantaa
Helsinki	0	0	11,679,900
Espoo	0	0	7,340,850
Tampere	0	0	36,825,882
Vantaa	0	0	0
Turku	0	0	30,325,320
Oulu	74,428,386	0	0
Jyväskylä	25,560,553	0	0
Lahti	6,263,364	0	0
Kuopio	24,741,021	0	0
Kouvola	0	0	0
Pori	0	0	20,631,891
Joensuu	23,280,960	0	0
Lappeenranta	6,329,752	0	0
Hämeenlinna	0	0	6,452,343
Rovaniemi	45,366,253	0	0
Vaasa	0	0	24,757,304
Seinäjoki	0	0	20,297,835
Salo	0	0	6,756,267
Kotka	0	0	0
Mikkeli	5,212,826	0	0
Porvoo	0	0	2,091,649
Kokkola	20,102,000	0	0
Hyvinkää	0	0	2,038,995
Rauma	0	0	10,298,358
Nurmijärvi	0	0	1,308,780
Lohja	0	0	2,560,870
Järvenpää	0	0	928,992
Kajaani	16,642,230	0	0
Tuusula	0	0	588,544
Kirkkonummi	0	0	1,680,886
Kerava	0	0	475,104
Nokia	0	0	5,851,932
Kaarina	0	0	5,201,313
Ylöjärvi	0	0	5,794,368
Raasepori	0	0	3,104,926
Imatra	3,438,480	0	0
Riihimäki	0	0	1,859,325
Kangasala	4,878,630	0	0
Vihti	0	0	1,675,440
Savonlinna	5,798,078	0	0
Sastamala	0	0	5,042,880
Raisio	0	0	4,283,400
Varkaus	4,447,838	0	0
Jämsä	4,079,582	0	0
Kemi	14,421,990	0	0
Raahe	11,781,098	0	0
Tornio	14,906,136	0	0
Iisalmi	7,764,050	0	0
Hollola	1,528,170	0	0
Hamina	0	558,584	0
Total costs		541,383,335	
Percent per least costs		84%	

Large numbers in the Table 28 above means that the distribution center with big number performs the distribution to that city e.g. Vantaa distributes to Helsinki, Espoo and Tampere whereas Kouvola distributes to Oulu, Jyväskylä, Lahti and Kuopio. As can be seen from Table 28, Kotka is the best distribution center only when transferring freight to Hamina. All the other 50 largest cities in Finland should be distributed from Kouvola and Vantaa. 21 of the largest cities are supposed to be distributed from Kouvola and 27 from Vantaa. It seems that Vantaa has better logistical location than Kouvola, but the logistical location of Kouvola is proper for eastern cities of Finland. Vantaa's coverage is mostly the metropolitan area of Finland and western Finland while Kouvola covers all the eastern cities and northern cities of Finland.

Next gravitational model takes two more distribution centers (Tampere in east of Finland and Oulu in North of Finland) into account to see the impact of midrange and distant dry ports in the distribution costs. Distribution centers are now located more like at the Port of Gothenburg described in the literature review. This model uses linear integer programming (LIP) to solve the best distribution centers for each 50 largest cities. Results are shown in Table 29.

Table 29 Linear integer program model of road transport in Finnish inland distribution with increased distribution centers.

	Kouvola	Kotka	Vantaa	Tampere	Oulu
Helsinki	0	0	11,679,900	0	0
Espoo	0	0	7,340,850	0	0
Tampere	0	0	0	0	0
Vantaa	0	0	0	0	0
Turku	0	0	0	28,562,220	0
Oulu	0	0	0	0	0
Jyväskylä	0	0	0	19,202,852	0
Lahti	6,263,364	0	0	0	0
Kuopio	24,741,021	0	0	0	0
Kouvola	0	0	0	0	0
Pori	0	0	0	9,197,349	0
Joensuu	23,280,960	0	0	0	0
Lappeenranta	6,329,752	0	0	0	0
Hämeenlinna	0	0	0	5,188,482	0
Rovaniemi	0	0	0	0	13,484,025
Vaasa	0	0	0	14,214,720	0
Seinäjoki	0	0	0	10,120,329	0
Salo	0	0	6,756,267	0	0
Kotka	0	0	0	0	0
Mikkeli	5,212,826	0	0	0	0
Porvoo	0	0	2,091,649	0	0
Kokkola	0	0	0	0	9,200,000
Hyvinkää	0	0	2,038,995	0	0
Rauma	0	0	0	5,685,966	0
Nurmijärvi	0	0	1,308,780	0	0
Lohja	0	0	2,560,870	0	0
Järvenpää	0	0	928,992	0	0
Kajaani	0	0	0	0	7,269,020
Tuusula	0	0	588,544	0	0
Kirkkonummi	0	0	1,680,886	0	0
Kerava	0	0	475,104	0	0
Nokia	0	0	0	471,930	0
Kaarina	0	0	0	5,170,536	0
Ylöjärvi	0	0	0	392,327	0
Raasepori	0	0	3,104,926	0	0
Imatra	3,438,480	0	0	0	0
Riihimäki	0	0	1,859,325	0	0
Kangasala	0	0	0	542,070	0
Vihti	0	0	1,675,440	0	0
Savonlinna	5,798,078	0	0	0	0
Sastamala	0	0	0	1,272,960	0
Raisio	0	0	0	3,944,600	0
Varkaus	4,447,838	0	0	0	0
Jämsä	0	0	0	2,131,467	0
Kemi	0	0	0	0	2,373,525
Raahe	0	0	0	0	1,734,502
Tornio	0	0	0	0	2,963,268
Iisalmi	0	0	0	0	4,480,966
Hollola	1,528,170	0	0	0	0
Hamina	0	558,584	0	0	0
Total costs			273,292,715		
Percent per least costs			50%		

Total distribution costs in Table 28 were almost 550 million. If Tampere and Oulu are also used as distribution centers, then costs can be decreased to approximately 270 million. Decrease in distribution costs is 50 percent. Of course freight still has to be transported to cities of Oulu and Tampere, but the transportation can be accomplished by rail transport, which is in terms of external and internal costs way more inexpensive. Transport costs of the whole transportation system can be decreased by using multiple dry ports even more than by using only one close dry port.

In tables above, it was assumed that all freight already was in the distribution cities i.e. the travel of freight to Kouvola and Vantaa was not observed. The results shown in Table 30 include freight's travel from Port of Vuosaari to Vantaa and from Port of Kotka to Kouvola. It is assumed that freight to Vantaa is transported from Port of Vuosaari and freight to Kouvola is transported from Port of Kotka.

Table 30 Distribution costs of road transport if distances between ports and cities of Vantaa and Kouvola are considered.

	Kouvola	Kotka	Vantaa
Total costs	970,954,418	853,972,370	692,940,928
Percent per least costs	140%	123%	100%

Results in Table 30 differ considerably if compared to previous tables. Vantaa maintains its ability to be the best place for a distribution center for 50 biggest cities in Finland due to short distance from Port of Vuosaari. Kouvola instead is more unfavorable than Kotka and Vantaa. Kouvola is 40 percent more expensive than Vantaa and 23 percent more expensive than Kotka.

In addition, gravitational models regarding transit traffic were created. They take into account the transit traffic to Moscow and St Petersburg. Since only a part of freight to St Petersburg and Moscow transports from Finland, an estimate had to be done during creation of the models concerning the influence of Russian cities. In year 2008 the container transit traffic in Finland was approximately 377,000 TEUs (Finnish Port Association, 2010). In the same year container traffic through ports at St Petersburg was almost 2,000,000 TEUs (Fossey *et al.*, 2009, p.55). To use linear integer programming in solving the best distribution location, some assumptions had to be made. First assumption is that 90 percent of the whole transit traffic between Finland and Russia is destined to St Petersburg and 10 percent to Moscow. Second assumption is that transit traffic from Finland is 377,000 / 2,000,000 * 100 = 18.85 percent of the whole freight transport to St Petersburg and Moscow. The purpose of these assumptions is to increase accuracy of the linear integer programming model. Population of St Petersburg and Moscow are 6,201,397 and 17,143,091 respectively (Statistics Finland, 2010). Population of St Petersburg is further multiplied with 90 percent and after that with 18.85 percent to get a proper population for further distribution cost research. Population of Moscow is first multiplied with 10 percent and second with 18.85 percent. Populations for distribution costs calculations for St Petersburg and Moscow are 1,052,067 and 323,147 respectively. Without these assumptions cities of St Petersburg and Moscow would dominate the location of distribution center unrealistically. Distribution costs calculated in Table 31 take into account also St Petersburg and Moscow. Distances from ports to distribution centers are not taken into account.

Table 31 Distribution costs of road transport in Finnish inland distribution with St Petersburg and Moscow.

	Kouvola	Kotka	Vantaa
Total costs	1,392,679,612	1,447,192,414	1,399,696,760
Percent per least costs	100%	104%	101%

In this case Kouvola has the best location to be the only distribution center for 50 largest Finnish cities and cities of St Petersburg and Moscow. Better position if compared to earlier models originates from large cities of St Petersburg and Moscow. They are the ones that move optimal distribution location more to east. The difference in distribution costs between Kouvola, Kotka and Vantaa is not large. Vantaa is only one percent and Kotka four percent more expensive than Kouvola.

Another model that takes into account the transit traffic was created as well. In addition to population and distance it also concerns salary differences between Finland and Russia. Salaries are converted to net salaries, which mean that taxes are already reduced. Distribution costs that also concern salary differences between Finland and Russia are presented in Table 32. Distances from ports to distribution centers are not taken into account.

Table 32 Distribution costs of road transport in Finnish inland distribution with St Petersburg and Moscow with salary differences.

	Kouvola	Kotka	Vantaa
Total costs	908,540,822	987,849,856	811,025,869
Percent per least costs	112%	122%	100%

When also the salary differences between Finland and Russia are regarded, Vantaa has the best location for a distribution center. Smaller salaries in St Petersburg and Moscow decrease the influence of moving distribution center more east. Kouvola's location is 12 percent worse than Vantaa's location. Kotka is in worst location being 22 percent more expensive than Vantaa. If salary levels at Russia increase beyond Finnish salary levels, then Kouvola and Kotka become better locations.

