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DATA ENVELOPMENT ANALYSIS OF HELSINKI-TALLINN TRANSPORTATION CHAINS

ABSTRACT

The Baltic Sea shipping is at a crossroads as sulphur regulation will lead to excessive cost increases from the year 2015 onwards and CO_2 emission trading is planned to be implemented for the entire shipping sector within the EU area. Therefore, shipping is going to be minimized and hinterland transportation (road and rail) will act as substitute. This research analyzes the situation on one of the highest volume general cargo transportation routes of Finland (operating between Helsinki, Finland and Tallinn, Estonia), including loading and unloading at seaports and short sea shipping activity in between. Based on the efficiency evaluation results, it seems that containers should be favoured over semi-trailers – containers could be carried efficiently either in container ships or even at currently favoured RoRo or RoPax ships. Our research illustrates that pure container shipping with larger container ships within the analyzed route is not entirely out of question, but lead time and hinterland operations should receive more attention. Alternatively, RoRo and RoPax ships can also do something to increase their competitiveness in environmental harm caused and diesel consumption – higher cargo loads and utilization levels are short-term key for continued dominance.

KEY WORDS

Short sea shipping, Helsinki, Tallinn, multi-dimensional performance, Data Envelopment Analysis

1. INTRODUCTION

Maritime transportation is at the top of the agenda in the majority of the world's export countries, whether they are landlocked or not. However, untypical is its level of dominance, which is revealed by the Finnish export and import statistics [1]. From the Finnish imports 81.7% in year 2011 were transported through seaports. Correspondingly, 87.7% were from exports share. After sea transportation the second highest alternative is the railways (basically serving eastern trade), where the share from imports is 8.7% and from exports 2.8%. So, Finland is entirely dependent on seaports and routes in foreign trade, and this activity should have high efficiency, quality, flexibility and cost standard.

Competitiveness is not only an internal issue as in export trade, but it is rather vital to have import flows as well (in order to achieve high enough fillrates in ships). So, it helps if a country is able to attract import transit (containers) to serve e.g. Russia and other eastern countries [2]. Another external factor to be taken into account is increasingly tightening environmental regulation. As most of the Finnish shipping routes are feeder traffic to larger hubs (Germany, Sweden and the Netherlands), then as the third it is worth to mention the increasing oil prices (connected to environmental regulation too as sulphur oxide restrictions will lead to much dearer oil used). Long-distance and ocean traffic is easy to be optimized with low steaming, but short sea shipping is entirely another story, where ships barely reach the lowest scale level (e.g. see emission curves in [3]). In empirical research works it has been e.g. found that short sea shipping (typically RoRo) is having hard time to compete cost-wise against road transportation [4-5], and typically the only remedy has been public sector subsidy in one form or another [4].

Due to peripheral location and thin transportation flows, the Finnish transportation logistics in the segment of general cargo has traditionally been built around trucks (and arising variations). This also leads to the wide variety in used transportation equipment. Containers are not that popular (of course, they have increased their share) as in other parts of the world, e.g. China and the leading Asian logistics centres. In a good year the Finnish seaports handle 1.4-1.5 million Twenty feet Equivalent Unit containers (TEUs; [6]). Similarly, in a good year the seaports of Finland handle 0.8-0.9 million trucks and semi-trailers [6]. As containers are measured and transformed in statistics to 20 feet equivalent units, their handling quantities should be divided by two to have comparable situation with trucks and semi-trailers (Forty feet Equivalent Unit, FEU, container is roughly the same in technical sense as a semi-trailer). So, in FEU terms the Finnish seaports handle still a bit smaller quantities of containers (0.7-0.75 million FEUs) than trucks and semi-trailers.

In the European transportation logistics solutions the Finnish industry and retail sector prefer to use trucks and semi-trailers over containers – this on a massive scale. One good example is Helsinki-Tallinn route, which is the main interest of this research. Based on Hilmola [7-8] in the years 2009-2010 the container ship connections between these two cities were few, basically two connections from Tallinn's Muuga terminal to Helsinki's Vuosaari (at a frequency of one or two weeks). However, the situation was not so bad before the global credit crisis – in early 2000 until year 2008 numerous connections served this route. It could only be guessed why such negative change has occurred. One explanation could be the massive investments and competition of RoPax ships and vessel operators on this route. However, it is difficult to reverse the situation, and basically in current volumes the containers have an extremely low market share on e.g. Helsinki-Tallinn route. Sundberg et al. [9] estimated that this share would be as low as 0.4%. Based on their longitudinal data, container transportation has been for a long time at very low levels.