Table 33 summarizes results calculated with linear integer programming. Every large city is being distributed from distribution center with least distribution costs. St Petersburg and Moscow are considered without salary differences. Distances from ports to distribution centers are not taken into account.

Table 33 Linear integer program model for road transport in Finnish inland distribution with St Petersburg and Moscow.

	Kouvola	Kotka	Vantaa
Connections	20	3	26
Total costs		1,134,603,379	
Percent per least costs		81%	

By using all distribution centers instead of only one, it is possible to decrease distribution costs by 19 percent. Kouvola would distribute to 20 cities, Vantaa to 26 cities and Kotka to 3 cities. Since Kotka is closest city to St Petersburg and Moscow by road, it would distribute to those cities.

Table 34 summarizes results of linear integer programming model, if cities on Tampere and Oulu are also added to be distribution centers (midrange and distant dry ports). Gravitational model is otherwise similar as the model showed in Table 33.

Table 34 Linear integer program model for road transport in Finnish inland distribution with St Petersburg and Moscow. Tampere and Oulu are added distribution centers.

	Kouvola	Kotka	Vantaa	Tampere	Oulu
Connections	9	3	14	14	7
Total costs			866,512,759		
Percent per least costs			76%		

Percentual decrease in relative distribution costs is 24 percent if compared to results in Table 33. It means that using midrange and distant dry ports the distribution costs can be further decreased.

Results in Table 35 are created by linear integer programming. Results are based on distances, populations and salary differences. Distribution centers are Kouvola, Kotka and Vantaa.

Table 35 Linear integer program model for road transport in Finnish inland distribution with St Petersburg and Moscow with salary differences.

	Kouvola	Kotka	Vantaa
Connections	20	3	26
Total costs		675,260,821	
Percent per least costs		83%	

If salary differences are taken into account, linear integer programming model can decrease distribution costs by 17 percent by using optimal distribution centers for the largest cities in Finland and St Petersburg and Moscow. Distribution to different cities is accomplished by same distribution centers as in previous model that did not consider salary differences, because distances to cities are the same in both models. Full tables of the above results can be seen in appendices 4-12.

5.6.2 Rail transport

Same kind of gravitational models are created also for rail network. Differences in models are different distances between largest cities and distribution centers. Reason for differences in distances is that rail and road networks in Finland are different road being very extensive, while rail is limited to largest cities. Also the distance between certain cities by road and rail might differ. Table 36 below presents relative distribution costs of rail transport if only populations and distances from distribution centers of Kotka, Kouvola and Kerava to 50 largest cities in Finland are regarded. Third distribution center in this case is Kerava, because there is no rail connection to and from Vantaa. An alternative distribution center had to be chosen.

Table 36 Distribution costs of rail transport if distances and populations are concerned.

	Kouvola	Kotka	Kerava
Helsinki	111,543,045	141,326,790	16,351,860
Espoo	41,842,845	54,322,290	1,957,560
Tampere	56,297,038	67,090,831	33,651,237
Vantaa	36,271,149	46,379,502	3,964,060
Turku	62,942,670	71,934,480	44,077,500
Oulu	115,823,949	122,932,278	100,910,396
Jyväskylä	34,253,736	40,870,935	40,481,688
Lahti	6,162,342	11,314,464	10,304,244
Kuopio	25,296,999	30,022,812	40,401,068
Kouvola	0	4,496,925	14,372,525
Pori	33,226,459	37,452,268	24,360,546
Joensuu	22,917,195	26,627,598	43,360,788
Lappeenranta	6,905,184	10,573,563	18,629,611
Hämeenlinna	12,372,534	15,765,003	5,255,001
Rovaniemi	62,925,450	65,981,829	56,513,047
Vaasa	33,819,188	36,839,816	27,481,792
Seinäjoki	28,416,969	31,332,996	22,299,030
Salo	14,226,611	17,027,990	8,349,208
Kotka	2,794,596	0	11,726,344
Mikkeli	5,505,134	7,989,752	13,494,886
Porvoo	7,685,594	10,166,387	1,653,862
Kokkola	28,980,000	31,326,000	24,058,000
Hyvinkää	6,026,363	8,337,224	1,359,330
Rauma	16,302,420	18,330,282	12,047,886
Nurmijärvi	7,337,100	9,359,760	872,520
Lohja	7,918,998	9,928,296	3,703,412
Järvenpää	5,999,740	7,973,848	309,664
Kajaani	27,239,696	29,190,854	23,146,090
Tuusula	6,216,496	8,092,480	220,704
Kirkkonummi	7,308,200	9,171,791	2,375,165
Kerava	5,531,568	7,262,304	0
Nokia	8,903,746	10,508,308	5,537,312
Kaarina	11,233,605	12,803,232	7,940,466
Ylöjärvi	8,419,941	9,959,070	5,190,788
Raasepori	9,140,670	10,620,588	6,180,834
Imatra	3,782,328	5,243,682	8,452,930
Riihimäki	3,432,600	4,891,455	1,230,015
Kangasala	8,131,050	9,586,080	5,078,340
Vihti	6,394,596	7,818,720	3,406,728
Savonlinna	6,769,048	8,183,890	12,567,126
Sastamala	7,784,640	9,033,120	5,165,280
Raisio	9,510,600	10,744,800	6,921,200
Varkaus	5,341,991	6,511,268	9,079,092
Jämsä	7,425,756	8,594,625	5,867,264
Kemi	21,180,885	22,333,740	18,762,150
Raahe	18,133,430	19,282,256	15,723,148
Tornio	21,618,387	22,763,286	19,216,344
Iisalmi	7,963,697	9,095,030	11,579,526
Hollola	1,528,170	2,641,551	2,423,241
Hamina	1,117,168	794,908	4,619,060
Total costs	1,007,901,576	1,180,830,957	762,629,868
Percent per least costs	132%	155%	100%

As Table 36 shows, Kerava has the best position to perform inland distribution to 50 largest cities in Finland. Kouvola has 32 percent higher distribution costs, if it does all the distribution whereas Kotka’s distribution costs are 55 percent higher if compared to Kerava. Differences in distribution costs are larger than for road network, because road network usually has more direct routes between different cities than rail network i.e. road network from Kouvola to e.g. north is direct, whereas rail network to north from Kouvola performs an indirect route.

In addition, a gravitational model using linear integer programming to find out how to minimize distribution costs, if any of the three distribution centers can be used was created. The results are shown in Table 37.

Table 37 Linear integer program model of rail transport in Finnish inland distribution.

	Kouvola	Kotka	Kerava
Helsinki	0	0	16,351,860
Espoo	0	0	1,957,560
Tampere	0	0	33,651,237
Vantaa	0	0	3,964,060
Turku	0	0	44,077,500
Oulu	0	0	100,910,396
Jyväskylä	34,253,736	0	0
Lahti	6,162,342	0	0
Kuopio	25,296,999	0	0
Kouvola	0	0	0
Pori	0	0	24,360,546
Joensuu	22,917,195	0	0
Lappeenranta	6,905,184	0	0
Hämeenlinna	0	0	5,255,001
Rovaniemi	0	0	56,513,047
Vaasa	0	0	27,481,792
Seinäjoki	0	0	22,299,030
Salo	0	0	8,349,208
Kotka	0	0	0
Mikkeli	5,505,134	0	0
Porvoo	0	0	1,653,862
Kokkola	0	0	24,058,000
Hyvinkää	0	0	1,359,330
Rauma	0	0	12,047,886
Nurmijärvi	0	0	872,520
Lohja	0	0	3,703,412
Järvenpää	0	0	309,664
Kajaani	0	0	23,146,090
Tuusula	0	0	220,704
Kirkkonummi	0	0	2,375,165
Kerava	0	0	0
Nokia	0	0	5,537,312
Kaarina	0	0	7,940,466
Ylöjärvi	0	0	5,190,788
Raasepori	0	0	6,180,834
Imatra	3,782,328	0	0
Riihimäki	0	0	1,230,015
Kangasala	0	0	5,078,340
Vihti	0	0	3,406,728
Savonlinna	6,769,048	0	0
Sastamala	0	0	5,165,280
Raisio	0	0	6,921,200
Varkaus	5,341,991	0	0
Jämsä	0	0	5,867,264
Kemi	0	0	18,762,150
Raahe	0	0	15,723,148
Tornio	0	0	19,216,344
Iisalmi	7,963,697	0	0
Hollola	1,528,170	0	0
Hamina	0	794,908	0
Total costs		648,358,471	
Percent per least costs		85%	

Now Kouvola would distribute to 11 different cities, while Kerava would distribute to 35 cities. Kotka would distribute only to Hamina. Difference between road and rail network is that Kouvola has not as good position when using rail transport. Main reason is that distances to Northern cities in Finland are longer from Kouvola as from Kerava by rail, whereas the distances to north by road are shorter from Kouvola than from Vantaa.

Next, a gravitational model with distances from Port of Vuosaari to Kerava and Port of Kotka to Kouvola were calculated. Results, if one city distributes all the 50 biggest cities in Finland are presented in Table 38.

Table 38 Distribution costs of rail transport if distances between ports and cities of Kerava and Kouvola are considered.

	Kouvola	Kotka	Kerava
Total costs	1,183,341,168	1,180,830,957	860,468,336
Percent per least costs	138%	137%	100%

As can be seen from Table 38, if distances from ports to Kouvola and Kerava are considered, Kerava maintains its status as the best distribution center. Kouvola becomes the most unsatisfactory location for distributing center being 38 percent more expensive than Kerava. Kotka is one percent more satisfactory than Kouvola. In this case, location of Kerava is outstanding.

Table 39 summarizes the results of the next gravitational model. In this model one city distributes all the 50 largest cities in Finland and Moscow and St Petersburg. Distances between ports and distribution centers are not taken into account.

Table 39 Distribution costs of rail transport in Finnish inland distribution with St Petersburg and Moscow.

	Kouvola	Kotka	Kerava
Total costs	1,732,897,787	1,975,963,095	1,711,786,004
Percent per least costs	101%	115%	100%

Results of Table 39 show that distribution costs from Kerava and Kouvola are almost as much, whereas distribution costs of Kotka are 15 percent higher than distribution costs of Kerava. Relative improvement of Kouvola’s distribution costs is consequence of St Petersburg and Moscow. Kouvola has a better location to St Petersburg and Moscow than Kerava and that improves Kouvola’s distribution costs if compared to Kerava. If St Petersburg and Moscow are not taken into account, then Kerava’s distribution costs are much lower than Kouvola's as can be seen in previous gravitational models.

Gravitational model in Table 40 considers in addition salary differences between Finland and Russia. Distances between ports and distribution centers are not taken into account.

Table 40 Distribution costs of rail transport in Finnish inland distribution with St Petersburg and Moscow with salary differences.

	Kouvola	Kotka	Kerava
Total costs	1,174,748,388	1,362,281,018	976,149,810
Percent per least costs	120%	140%	100%

If salary differences are considered in addition to distances and population, the advantage of Kouvola decreases considerable if compared to previous gravitational model. Smaller salaries in St Petersburg and Moscow if compared to Finland increases impact of Finnish cities in distribution costs. Kotka maintains its status as the most expensive distribution center. Distance to all cities except Hamina from Kotka is longer than from Kouvola because rail network from Kotka goes always through Kouvola.

Next gravitational models are created using linear integer programming. Results in Table 41 are based on gravitational model that consist of largest Finnish cities with St Petersburg and Moscow. Populations and distances are considered. Salaries and distances between ports and distribution centers are not taken into account.

Table 41 Linear integer program model for rail transport in Finnish inland distribution with St Petersburg and Moscow.

	Kouvola	Kotka	Kerava
Connections	13	1	35
Total costs		1,373,354,682	
Percent per least costs		80%	

Results of Table 41 show that distribution costs can be decreased by 20 percent if each of the largest cities is distributed from an optimal location. Kouvola would distribute 13 cities, Kerava 35 cities and Kotka only one city, which is Hamina.

Kerava maintains its status as a very good distribution center. Kouvola would distribute all the eastern cities of Finland and both Russian cities.

Difference of results in Table 42 is that it takes salary differences between Finland and Russia into account. Distances between ports and distribution centers are not taken into account.

Table 42 Linear integer program model for rail transport in Finnish inland distribution with St Petersburg and Moscow with salary differences.

	Kouvola	Kotka	Kerava
Connections	13	1	35
Total costs		815,205,283	
Percent per least costs		84%	

Same distribution centers distribute to same cities as in previous gravitational model. Now the total distribution costs can be decreased by 16 percent. Kerava is still in the best location. All the full gravitational models below can be seen in appendices 13-19.

6 DISCUSSION

In literature review, it was stated that road transport is the more polluting transport mode than rail transport. Rail transport has been studied to be more cost-efficient and environmentally friendlier mode of transport. In empirical part road and rail transport were compared through costs of transport. Costs were further divided into internal and external costs. The environmental attractiveness can be efficiently compared by comparing external costs. Both the internal and external costs of rail transport were less when compared to road transport. Empirical results of this study support literature review. In fact, results of this study show an even larger difference in external costs of road and rail transport, if compared to literature review. In that way rail transport seems environmentally friendlier than it was stated in the literature review.

It has to be noted that in this research costs regarding transshipments at intermodal terminals are not taken into account. Difference in total transport costs between road and rail transport are truly not so large than the results of empirical part of this research, because in almost every transport chain there is transshipment at some part of the transportation chain. That is a consequence of rail transport almost never can transport freight all the way from starting point to destination.

According to literature review, a possible problem in implementing a close dry port is the limited distance of rail transport. Discrete-event simulation model supports that. Cost-efficiency and environmental friendliness of a dry port implemented transport system increase, if proportion of modal share of rail increases. If distance between seaport and dry port is short, then the benefits are limited. Cost-efficiency and environmental friendliness of a transport system can be increased further with more distant dry ports i.e. distant dry ports are better than close dry ports in terms of cost-efficiency and environmental friendliness. Indirect route that rail network does when freight is transported to border of Russia reduces benefits of a dry port solution at city of Kouvola. A straighter rail link to Russian border would increase cost-efficiency and environmental friendliness of transportation more. However, costs of rail transport are that much smaller than costs of road transport, that rail transport is still more cost-efficient and environmental friendlier.

There would be many different benefits of the dry port. Environmental impacts of the transport system could be decreased in terms of congestion, accidents, noise and CO_2 emissions with the dry port. There are strict limits in how much EU countries are allowed to create externalities. By implementing dry port concept and increasing modal share of rail transport, Finland could lower externalities and achieve lower external costs. Long truck queues at Russian border could be relieved with the dry port concept. Regional roads around ports of Kotka and Hamina and city of Kouvola could also be relieved from congestion with the dry port implementation. In addition, possible congestion at the seaports can be lowered. The dry port implementation could create new job opportunities in the transport system, especially at the city of Kouvola and its surroundings. Ports of Kotka and Hamina could concentrate on their core tasks and competences by outsourcing some of their services at the dry port city. Seaports can expand their hinterland with dry port cities. New opportunities would rise to rail companies with increased rail transport, and that would make Finland more attractive location for rail corporation investors. That would possibly lead to more competition at rail transport sector. The market for logistics truck operators could decrease, because the aim of the dry port is to use rail transport as the main transport mode. Shippers would gain improved seaport access with dry port implementations. In addition, they could get more versatile services. Dry port concept can also be used as a part of environmental marketing strategy.

Different gravitational models were used to research optimal location for a distribution center in Finland. Three distribution centers were chosen for road and rail transport. Road transport’s distribution centers were Vantaa, Kouvola and Kotka. Rail transport’s distribution centers were Kerava, Kouvola and Vantaa. Kerava was chosen for rail transport, because Vantaa does not have a direct rail connection from Port of Vuosaari. Kerava and Vantaa are located near each other. Results of gravitational models support city of Kouvola to be a rational location for a dry port implementation in both the road and rail network. Although, Vantaa and Kerava are the best locations to be distribution centers for Finnish inland distribution, Kouvola is in a very good geographical situation, especially if the transit transport between Russia is taken into account. Locations of Vantaa and Kerava are the most optimal for distribution in metropolitan area of Finland and for western cities. Kouvola has the best location for eastern cities and transit traffic to Russia if rail network is used. Kotka has best position for St Petersburg by road.

7 CONCLUSIONS

7.1 Results of the study

This research was part of a larger project called Mobile Port project. Main purpose of this study was to find out, if it is financially and environmentally rational to implement a dry port solution in city of Kouvola.

Based on the costs of road and rail transport and simulation model, the environmental impacts of a dry port are decreased CO_2 emissions, congestion, accidents and noise. Overall, dry port solution can decrease the total external costs of transport. By implementing the dry port solution, internal costs of transport can also be reduced. It means that dry port solution is more cost-effective than traditional road transport. Though, it has to be noted that transshipment costs are not taken into consideration in this research. True costs of dry port implemented transport could be higher than costs of traditional road transport, if the dry port is situated near seaport. Cost-efficiency and environmental friendliness can be increased by using more distant dry ports. Position of Kouvola as a distribution center is above average. Kouvola has a good location for eastern cities of Finland and transit traffic. Cities at metropolitan area of Finland have better locations to do the distribution to metropolitan and western cities of Finland. Potential warehousing areas at cities of Kouvola and Lappeenranta would certainly be enough for warehousing the containers. If dry port traffic increases considerable, then there is a need for even more warehousing capacity. There are a lot of empty areas where city of Kouvola can construct more warehousing space.

Based on this research, the financial and environmental impacts of a dry port implementation in city of Kouvola are decreased total costs of transport in terms of both the internal and external costs. Cost-efficiency of the transport system can be improved with the dry port implementation. In addition, external costs of transport system can be decreased with the dry port implementation i.e. environmental friendliness increases.

7.2 Suggestions for further research

Further research could include also the costs occurring from transshipments in the intermodal nodes. That would make total costs more accurate when comparing conventional road transport and intermodal transport. In addition, more specific cost models could be created for different vehicle categories. Other transport modes could as well be taken into account when performing cost accounting about costs of transport. Including other external costs in calculations would improve results of total external costs. More accurate input data could be included in simulation model so that it would simulate real-world with increased accuracy. Local external costs (such as congestion and noise) could be researched in Finland. Congestion costs used in this research are in the first place estimated for larger cities.

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APPENDIX 1: INTERVIEWS

Hasu Seppo, maankäyttöjohtaja, Kouvolan kaupunki, 3.3.2010.

Lähde Markku, tonttipäällikkö, Kouvolan kaupunki, 3.3.2010.

Pohjola Vesa, kaupunginarkkitehti, Haminan kaupunki, 24.3.2010.

Willberg Juha, kaupunginsihteeri, Lappeenrannan kaupunki 10.3.2010.