In this research work the data were gathered regarding different measures of transportation chains within the Helsinki-Tallinn route. All of the data are numeric and based on real-life sources or trustworthy databases (units and scales of course do differ between measured items). Two Data Envelopment Analysis (DEA) models were developed and analyzed with the efficiency evaluation program [20]. This gives us the opportunity to evaluate objectively the performance of different transportation chains. Data Envelopment Analysis is based on linear programming and it fits the scale curves on multidimensional non-parametric data during the efficiency estimation process. Research does not only report ordinary DEA efficiency in the range from 0-100%, but it gives super-efficiency values, which are more suitable in situations, where differences between the evaluated units are minor [26].

This research is structured as follows: In the following Section 2 the research environment is being analyzed primarily through second-hand statistics. Thereafter, in Section 3 the research methodology is presented, which introduces the used DEA efficiency evaluation model and also explains the performance of alternative transportation chain options in a particular input-output area (used measures in the model). The empirical data analysis is provided in Section 4, where data are analyzed both with smaller and larger DEA models. Empirical section also contains some further analysis as fillrates of ships and weight of cargo units are being altered. In Section 5 the research results are discussed, mostly through the perspective of developing container ship option better on the analyzed short sea shipping route. Research work is concluded in Section 6 with the consideration of further research avenues in the topic area.

2. RESEARCH ENVIRONMENT OF SHORT SEA SHIPPING BETWEEN HELSINKI AND TALLINN

On the one hand, the seaport of Helsinki is growing, if passenger transport and the related services are concerned. During the year 2012 Helsinki served more than 10 million passengers; most of these on the Helsinki-Tallinn route (7.58 million). As Finland is a remote place with low population density in the periphery, then passenger traffic is tied to freight transportation due to the shipping profitability reasons (either one alone does not have enough justification for high frequency). Therefore, it is not surprising to find that Helsinki as a seaport is a dominant player in truck and semi-trailer handling. Actually, it is larger than all of its domestic rivals combined – this situation has persisted from the year 2007 onwards. For passengers and truck-based freight seaport is still clearly on the growth track, both in long and short term.

The described growth is not only increasing handling amounts of road vehicles on freight category. Strikingly rapid and also alarming growth is the transport of passenger cars (and vans) in RoPax ferries (*Figure 1*). After its initial public offering to Tallinn Stock Exchange, the Tallink Group has recorded continuously increasing car handling at the Helsinki-Tallinn route (data gathered from press releases in *Figure 1*). Growth is having of course a clear linear component, but shows also seasonal fluctuation, having the peak in the summer vacation month, July. It is worth noticing that this growth has been around even in the mid of the credit crisis, which changed basically every other aspect of global transportation system. In the most recent 12-month period (July 2012-June 2013) the amount of car handling increased above 784 thousand units. This is the situation only regarding one ferry operator (leader), including others (Eckerö and Viking Line) and total number will be clearly above 1 million cars handled [10]. The volumes are about to continue their growth in the future.

Even if trucks and semi-trailers in freight transportation are experiencing in overall strong growth, this is not that unevenly distributed among different options (RoRo, RoPax and different routes). For example, Tallink group reports similar growth levels as the general aggregates show (*Figure 2*) and is having currently 50%

market share from truck and semi-trailer traffic between Helsinki and Tallinn [10] for the overall volume). So, RoPax vessel alternative is not super popular in the sense like in transporting of cars.