APPENDIX 2: ROAD NETWORK DISTANCES AND POPULATION OF 50 LARGEST CITIES IN FINLAND AND ST PETERSBURG AND MOSCOW

	Population	Kouvola	Kotka	Vantaa
Helsinki	583,995	138	133	20
Espoo	244,695	151	147	30
Tampere	211,643	212	274	174
Vantaa	198,203	128	125	
Turku	176,310	297	293	172
Oulu	139,379	534	583	598
Jyväskylä	129,749	197	246	260
Lahti	101,022	62	120	94
Kuopio	92,663	267	319	374
Kouvola	88,175		59	128
Pori	82,859	304	370	249
Joensuu	72,753	320	342	426
Lappeenranta	71,929	88	110	216
Hämeenlinna	66,519	135	194	97
Rovaniemi	59,929	757	806	820
Vaasa	59,228	433	539	418
Seinäjoki	57,177	361	440	355
Salo	54,929	248	244	123
Kotka	54,796	59		125
Mikkeli	48,718	107	158	220
Porvoo	48,643	87	83	43
Kokkola	46,000	437	486	494
Hyvinkää	45,311	129	144	45
Rauma	39,762	332	380	259
Nurmijärvi	39,660	148	155	33
Lohja	39,398	190	186	65
Järvenpää	38,708	129	124	24
Kajaani	38,258	435	487	541
Tuusula	36,784	129	124	16
Kirkkonummi	36,541	172	167	46
Kerava	33,936	125	121	14
Nokia	31,462	224	283	186
Kaarina	30,777	294	290	169
Ylöjärvi	30,179	231	289	192
Raasepori	29,018	238	234	107
Imatra	28,654	120	143	248
Riihimäki	28,605	123	158	65
Kangasala	28,530	171	230	189
Vihti	27,924	168	181	60
Savonlinna	27,742	209	265	321
Sastamala	24,480	245	307	206
Raisio	24,200	302	297	177
Varkaus	22,927	194	246	307
Jämsä	22,919	178	233	214
Kemi	22,605	638	687	701
Raahe	22,526	523	572	586
Tornio	22,449	664	714	728
Iisalmi	22,183	350	402	457
Hollola	21,831	70	127	97
Hamina	21,484	55	26	138
St Petersburg	6,201,397	286	265	382
Moscow	17,143,091	1,002	973	1,098

APPENDIX 3: RAIL NETWORK DISTANCES

	Kouvola	Kotka	Kerava
Helsinki	191	242	28
Espoo	171	222	8
Tampere	266	317	159
Vantaa	183	234	20
Turku	357	408	250
Oulu	831	882	724
Jyväskylä	264	315	312
Lahti	61	112	102
Kuopio	273	324	436
Kouvola	0	51	163
Pori	401	452	294
Joensuu	315	366	596
Lappeenranta	96	147	259
Hämeenlinna	186	237	79
Rovaniemi	1,050	1,101	943
Vaasa	571	622	464
Seinäjoki	497	548	390
Salo	259	310	152
Kotka	51	0	214
Mikkeli	113	164	277
Porvoo	158	209	34
Kokkola	630	681	523
Hyvinkää	133	184	30
Rauma	410	461	303
Nurmijärvi	185	236	22
Lohja	201	252	94
Järvenpää	155	206	8
Kajaani	712	763	605
Tuusula	169	220	6
Kirkkonummi	200	251	65
Kerava	163	214	0
Nokia	283	334	176
Kaarina	365	416	258
Ylöjärvi	279	330	172
Raasepori	315	366	213
Imatra	132	183	295
Riihimäki	120	171	43
Kangasala	285	336	178
Vihti	229	280	122
Savonlinna	244	295	453
Sastamala	318	369	211
Raisio	393	444	286
Varkaus	233	284	396
Jämsä	324	375	256
Kemi	937	988	830
Raahe	805	856	698
Tornio	963	1,014	856
Iisalmi	359	410	522
Hollola	70	121	111
Hamina	52	37	215
St Petersburg	272	323	435
Moscow	1,358	1,409	1,521

APPENDIX 4: DISTRIBUTION COSTS OF ROAD TRANSPORT IN FINNISH INLAND TRANSPORTATION

	Kouvola	Kotka	Vantaa
Helsinki	80,591,310	77,671,335	11,679,900
Espoo	36,948,945	35,970,165	7,340,850
Tampere	44,868,316	57,990,182	36,825,882
Vantaa	25,369,984	24,775,375	0
Turku	52,364,070	51,658,830	30,325,320
Oulu	74,428,386	81,257,957	83,348,642
Jyväskylä	25,560,553	31,918,254	33,734,740
Lahti	6,263,364	12,122,640	9,496,068
Kuopio	24,741,021	29,559,497	34,655,962
Kouvola	0	5,202,325	11,286,400
Pori	25,189,136	30,657,830	20,631,891
Joensuu	23,280,960	24,881,526	30,992,778
Lappeenranta	6,329,752	7,912,190	15,536,664
Hämeenlinna	8,980,065	12,904,686	6,452,343
Rovaniemi	45,366,253	48,302,774	49,141,780
Vaasa	25,645,724	31,923,892	24,757,304
Seinäjoki	20,640,897	25,157,880	20,297,835
Salo	13,622,392	13,402,676	6,756,267
Kotka	3,232,964	0	6,849,500
Mikkeli	5,212,826	7,697,444	10,717,960
Porvoo	4,231,941	4,037,369	2,091,649
Kokkola	20,102,000	22,356,000	22,724,000
Hyvinkää	5,845,119	6,524,784	2,038,995
Rauma	13,200,984	15,109,560	10,298,358
Nurmijärvi	5,869,680	6,147,300	1,308,780
Lohja	7,485,620	7,328,028	2,560,870
Järvenpää	4,993,332	4,799,792	928,992
Kajaani	16,642,230	18,631,646	20,697,578
Tuusula	4,745,136	4,561,216	588,544
Kirkkonummi	6,285,052	6,102,347	1,680,886
Kerava	4,242,000	4,106,256	475,104
Nokia	7,047,488	8,903,746	5,851,932
Kaarina	9,048,438	8,925,330	5,201,313
Ylöjärvi	6,971,349	8,721,731	5,794,368
Raasepori	6,906,284	6,790,212	3,104,926
Imatra	3,438,480	4,097,522	7,106,192
Riihimäki	3,518,415	4,519,590	1,859,325
Kangasala	4,878,630	6,561,900	5,392,170
Vihti	4,691,232	5,054,244	1,675,440
Savonlinna	5,798,078	7,351,630	8,905,182
Sastamala	5,997,600	7,515,360	5,042,880
Raisio	7,308,400	7,187,400	4,283,400
Varkaus	4,447,838	5,640,042	7,038,589
Jämsä	4,079,582	5,340,127	4,904,666
Kemi	14,421,990	15,529,635	15,846,105
Raahe	11,781,098	12,884,872	13,200,236
Tornio	14,906,136	16,028,586	16,342,872
Iisalmi	7,764,050	8,917,566	10,137,631
Hollola	1,528,170	2,772,537	2,117,607
Hamina	1,181,620	558,584	2,964,792
Total costs	767,994,890	853,972,370	642,991,468
Percent per least costs	119%	133%	100%

APPENDIX 5: DISTRIBUTION COSTS OF ROAD TRANSPORT IN FINNISH INLAND TRANSPORTATION (DISTANCE FROM SEAPORT TO DISTRIBUTION CENTER TAKEN INTO ACCOUNT)

	Kouvola	Kotka	Vantaa
Helsinki	115,047,015	77,671,335	20,439,825
Espoo	51,385,950	35,970,165	11,011,275
Tampere	57,355,253	57,990,182	40,000,527
Vantaa	37,063,961	24,775,375	0
Turku	62,766,360	51,658,830	32,969,970
Oulu	82,651,747	81,257,957	85,439,327
Jyväskylä	33,215,744	31,918,254	35,680,975
Lahti	12,223,662	12,122,640	11,011,398
Kuopio	30,208,138	29,559,497	36,045,907
Kouvola	0	5,202,325	12,609,025
Pori	30,077,817	30,657,830	21,874,776
Joensuu	27,573,387	24,881,526	32,084,073
Lappeenranta	10,573,563	7,912,190	16,615,599
Hämeenlinna	12,904,686	12,904,686	7,450,128
Rovaniemi	48,902,064	48,302,774	50,040,715
Vaasa	29,140,176	31,923,892	25,645,724
Seinäjoki	24,014,340	25,157,880	21,155,490
Salo	16,863,203	13,402,676	7,580,202
Kotka	6,465,928	0	7,671,440
Mikkeli	8,087,188	7,697,444	11,448,730
Porvoo	7,101,878	4,037,369	2,821,294
Kokkola	22,816,000	22,356,000	23,414,000
Hyvinkää	8,518,468	6,524,784	2,718,660
Rauma	15,546,942	15,109,560	10,894,788
Nurmijärvi	8,209,620	6,147,300	1,903,680
Lohja	9,810,102	7,328,028	3,151,840
Järvenpää	7,277,104	4,799,792	1,509,612
Kajaani	18,899,452	18,631,646	21,271,448
Tuusula	6,915,392	4,561,216	1,140,304
Kirkkonummi	8,440,971	6,102,347	2,229,001
Kerava	6,244,224	4,106,256	984,144
Nokia	8,903,746	8,903,746	6,323,862
Kaarina	10,864,281	8,925,330	5,662,968
Ylöjärvi	8,751,910	8,721,731	6,247,053
Raasepori	8,618,346	6,790,212	3,540,196
Imatra	5,129,066	4,097,522	7,536,002
Riihimäki	5,206,110	4,519,590	2,288,400
Kangasala	6,561,900	6,561,900	5,820,120
Vihti	6,338,748	5,054,244	2,094,300
Savonlinna	7,434,856	7,351,630	9,321,312
Sastamala	7,441,920	7,515,360	5,410,080
Raisio	8,736,200	7,187,400	4,646,400
Varkaus	5,800,531	5,640,042	7,382,494
Jämsä	5,431,803	5,340,127	5,248,451
Kemi	15,755,685	15,529,635	16,185,180
Raahe	13,110,132	12,884,872	13,538,126
Tornio	16,230,627	16,028,586	16,679,607
Iisalmi	9,072,847	8,917,566	10,470,376
Hollola	2,816,199	2,772,537	2,445,072
Hamina	2,449,176	558,584	3,287,052
Total costs	970,954,418	853,972,370	692,940,928
Percent per least costs	140%	123%	100%

APPENDIX 6: DISTRIBUTION COSTS OF ROAD TRANSPORT IN FINNISH INLAND LOCATIONS WITH ST PETERSBURG AND MOSCOW

	Kouvola	Kotka	Vantaa
Helsinki	80,591,310	77,671,335	11,679,900
Espoo	36,948,945	35,970,165	7,340,850
Tampere	44,868,316	57,990,182	36,825,882
Vantaa	25,369,984	24,775,375	0
Turku	52,364,070	51,658,830	30,325,320
Oulu	74,428,386	81,257,957	83,348,642
Jyväskylä	25,560,553	31,918,254	33,734,740
Lahti	6,263,364	12,122,640	9,496,068
Kuopio	24,741,021	29,559,497	34,655,962
Kouvola	0	5,202,325	11,286,400
Pori	25,189,136	30,657,830	20,631,891
Joensuu	23,280,960	24,881,526	30,992,778
Lappeenranta	6,329,752	7,912,190	15,536,664
Hämeenlinna	8,980,065	12,904,686	6,452,343
Rovaniemi	45,366,253	48,302,774	49,141,780
Vaasa	25,645,724	31,923,892	24,757,304
Seinäjoki	20,640,897	25,157,880	20,297,835
Salo	13,622,392	13,402,676	6,756,267
Kotka	3,232,964	0	6,849,500
Mikkeli	5,212,826	7,697,444	10,717,960
Porvoo	4,231,941	4,037,369	2,091,649
Kokkola	20,102,000	22,356,000	22,724,000
Hyvinkää	5,845,119	6,524,784	2,038,995
Rauma	13,200,984	15,109,560	10,298,358
Nurmijärvi	5,869,680	6,147,300	1,308,780
Lohja	7,485,620	7,328,028	2,560,870
Järvenpää	4,993,332	4,799,792	928,992
Kajaani	16,642,230	18,631,646	20,697,578
Tuusula	4,745,136	4,561,216	588,544
Kirkkonummi	6,285,052	6,102,347	1,680,886
Kerava	4,242,000	4,106,256	475,104
Nokia	7,047,488	8,903,746	5,851,932
Kaarina	9,048,438	8,925,330	5,201,313
Ylöjärvi	6,971,349	8,721,731	5,794,368
Raasepori	6,906,284	6,790,212	3,104,926
Imatra	3,438,480	4,097,522	7,106,192
Riihimäki	3,518,415	4,519,590	1,859,325
Kangasala	4,878,630	6,561,900	5,392,170
Vihti	4,691,232	5,054,244	1,675,440
Savonlinna	5,798,078	7,351,630	8,905,182
Sastamala	5,997,600	7,515,360	5,042,880
Raisio	7,308,400	7,187,400	4,283,400
Varkaus	4,447,838	5,640,042	7,038,589
Jämsä	4,079,582	5,340,127	4,904,666
Kemi	14,421,990	15,529,635	15,846,105
Raahe	11,781,098	12,884,872	13,200,236
Tornio	14,906,136	16,028,586	16,342,872
Iisalmi	7,764,050	8,917,566	10,137,631
Hollola	1,528,170	2,772,537	2,117,607
Hamina	1,181,620	558,584	2,964,792
St Petersburg	300,891,162	278,797,755	401,889,594
Moscow	323,793,560	314,422,289	354,815,697
Total costs	1,392,679,612	1,447,192,414	1,399,696,760
Percent per least costs	100%	104%	101%

APPENDIX 7: DISTRIBUTION COSTS OF ROAD TRANSPORT IN FINNISH INLAND LOCATIONS WITH ST PETERSBURG AND MOSCOW (SALARY DIFFERENCIES TAKEN INTO ACCOUNT)

	Kouvola	Kotka	Vantaa
Helsinki	80,591,310	77,671,335	11,679,900
Espoo	36,948,945	35,970,165	7,340,850
Tampere	44,868,316	57,990,182	36,825,882
Vantaa	25,369,984	24,775,375	0
Turku	52,364,070	51,658,830	30,325,320
Oulu	74,428,386	81,257,957	83,348,642
Jyväskylä	25,560,553	31,918,254	33,734,740
Lahti	6,263,364	12,122,640	9,496,068
Kuopio	24,741,021	29,559,497	34,655,962
Kouvola	0	5,202,325	11,286,400
Pori	25,189,136	30,657,830	20,631,891
Joensuu	23,280,960	24,881,526	30,992,778
Lappeenranta	6,329,752	7,912,190	15,536,664
Hämeenlinna	8,980,065	12,904,686	6,452,343
Rovaniemi	45,366,253	48,302,774	49,141,780
Vaasa	25,645,724	31,923,892	24,757,304
Seinäjoki	20,640,897	25,157,880	20,297,835
Salo	13,622,392	13,402,676	6,756,267
Kotka	3,232,964	0	6,849,500
Mikkeli	5,212,826	7,697,444	10,717,960
Porvoo	4,231,941	4,037,369	2,091,649
Kokkola	20,102,000	22,356,000	22,724,000
Hyvinkää	5,845,119	6,524,784	2,038,995
Rauma	13,200,984	15,109,560	10,298,358
Nurmijärvi	5,869,680	6,147,300	1,308,780
Lohja	7,485,620	7,328,028	2,560,870
Järvenpää	4,993,332	4,799,792	928,992
Kajaani	16,642,230	18,631,646	20,697,578
Tuusula	4,745,136	4,561,216	588,544
Kirkkonummi	6,285,052	6,102,347	1,680,886
Kerava	4,242,000	4,106,256	475,104
Nokia	7,047,488	8,903,746	5,851,932
Kaarina	9,048,438	8,925,330	5,201,313
Ylöjärvi	6,971,349	8,721,731	5,794,368
Raasepori	6,906,284	6,790,212	3,104,926
Imatra	3,438,480	4,097,522	7,106,192
Riihimäki	3,518,415	4,519,590	1,859,325
Kangasala	4,878,630	6,561,900	5,392,170
Vihti	4,691,232	5,054,244	1,675,440
Savonlinna	5,798,078	7,351,630	8,905,182
Sastamala	5,997,600	7,515,360	5,042,880
Raisio	7,308,400	7,187,400	4,283,400
Varkaus	4,447,838	5,640,042	7,038,589
Jämsä	4,079,582	5,340,127	4,904,666
Kemi	14,421,990	15,529,635	15,846,105
Raahe	11,781,098	12,884,872	13,200,236
Tornio	14,906,136	16,028,586	16,342,872
Iisalmi	7,764,050	8,917,566	10,137,631
Hollola	1,528,170	2,772,537	2,117,607
Hamina	1,181,620	558,584	2,964,792
St Petersburg	58,464,218	54,171,390	78,088,570
Moscow	82,081,714	79,706,096	89,945,831
Total costs	908,540,822	987,849,856	811,025,869
Percent per least costs	112%	122%	100%

APPENDIX 8: OPTIMAL DISTRIBUTION CENTERS FOR FINNISH INLAND LOCATIONS BY LINEAR INTEGER PROGRAMMING FOR ROAD TRANSPORT

	Kouvola	Kotka	Vantaa
Helsinki	0	0	11,679,900
Espoo	0	0	7,340,850
Tampere	0	0	36,825,882
Vantaa	0	0	0
Turku	0	0	30,325,320
Oulu	74,428,386	0	0
Jyväskylä	25,560,553	0	0
Lahti	6,263,364	0	0
Kuopio	24,741,021	0	0
Kouvola	0	0	0
Pori	0	0	20,631,891
Joensuu	23,280,960	0	0
Lappeenranta	6,329,752	0	0
Hämeenlinna	0	0	6,452,343
Rovaniemi	45,366,253	0	0
Vaasa	0	0	24,757,304
Seinäjoki	0	0	20,297,835
Salo	0	0	6,756,267
Kotka	0	0	0
Mikkeli	5,212,826	0	0
Porvoo	0	0	2,091,649
Kokkola	20,102,000	0	0
Hyvinkää	0	0	2,038,995
Rauma	0	0	10,298,358
Nurmijärvi	0	0	1,308,780
Lohja	0	0	2,560,870
Järvenpää	0	0	928,992
Kajaani	16,642,230	0	0
Tuusula	0	0	588,544
Kirkkonummi	0	0	1,680,886
Kerava	0	0	475,104
Nokia	0	0	5,851,932
Kaarina	0	0	5,201,313
Ylöjärvi	0	0	5,794,368
Raasepori	0	0	3,104,926
Imatra	3,438,480	0	0
Riihimäki	0	0	1,859,325
Kangasala	4,878,630	0	0
Vihti	0	0	1,675,440
Savonlinna	5,798,078	0	0
Sastamala	0	0	5,042,880
Raisio	0	0	4,283,400
Varkaus	4,447,838	0	0
Jämsä	4,079,582	0	0
Kemi	14,421,990	0	0
Raahe	11,781,098	0	0
Tornio	14,906,136	0	0
Iisalmi	7,764,050	0	0
Hollola	1,528,170	0	0
Hamina	0	558,584	0
Total costs		541,383,335	
Percent per least costs		84%	

APPENDIX 9: OPTIMAL DISTRIBUTION CENTERS FOR FINNISH INLAND LOCATIONS BY LINEAR INTEGER PROGRAMMING FOR ROAD TRANSPORT (TAMPERE AND OULU ADDED)