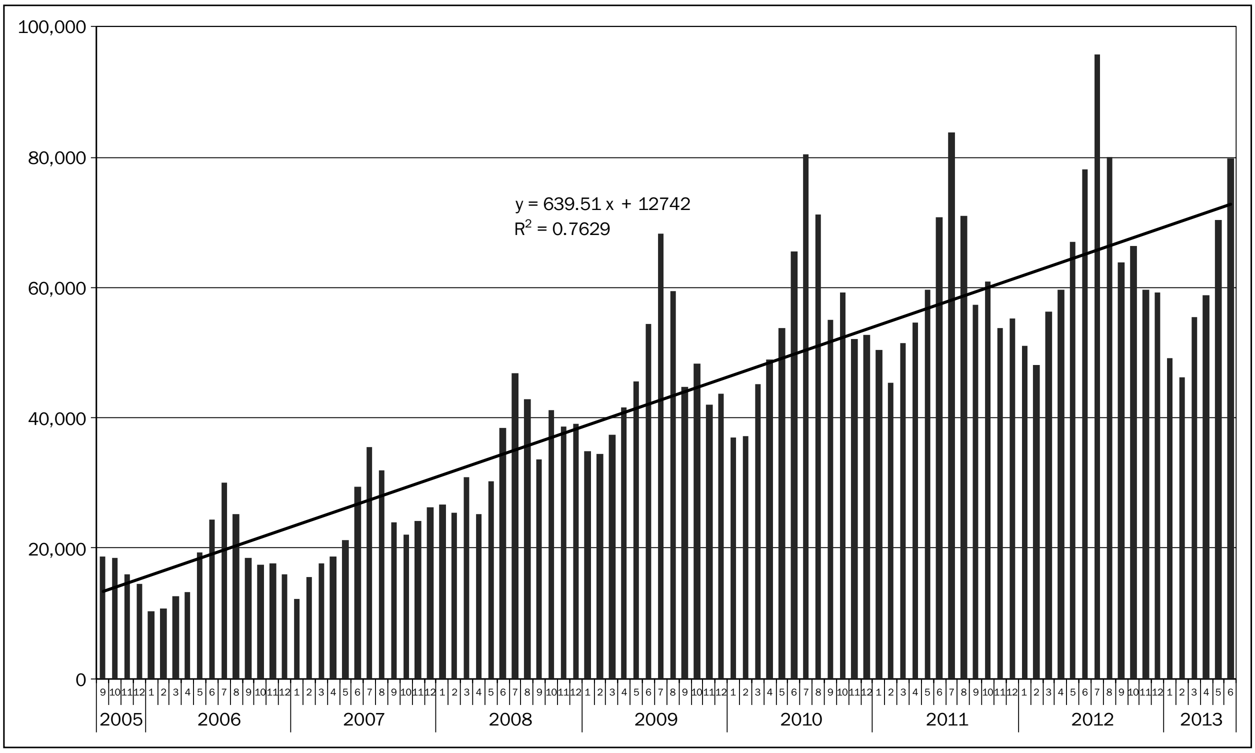

Figure 1 - Passenger cars travelling (monthly) between Estonia and Finland on Tallink-Silja ferry line during period of Sept. 2005-June 2013

Source (data): Tallink [13]