	Kouvola	Kotka	Vantaa	Tampere	Oulu
Helsinki	0	0	11,679,900	0	0
Espoo	0	0	7,340,850	0	0
Tampere	0	0	0	0	0
Vantaa	0	0	0	0	0
Turku	0	0	0	28,562,220	0
Oulu	0	0	0	0	0
Jyväskylä	0	0	0	19,202,852	0
Lahti	6,263,364	0	0	0	0
Kuopio	24,741,021	0	0	0	0
Kouvola	0	0	0	0	0
Pori	0	0	0	9,197,349	0
Joensuu	23,280,960	0	0	0	0
Lappeenranta	6,329,752	0	0	0	0
Hämeenlinna	0	0	0	5,188,482	0
Rovaniemi	0	0	0	0	13,484,025
Vaasa	0	0	0	14,214,720	0
Seinäjoki	0	0	0	10,120,329	0
Salo	0	0	6,756,267	0	0
Kotka	0	0	0	0	0
Mikkeli	5,212,826	0	0	0	0
Porvoo	0	0	2,091,649	0	0
Kokkola	0	0	0	0	9,200,000
Hyvinkää	0	0	2,038,995	0	0
Rauma	0	0	0	5,685,966	0
Nurmijärvi	0	0	1,308,780	0	0
Lohja	0	0	2,560,870	0	0
Järvenpää	0	0	928,992	0	0
Kajaani	0	0	0	0	7,269,020
Tuusula	0	0	588,544	0	0
Kirkkonummi	0	0	1,680,886	0	0
Kerava	0	0	475,104	0	0
Nokia	0	0	0	471,930	0
Kaarina	0	0	0	5,170,536	0
Ylöjärvi	0	0	0	392,327	0
Raasepori	0	0	3,104,926	0	0
Imatra	3,438,480	0	0	0	0
Riihimäki	0	0	1,859,325	0	0
Kangasala	0	0	0	542,070	0
Vihti	0	0	1,675,440	0	0
Savonlinna	5,798,078	0	0	0	0
Sastamala	0	0	0	1,272,960	0
Raisio	0	0	0	3,944,600	0
Varkaus	4,447,838	0	0	0	0
Jämsä	0	0	0	2,131,467	0
Kemi	0	0	0	0	2,373,525
Raahe	0	0	0	0	1,734,502
Tornio	0	0	0	0	2,963,268
Iisalmi	0	0	0	0	4,480,966
Hollola	1,528,170	0	0	0	0
Hamina	0	558,584	0	0	0
Total costs			273,292,715		
Percent per least costs			50%		

APPENDIX 10: OPTIMAL DISTRIBUTION CENTERS FOR FINNISH INLAND LOCATIONS AND ST PETERSBURG AND MOSCOW BY LINEAR INTEGER PROGRAMMING FOR ROAD TRANSPORT

	Kouvola	Kotka	Vantaa
Helsinki	0	0	11,679,900
Espoo	0	0	7,340,850
Tampere	0	0	36,825,882
Vantaa	0	0	0
Turku	0	0	30,325,320
Oulu	74,428,386	0	0
Jyväskylä	25,560,553	0	0
Lahti	6,263,364	0	0
Kuopio	24,741,021	0	0
Kouvola	0	0	0
Pori	0	0	20,631,891
Joensuu	23,280,960	0	0
Lappeenranta	6,329,752	0	0
Hämeenlinna	0	0	6,452,343
Rovaniemi	45,366,253	0	0
Vaasa	0	0	24,757,304
Seinäjoki	0	0	20,297,835
Salo	0	0	6,756,267
Kotka	0	0	0
Mikkeli	5,212,826	0	0
Porvoo	0	0	2,091,649
Kokkola	20,102,000	0	0
Hyvinkää	0	0	2,038,995
Rauma	0	0	10,298,358
Nurmijärvi	0	0	1,308,780
Lohja	0	0	2,560,870
Järvenpää	0	0	928,992
Kajaani	16,642,230	0	0
Tuusula	0	0	588,544
Kirkkonummi	0	0	1,680,886
Kerava	0	0	475,104
Nokia	0	0	5,851,932
Kaarina	0	0	5,201,313
Ylöjärvi	0	0	5,794,368
Raasepori	0	0	3,104,926
Imatra	3,438,480	0	0
Riihimäki	0	0	1,859,325
Kangasala	4,878,630	0	0
Vihti	0	0	1,675,440
Savonlinna	5,798,078	0	0
Sastamala	0	0	5,042,880
Raisio	0	0	4,283,400
Varkaus	4,447,838	0	0
Jämsä	4,079,582	0	0
Kemi	14,421,990	0	0
Raahe	11,781,098	0	0
Tornio	14,906,136	0	0
Iisalmi	7,764,050	0	0
Hollola	1,528,170	0	0
Hamina	0	558,584	0
St Petersburg	0	278,797,755	0
Moscow	0	314,422,289	0
Total costs		1,134,603,379	
Percent per least costs		81%	

APPENDIX 11: OPTIMAL DISTRIBUTION CENTERS FOR FINNISH INLAND LOCATIONS AND ST PETERSBURG AND MOSCOW BY LINEAR INTEGER PROGRAMMING FOR ROAD TRANSPORT (TAMPERE AND OULU ADDED)

	Kouvola	Kotka	Vantaa	Tampere	Oulu
Helsinki	0	0	11,679,900	0	0
Espoo	0	0	7,340,850	0	0
Tampere	0	0	0	0	0
Vantaa	0	0	0	0	0
Turku	0	0	0	28,562,220	0
Oulu	0	0	0	0	0
Jyväskylä	0	0	0	19,202,852	0
Lahti	6,263,364	0	0	0	0
Kuopio	24,741,021	0	0	0	0
Kouvola	0	0	0	0	0
Pori	0	0	0	9,197,349	0
Joensuu	23,280,960	0	0	0	0
Lappeenranta	6,329,752	0	0	0	0
Hämeenlinna	0	0	0	5,188,482	0
Rovaniemi	0	0	0	0	13,484,025
Vaasa	0	0	0	14,214,720	0
Seinäjoki	0	0	0	10,120,329	0
Salo	0	0	6,756,267	0	0
Kotka	0	0	0	0	0
Mikkeli	5,212,826	0	0	0	0
Porvoo	0	0	2,091,649	0	0
Kokkola	0	0	0	0	9,200,000
Hyvinkää	0	0	2,038,995	0	0
Rauma	0	0	0	5,685,966	0
Nurmijärvi	0	0	1,308,780	0	0
Lohja	0	0	2,560,870	0	0
Järvenpää	0	0	928,992	0	0
Kajaani	0	0	0	0	7,269,020
Tuusula	0	0	588,544	0	0
Kirkkonummi	0	0	1,680,886	0	0
Kerava	0	0	475,104	0	0
Nokia	0	0	0	471,930	0
Kaarina	0	0	0	5,170,536	0
Ylöjärvi	0	0	0	392,327	0
Raasepori	0	0	3,104,926	0	0
Imatra	3,438,480	0	0	0	0
Riihimäki	0	0	1,859,325	0	0
Kangasala	0	0	0	542,070	0
Vihti	0	0	1,675,440	0	0
Savonlinna	5,798,078	0	0	0	0
Sastamala	0	0	0	1,272,960	0
Raisio	0	0	0	3,944,600	0
Varkaus	4,447,838	0	0	0	0
Jämsä	0	0	0	2,131,467	0
Kemi	0	0	0	0	2,373,525
Raahe	0	0	0	0	1,734,502
Tornio	0	0	0	0	2,963,268
Iisalmi	0	0	0	0	4,480,966
Hollola	1,528,170	0	0	0	0
Hamina	0	558,584	0	0	0
St Petersburg	0	278,797,755	0	0	0
Moscow	0	314,422,289	0	0	0
Total costs			866,512,759		
Percent per least costs			76%		

APPENDIX 12: OPTIMAL DISTRIBUTION CENTERS FOR FINNISH INLAND LOCATIONS AND ST PETERSBURG AND MOSCOW BY LINEAR INTEGER PROGRAMMING FOR ROAD TRANSPORT (SALARY DIFFERENCES TAKEN INTO ACCOUNT)

	Kouvola	Kotka	Vantaa
Helsinki	0	0	11,679,900
Espoo	0	0	7,340,850
Tampere	0	0	36,825,882
Vantaa	0	0	0
Turku	0	0	30,325,320
Oulu	74,428,386	0	0
Jyväskylä	25,560,553	0	0
Lahti	6,263,364	0	0
Kuopio	24,741,021	0	0
Kouvola	0	0	0
Pori	0	0	20,631,891
Joensuu	23,280,960	0	0
Lappeenranta	6,329,752	0	0
Hämeenlinna	0	0	6,452,343
Rovaniemi	45,366,253	0	0
Vaasa	0	0	24,757,304
Seinäjoki	0	0	20,297,835
Salo	0	0	6,756,267
Kotka	0	0	0
Mikkeli	5,212,826	0	0
Porvoo	0	0	2,091,649
Kokkola	20,102,000	0	0
Hyvinkää	0	0	2,038,995
Rauma	0	0	10,298,358
Nurmijärvi	0	0	1,308,780
Lohja	0	0	2,560,870
Järvenpää	0	0	928,992
Kajaani	16,642,230	0	0
Tuusula	0	0	588,544
Kirkkonummi	0	0	1,680,886
Kerava	0	0	475,104
Nokia	0	0	5,851,932
Kaarina	0	0	5,201,313
Ylöjärvi	0	0	5,794,368
Raasepori	0	0	3,104,926
Imatra	3,438,480	0	0
Riihimäki	0	0	1,859,325
Kangasala	4,878,630	0	0
Vihti	0	0	1,675,440
Savonlinna	5,798,078	0	0
Sastamala	0	0	5,042,880
Raisio	0	0	4,283,400
Varkaus	4,447,838	0	0
Jämsä	4,079,582	0	0
Kemi	14,421,990	0	0
Raahe	11,781,098	0	0
Tornio	14,906,136	0	0
Iisalmi	7,764,050	0	0
Hollola	1,528,170	0	0
Hamina	0	558,584	0
St Petersburg	0	54,171,390	0
Moscow	0	79,706,096	0
Total costs		675,260,821	
Percent per least costs		83%	