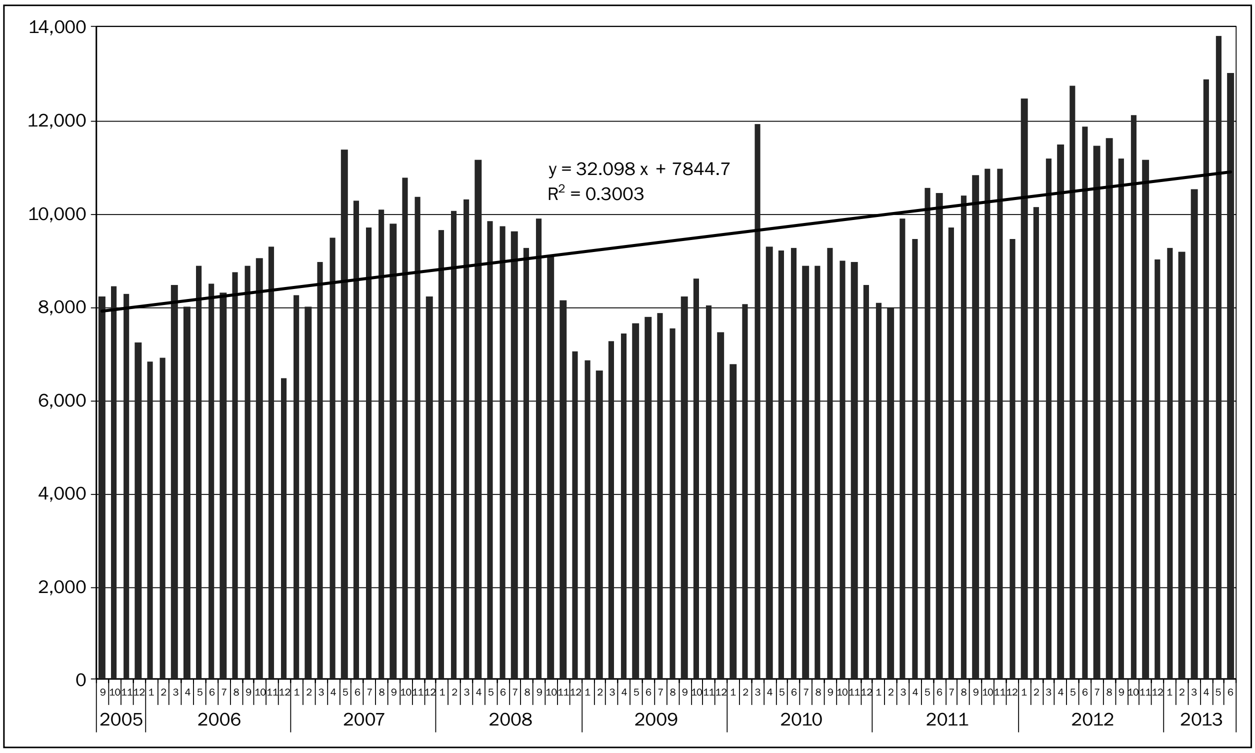

Figure 2 - Cargo unit volume (monthly) between Estonia and Finland on Tallink-Silja ferry line during the period of Sept. 2005 – June 2013

Source (data): Tallink [13]

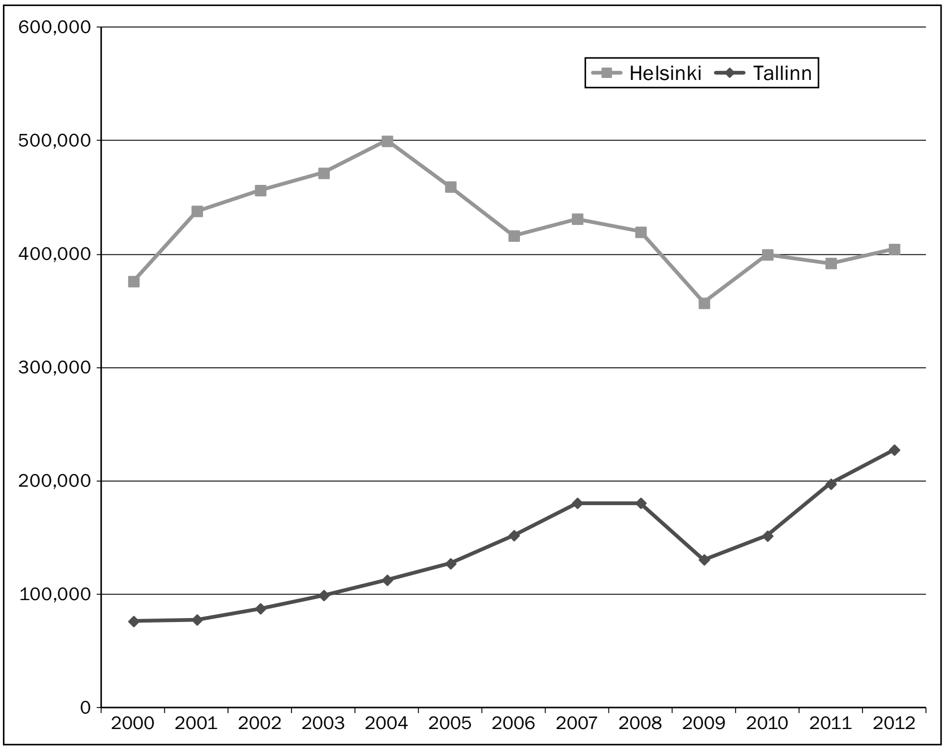

Figure 3 - Container handling (Twenty feet Equivalent Units, TEUs) in Helsinki (Finland) and Tallinn (Estonia) seaports during period of 2000-2012

Source (data): Finnports [6] and Port of Tallinn [14]

However, there exists a possibility that this current situation could be changing. From the year 2015 onwards the sulphur regulation of the International Maritime Organization (IMO) and the European Union (EU) will increase the sea-based transportation cost from Finland to Europe with 30-40% (e.g. [11-12]), and could considerably increase the popularity of short distance RoPax options. In *Figure 2* one anomaly for this could be detected from March 2010, when stevedoring strike in Finland stopped the handling at all seaports. This only with the exception of RoPax vessels, where drivers do the actual loading and unloading work. Monthly handling amounts spiked from Feb. 2010 with nearly 50%, and reached the level of slightly below 12,000 units handled on a monthly basis. This sort of spike is a possibility in the post-2015 world, where hinterland transportation will replace the sea transport to/from Europe. There is already strong evidence that current volumes of Helsinki-Tallinn route serve the foreign trade of other than Finnish-Estonian axle [9].

As concluded earlier, the container transportation volumes between Helsinki and Tallinn are marginal, and nearly non-existing. However, these two seaports perform rather differently in overall volumes (both do have intensive connections to Central Europe). Where Helsinki has been for twelve years on a flat or levelled-off mode, Tallinn has continuously improved (*Figure 3*). Actually, one could detect a clearly declining volume in case of Helsinki from the year 2004 onwards – it has lost its volumes to other seaports in Finland, such as HaminaKotka and Rauma. However, from the point of view of this research work, both seaports are having significant absolute volumes already at the container side, and readiness to serve even very short distance container transportation (if it is needed due to environmental reasons and/or better fuel economy).

3. RESEARCH METHODOLOGY

The gathered data in this efficiency evaluation research work is arising from externally funded research project, which was ordered by the larger project of cities of Helsinki and Tallinn – these two do also hold considerable influence over areal seaports (in case of Helsinki, Finland actually the seaport is city owned, while in Tallinn it is state owned). Project concentrated on gathering and modelling performance of various transportation chain alternatives operating between these two cities. The physical distance of this seaport pair is short, and depends on what terminals are calling from these respective cities, but 84 km distance gives good and accurate enough number from the short sea shipping operations. Estonia holds the importance not only to the capital region of Finland, but also in a larger context, since the seaport of Helsinki is leading in RoRo/RoPax transport in Finland (actually its truck and semi-trailer handling volumes are larger

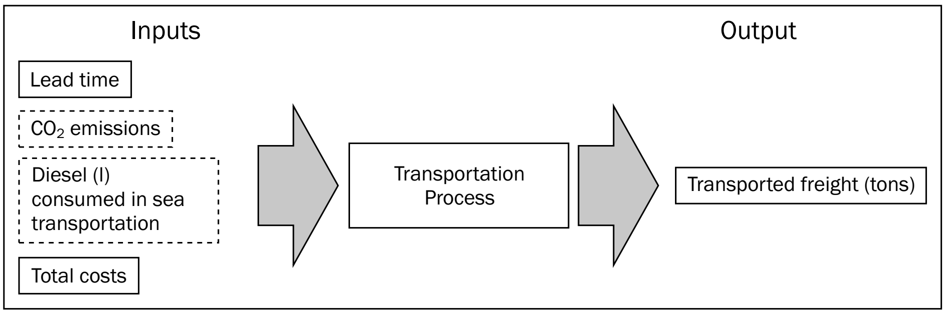

Figure 4 - Used Data Envelopment Analysis models in this study – input focused model with four or two inputs and one output

Table 1 - Four inputs (within brackets letter 'I') and one output used in DEA efficiency evaluation – utilization of ship 50%

Transportation Chain Alternative	Total costs {I}	Diesel {I}	CO_2 {I}	Lead time {I}	Tons {O}
RoRo: Semi-trailers with cabin	642.8	90.0	245,026.0	5.0	13.9
RoRo: Semi-trailers without cabin	494.3	71.8	196,623.7	6.0	13.9
RoRo: FEU on platform with cabin	661.3	83.8	230,822.2	5.0	16.7
RoRo: FEU on platform without cabin	512.8	65.6	182,440.5	6.0	16.7
RoRo: FEU on MAFI roll trailer	512.8	64.2	179,951.2	6.0	16.7
RoPax: Semi-trailers with cabin	579.8	107.9	292,548.5	3.5	13.9
RoPax: Semi-trailers without cabin	538.1	86.9	236,803.8	4.5	13.9
RoPax: FEU on platform with cabin	598.3	100.9	276,457.4	3.5	16.7
RoPax: FEU on platform without cabin	556.6	78.2	216,114.4	4.5	16.7
RoPax: FEU on MAFI roll trailer	556.6	76.3	212,261.5	4.5	16.7
Container ship (500 TEU): FEU	560.5	32.9	102,988.4	72.0	16.7
Container ship (1,000 TEU): FEU	560.5	23.5	77,897.2	72.0	16.7

than all of the other seaports together in Finland; see more [15]), and Estonia is offering the shortest sea distance to the European continent (another alternative to Helsinki seaport is Stockholm, where additional 400 km sea journey is needed).