APPENDIX 13: DISTRIBUTION COSTS OF RAIL TRANSPORT IN FINNISH INLAND TRANSPORTATION

	Kouvola	Kotka	Kerava
Helsinki	111,543,045	141,326,790	16,351,860
Espoo	41,842,845	54,322,290	1,957,560
Tampere	56,297,038	67,090,831	33,651,237
Vantaa	36,271,149	46,379,502	3,964,060
Turku	62,942,670	71,934,480	44,077,500
Oulu	115,823,949	122,932,278	100,910,396
Jyväskylä	34,253,736	40,870,935	40,481,688
Lahti	6,162,342	11,314,464	10,304,244
Kuopio	25,296,999	30,022,812	40,401,068
Kouvola	0	4,496,925	14,372,525
Pori	33,226,459	37,452,268	24,360,546
Joensuu	22,917,195	26,627,598	43,360,788
Lappeenranta	6,905,184	10,573,563	18,629,611
Hämeenlinna	12,372,534	15,765,003	5,255,001
Rovaniemi	62,925,450	65,981,829	56,513,047
Vaasa	33,819,188	36,839,816	27,481,792
Seinäjoki	28,416,969	31,332,996	22,299,030
Salo	14,226,611	17,027,990	8,349,208
Kotka	2,794,596	0	11,726,344
Mikkeli	5,505,134	7,989,752	13,494,886
Porvoo	7,685,594	10,166,387	1,653,862
Kokkola	28,980,000	31,326,000	24,058,000
Hyvinkää	6,026,363	8,337,224	1,359,330
Rauma	16,302,420	18,330,282	12,047,886
Nurmijärvi	7,337,100	9,359,760	872,520
Lohja	7,918,998	9,928,296	3,703,412
Järvenpää	5,999,740	7,973,848	309,664
Kajaani	27,239,696	29,190,854	23,146,090
Tuusula	6,216,496	8,092,480	220,704
Kirkkonummi	7,308,200	9,171,791	2,375,165
Kerava	5,531,568	7,262,304	0
Nokia	8,903,746	10,508,308	5,537,312
Kaarina	11,233,605	12,803,232	7,940,466
Ylöjärvi	8,419,941	9,959,070	5,190,788
Raasepori	9,140,670	10,620,588	6,180,834
Imatra	3,782,328	5,243,682	8,452,930
Riihimäki	3,432,600	4,891,455	1,230,015
Kangasala	8,131,050	9,586,080	5,078,340
Vihti	6,394,596	7,818,720	3,406,728
Savonlinna	6,769,048	8,183,890	12,567,126
Sastamala	7,784,640	9,033,120	5,165,280
Raisio	9,510,600	10,744,800	6,921,200
Varkaus	5,341,991	6,511,268	9,079,092
Jämsä	7,425,756	8,594,625	5,867,264
Kemi	21,180,885	22,333,740	18,762,150
Raahe	18,133,430	19,282,256	15,723,148
Tornio	21,618,387	22,763,286	19,216,344
Iisalmi	7,963,697	9,095,030	11,579,526
Hollola	1,528,170	2,641,551	2,423,241
Hamina	1,117,168	794,908	4,619,060
Total costs	1,007,901,576	1,180,830,957	762,629,868
Percent per least costs	132%	155%	100%

APPENDIX 14: DISTRIBUTION COSTS OF RAIL TRANSPORT IN FINNISH INLAND TRANSPORTATION (DISTANCE FROM SEAPORT TO DISTRIBUTION CENTER TAKEN INTO ACCOUNT)

	Kouvola	Kotka	Kerava
Helsinki	141,326,790	141,326,790	32,703,720
Espoo	54,322,290	54,322,290	8,809,020
Tampere	67,090,831	67,090,831	39,577,241
Vantaa	46,379,502	46,379,502	9,513,744
Turku	71,934,480	71,934,480	49,014,180
Oulu	122,932,278	122,932,278	104,813,008
Jyväskylä	40,870,935	40,870,935	44,114,660
Lahti	11,314,464	11,314,464	13,132,860
Kuopio	30,022,812	30,022,812	42,995,632
Kouvola	0	4,496,925	16,841,425
Pori	37,452,268	37,452,268	26,680,598
Joensuu	26,627,598	26,627,598	45,397,872
Lappeenranta	10,573,563	10,573,563	20,643,623
Hämeenlinna	15,765,003	15,765,003	7,117,533
Rovaniemi	65,981,829	65,981,829	58,191,059
Vaasa	36,839,816	36,839,816	29,140,176
Seinäjoki	31,332,996	31,332,996	23,899,986
Salo	17,027,990	17,027,990	9,887,220
Kotka	5,589,192	0	13,260,632
Mikkeli	7,989,752	7,989,752	14,858,990
Porvoo	10,166,387	10,166,387	3,015,866
Kokkola	31,326,000	31,326,000	25,346,000
Hyvinkää	8,337,224	8,337,224	2,628,038
Rauma	18,330,282	18,330,282	13,161,222
Nurmijärvi	9,359,760	9,359,760	1,983,000
Lohja	9,928,296	9,928,296	4,806,556
Järvenpää	7,973,848	7,973,848	1,393,488
Kajaani	29,190,854	29,190,854	24,217,314
Tuusula	8,092,480	8,092,480	1,250,656
Kirkkonummi	9,171,791	9,171,791	3,398,313
Kerava	7,262,304	7,262,304	0
Nokia	10,508,308	10,508,308	6,418,248
Kaarina	12,803,232	12,803,232	8,802,222
Ylöjärvi	9,959,070	9,959,070	6,035,800
Raasepori	10,620,588	10,620,588	6,993,338
Imatra	5,243,682	5,243,682	9,255,242
Riihimäki	4,891,455	4,891,455	2,030,955
Kangasala	9,586,080	9,586,080	5,877,180
Vihti	7,818,720	7,818,720	4,188,600
Savonlinna	8,183,890	8,183,890	13,343,902
Sastamala	9,033,120	9,033,120	5,850,720
Raisio	10,744,800	10,744,800	7,598,800
Varkaus	6,511,268	6,511,268	9,721,048
Jämsä	8,594,625	8,594,625	6,508,996
Kemi	22,333,740	22,333,740	19,395,090
Raahe	19,282,256	19,282,256	16,353,876
Tornio	22,763,286	22,763,286	19,844,916
Iisalmi	9,095,030	9,095,030	12,200,650
Hollola	2,641,551	2,641,551	3,034,509
Hamina	2,212,852	794,908	5,220,612
Total costs	1,183,341,168	1,180,830,957	860,468,336
Percent per least costs	138%	137%	100%

APPENDIN 15: DISTRIBUTION COSTS OF RAIL TRANSPORT IN FINNISH INLAND LOCATIONS WITH ST PETERSBURG AND MOSCOW

	Kouvola	Kotka	Kerava
Helsinki	111,543,045	141,326,790	16,351,860
Espoo	41,842,845	54,322,290	1,957,560
Tampere	56,297,038	67,090,831	33,651,237
Vantaa	36,271,149	46,379,502	3,964,060
Turku	62,942,670	71,934,480	44,077,500
Oulu	115,823,949	122,932,278	100,910,396
Jyväskylä	34,253,736	40,870,935	40,481,688
Lahti	6,162,342	11,314,464	10,304,244
Kuopio	25,296,999	30,022,812	40,401,068
Kouvola	0	4,496,925	14,372,525
Pori	33,226,459	37,452,268	24,360,546
Joensuu	22,917,195	26,627,598	43,360,788
Lappeenranta	6,905,184	10,573,563	18,629,611
Hämeenlinna	12,372,534	15,765,003	5,255,001
Rovaniemi	62,925,450	65,981,829	56,513,047
Vaasa	33,819,188	36,839,816	27,481,792
Seinäjoki	28,416,969	31,332,996	22,299,030
Salo	14,226,611	17,027,990	8,349,208
Kotka	2,794,596	0	11,726,344
Mikkeli	5,505,134	7,989,752	13,494,886
Porvoo	7,685,594	10,166,387	1,653,862
Kokkola	28,980,000	31,326,000	24,058,000
Hyvinkää	6,026,363	8,337,224	1,359,330
Rauma	16,302,420	18,330,282	12,047,886
Nurmijärvi	7,337,100	9,359,760	872,520
Lohja	7,918,998	9,928,296	3,703,412
Järvenpää	5,999,740	7,973,848	309,664
Kajaani	27,239,696	29,190,854	23,146,090
Tuusula	6,216,496	8,092,480	220,704
Kirkkonummi	7,308,200	9,171,791	2,375,165
Kerava	5,531,568	7,262,304	0
Nokia	8,903,746	10,508,308	5,537,312
Kaarina	11,233,605	12,803,232	7,940,466
Ylöjärvi	8,419,941	9,959,070	5,190,788
Raasepori	9,140,670	10,620,588	6,180,834
Imatra	3,782,328	5,243,682	8,452,930
Riihimäki	3,432,600	4,891,455	1,230,015
Kangasala	8,131,050	9,586,080	5,078,340
Vihti	6,394,596	7,818,720	3,406,728
Savonlinna	6,769,048	8,183,890	12,567,126
Sastamala	7,784,640	9,033,120	5,165,280
Raisio	9,510,600	10,744,800	6,921,200
Varkaus	5,341,991	6,511,268	9,079,092
Jämsä	7,425,756	8,594,625	5,867,264
Kemi	21,180,885	22,333,740	18,762,150
Raahe	18,133,430	19,282,256	15,723,148
Tornio	21,618,387	22,763,286	19,216,344
Iisalmi	7,963,697	9,095,030	11,579,526
Hollola	1,528,170	2,641,551	2,423,241
Hamina	1,117,168	794,908	4,619,060
St Petersburg	286,162,224	339,817,641	457,649,145
Moscow	438,833,986	455,314,497	491,506,991
Total costs	1,732,897,787	1,975,963,095	1,711,786,004
Percent per least costs	101%	115%	100%

APPENDIX 16: DISTRIBUTION COSTS OF RAIL TRANSPORT IN FINNISH INLAND LOCATIONS WITH ST PETERSBURG AND MOSCOW (SALARY DIFFERENCIES TAKEN INTO ACCOUNT)

	Kouvola	Kotka	Kerava
Helsinki	111,543,045	141,326,790	16,351,860
Espoo	41,842,845	54,322,290	1,957,560
Tampere	56,297,038	67,090,831	33,651,237
Vantaa	36,271,149	46,379,502	3,964,060
Turku	62,942,670	71,934,480	44,077,500
Oulu	115,823,949	122,932,278	100,910,396
Jyväskylä	34,253,736	40,870,935	40,481,688
Lahti	6,162,342	11,314,464	10,304,244
Kuopio	25,296,999	30,022,812	40,401,068
Kouvola	0	4,496,925	14,372,525
Pori	33,226,459	37,452,268	24,360,546
Joensuu	22,917,195	26,627,598	43,360,788
Lappeenranta	6,905,184	10,573,563	18,629,611
Hämeenlinna	12,372,534	15,765,003	5,255,001
Rovaniemi	62,925,450	65,981,829	56,513,047
Vaasa	33,819,188	36,839,816	27,481,792
Seinäjoki	28,416,969	31,332,996	22,299,030
Salo	14,226,611	17,027,990	8,349,208
Kotka	2,794,596	0	11,726,344
Mikkeli	5,505,134	7,989,752	13,494,886
Porvoo	7,685,594	10,166,387	1,653,862
Kokkola	28,980,000	31,326,000	24,058,000
Hyvinkää	6,026,363	8,337,224	1,359,330
Rauma	16,302,420	18,330,282	12,047,886
Nurmijärvi	7,337,100	9,359,760	872,520
Lohja	7,918,998	9,928,296	3,703,412
Järvenpää	5,999,740	7,973,848	309,664
Kajaani	27,239,696	29,190,854	23,146,090
Tuusula	6,216,496	8,092,480	220,704
Kirkkonummi	7,308,200	9,171,791	2,375,165
Kerava	5,531,568	7,262,304	0
Nokia	8,903,746	10,508,308	5,537,312
Kaarina	11,233,605	12,803,232	7,940,466
Ylöjärvi	8,419,941	9,959,070	5,190,788
Raasepori	9,140,670	10,620,588	6,180,834
Imatra	3,782,328	5,243,682	8,452,930
Riihimäki	3,432,600	4,891,455	1,230,015
Kangasala	8,131,050	9,586,080	5,078,340
Vihti	6,394,596	7,818,720	3,406,728
Savonlinna	6,769,048	8,183,890	12,567,126
Sastamala	7,784,640	9,033,120	5,165,280
Raisio	9,510,600	10,744,800	6,921,200
Varkaus	5,341,991	6,511,268	9,079,092
Jämsä	7,425,756	8,594,625	5,867,264
Kemi	21,180,885	22,333,740	18,762,150
Raahe	18,133,430	19,282,256	15,723,148
Tornio	21,618,387	22,763,286	19,216,344
Iisalmi	7,963,697	9,095,030	11,579,526
Hollola	1,528,170	2,641,551	2,423,241
Hamina	1,117,168	794,908	4,619,060
St Petersburg	55,602,333	66,027,770	88,922,848
Moscow	111,244,479	115,422,291	124,597,093
Total costs	1,174,748,388	1,362,281,018	976,149,810
Percent per least costs	120%	140%	100%

APPENDIX 17: OPTIMAL DISTRIBUTION CENTERS FOR FINNISH INLAND LOCATIONS BY LINEAR INTEGER PROGRAMMING FOR RAIL TRANSPORT

	Kouvola	Kotka	Kerava
Helsinki	0	0	16,351,860
Espoo	0	0	1,957,560
Tampere	0	0	33,651,237
Vantaa	0	0	3,964,060
Turku	0	0	44,077,500
Oulu	0	0	100,910,396
Jyväskylä	34,253,736	0	0
Lahti	6,162,342	0	0
Kuopio	25,296,999	0	0
Kouvola	0	0	0
Pori	0	0	24,360,546
Joensuu	22,917,195	0	0
Lappeenranta	6,905,184	0	0
Hämeenlinna	0	0	5,255,001
Rovaniemi	0	0	56,513,047
Vaasa	0	0	27,481,792
Seinäjoki	0	0	22,299,030
Salo	0	0	8,349,208
Kotka	0	0	0
Mikkeli	5,505,134	0	0
Porvoo	0	0	1,653,862
Kokkola	0	0	24,058,000
Hyvinkää	0	0	1,359,330
Rauma	0	0	12,047,886
Nurmijärvi	0	0	872,520
Lohja	0	0	3,703,412
Järvenpää	0	0	309,664
Kajaani	0	0	23,146,090
Tuusula	0	0	220,704
Kirkkonummi	0	0	2,375,165
Kerava	0	0	0
Nokia	0	0	5,537,312
Kaarina	0	0	7,940,466
Ylöjärvi	0	0	5,190,788
Raasepori	0	0	6,180,834
Imatra	3,782,328	0	0
Riihimäki	0	0	1,230,015
Kangasala	0	0	5,078,340
Vihti	0	0	3,406,728
Savonlinna	6,769,048	0	0
Sastamala	0	0	5,165,280
Raisio	0	0	6,921,200
Varkaus	5,341,991	0	0
Jämsä	0	0	5,867,264
Kemi	0	0	18,762,150
Raahe	0	0	15,723,148
Tornio	0	0	19,216,344
Iisalmi	7,963,697	0	0
Hollola	1,528,170	0	0
Hamina	0	794,908	0
Total costs		648,358,471	
Percent per least costs		85%	

APPENDIX 18: OPTIMAL DISTRIBUTION CENTERS FOR FINNISH INLAND LOCATIONS AND ST PETERSBURG AND MOSCOW BY LINEAR INTEGER PROGRAMMING FOR RAIL TRANSPORT

	Kouvola	Kotka	Kerava
Helsinki	0	0	16,351,860
Espoo	0	0	1,957,560
Tampere	0	0	33,651,237
Vantaa	0	0	3,964,060
Turku	0	0	44,077,500
Oulu	0	0	100,910,396
Jyväskylä	34,253,736	0	0
Lahti	6,162,342	0	0
Kuopio	25,296,999	0	0
Kouvola	0	0	0
Pori	0	0	24,360,546
Joensuu	22,917,195	0	0
Lappeenranta	6,905,184	0	0
Hämeenlinna	0	0	5,255,001
Rovaniemi	0	0	56,513,047
Vaasa	0	0	27,481,792
Seinäjoki	0	0	22,299,030
Salo	0	0	8,349,208
Kotka	0	0	0
Mikkeli	5,505,134	0	0
Porvoo	0	0	1,653,862
Kokkola	0	0	24,058,000
Hyvinkää	0	0	1,359,330
Rauma	0	0	12,047,886
Nurmijärvi	0	0	872,520
Lohja	0	0	3,703,412
Järvenpää	0	0	309,664
Kajaani	0	0	23,146,090
Tuusula	0	0	220,704
Kirkkonummi	0	0	2,375,165
Kerava	0	0	0
Nokia	0	0	5,537,312
Kaarina	0	0	7,940,466
Ylöjärvi	0	0	5,190,788
Raasepori	0	0	6,180,834
Imatra	3,782,328	0	0
Riihimäki	0	0	1,230,015
Kangasala	0	0	5,078,340
Vihti	0	0	3,406,728
Savonlinna	6,769,048	0	0
Sastamala	0	0	5,165,280
Raisio	0	0	6,921,200
Varkaus	5,341,991	0	0
Jämsä	0	0	5,867,264
Kemi	0	0	18,762,150
Raahe	0	0	15,723,148
Tornio	0	0	19,216,344
Iisalmi	7,963,697	0	0
Hollola	1,528,170	0	0
Hamina	0	794,908	0
St Petersburg	286,162,224	0	0
Moscow	438,833,986	0	0
Total costs		1,373,354,682	
Percent per least costs		80%	

APPENDIX 19: OPTIMAL DISTRIBUTION CENTERS FOR FINNISH INLAND LOCATIONS AND ST PETERSBURG AND MOSCOW BY LINEAR INTEGER PROGRAMMING FOR RAIL TRANSPORT (SALARY DIFFERENCES TAKEN INTO ACCOUNT)

	Kouvola	Kotka	Kerava
Helsinki	0	0	16,351,860
Espoo	0	0	1,957,560
Tampere	0	0	33,651,237
Vantaa	0	0	3,964,060
Turku	0	0	44,077,500
Oulu	0	0	100,910,396
Jyväskylä	34,253,736	0	0
Lahti	6,162,342	0	0
Kuopio	25,296,999	0	0
Kouvola	0	0	0
Pori	0	0	24,360,546
Joensuu	22,917,195	0	0
Lappeenranta	6,905,184	0	0
Hämeenlinna	0	0	5,255,001
Rovaniemi	0	0	56,513,047
Vaasa	0	0	27,481,792
Seinäjoki	0	0	22,299,030
Salo	0	0	8,349,208
Kotka	0	0	0
Mikkeli	5,505,134	0	0
Porvoo	0	0	1,653,862
Kokkola	0	0	24,058,000
Hyvinkää	0	0	1,359,330
Rauma	0	0	12,047,886
Nurmijärvi	0	0	872,520
Lohja	0	0	3,703,412
Järvenpää	0	0	309,664
Kajaani	0	0	23,146,090
Tuusula	0	0	220,704
Kirkkonummi	0	0	2,375,165
Kerava	0	0	0
Nokia	0	0	5,537,312
Kaarina	0	0	7,940,466
Ylöjärvi	0	0	5,190,788
Raasepori	0	0	6,180,834
Imatra	3,782,328	0	0
Riihimäki	0	0	1,230,015
Kangasala	0	0	5,078,340
Vihti	0	0	3,406,728
Savonlinna	6,769,048	0	0
Sastamala	0	0	5,165,280
Raisio	0	0	6,921,200
Varkaus	5,341,991	0	0
Jämsä	0	0	5,867,264
Kemi	0	0	18,762,150
Raahe	0	0	15,723,148
Tornio	0	0	19,216,344
Iisalmi	7,963,697	0	0
Hollola	1,528,170	0	0
Hamina	0	794,908	0
St Petersburg	55,602,333	0	0
Moscow	111,244,479	0	0
Total costs		815,205,283	
Percent per least costs		84%	

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