In order to evaluate the currently existing short sea shipping alternatives on Helsinki-Tallinn route, DEA model shown in *Figure 4* was developed. This efficiency evaluation has not been completed for the externally funded research project, but it resulted from its data as it was seen in the research sense as interesting for the development of the discipline. To obtain the data, different approaches were used. For example, lead time and total costs were accessed from sea vessel operators and sea ports, while diesel oil consumption at sea is based on technical databases [16-17] regarding short sea shipping operations as well as the used ship utilization levels. CO_2 emissions within transportation process are a combination of technical databases and site visits – hinterland operations and processes differ considerably between shipping alternatives, and in some cases (like container ships) these hinterland loading and unloading arrangements could contribute 10% to more than 20% from the entire transportation chain CO_2 emissions (depending on the ship size and ship utilization). However, in RoRo and RoPax options putting a semi-trailer onto the ship with a truck is a very short lead time operation and simple – in the end the contribution to CO_2 emissions is very marginal, few percents at best from the entire transportation chain emissions.

Differences in input values exist everywhere else except in total costs (incl. sea freight, bunker surcharge, cargo charge of seaport and estimated fleet holding costs and possible driver during the sea journey). It is somehow surprising that short sea shipping costs of 84 km (*Table 1*) are at a minimum approx. 500 euro per transported unit (€6.1 per km – basically more than three times higher than any road transport charge for truck and semi-trailer), and the maximum is more than 650 euro (€7.9 per km). It should be noted that during the time of the study, the oil prices were rather high and this resulted e.g. in high bunker charges. Both bunker surcharge and cargo charge of seaport are driven by transported tons, and FEU containers pay correspondingly more than semi-trailers (due to higher load: see *Table 1* last column). The transportation fleet was estimated to have a value of half of the new purchase price and an economic use time of 15 years. Similarly, conservative approach was used for driver salaries (incl. direct and indirect costs), which were 50% of the Finnish salary system costs. This corresponds to the real-life as drivers are typically from the Baltic States, Poland, Russia, Belorussia or

Ukraine – in all of these countries truck drivers earn significantly lower rates than in Finland.

Both diesel consumption at sea and CO_2 emissions hold considerable differences between short sea shipping alternatives (*Table 1*; similar to earlier studies such as [3]). As container ships are only devoted to transport of cargo stored in boxes, and not passengers (RoPax) in need of enjoyment (restaurants, dancing, swimming, tax-free shopping, large-scale hotel operations, etc.) or trucks together with semi-trailers (RoRo and RoPax), they do consume much lower amounts of diesel oil and produce lower amounts of CO_2 emissions than other alternatives. Downside of this is the needed lead time for transport, three days. Based on the completed site visits, one day is spent on sea, while one day on both sides of the Gulf of Finland for hinterland operations. Another extreme regarding lead time are RoPax operations, where a ship will spend at sea only two hours! This of course has its trade-off with much higher diesel requirements and higher CO_2 emissions.

The estimates regarding RoRo and RoPax ship emissions used in this research work are in line with previous research in the field, as Walsh & Bows [3] argued that RoRo ships emit from 63% up to 219% more CO_2 than container ships (it should be noted that the emissions in *Table 1* include also hinterland operations, which will balance significant difference of plain sea transport operation between container ships and RoRo/RoPax). CO_2 emissions (and also diesel consumption) of RoRo and RoPax options are extremely high on this short sea route, but one should remember that even in the traffic between continents their emissions are nearly equivalent to road transport [18].

Utilization of the ship cargo space is one major factor, which has an impact on CO_2 emissions and diesel consumption. Based on earlier research work from North European short sea shipping (e.g. [19]) and also for expert opinions, in this research work 50% ship utilization was chosen as the base case (which is a bit higher than [19] gave for general estimate). This is increased within DEA analysis up to 80%. Regarding CO_2 emissions and diesel oil consumption of sea operations it is assumed that ships consume the same amount of fuel whatever the load (fuel consumption taken from [16] database where it is assumed that 80% utilization exist for RoRo/RoPax and 65% correspondingly for container ships) and this environmental load is just spread to different amounts of unitized cargo carried by the ship. This estimation practice could be justified with the use of ballast water, e.g. in RoRo and RoPax ferries, because they need to enter the fixed ramps at seaports, which require always the same load on the ship (whether the load is actual cargo or not). As container ships are having such a low utilization level in technical databases, in this research work diesel oil consumption is being increased linearly with added weight for 80% fillrate situation of a ship.

As could be noted from *Table 1*, the freight amount inside the boxes of FEU containers and semi-trailers differs in this research work. This is because on the average during the years 2003-2011 FEU containers handled in the Finnish seaports had a weight of 16.69 tons, while semi-trailers had 2.84 tons less cargo inside. It could only be guessed, why this is the case. One reason is that shorter transportation logistics in Finland is implemented nearly solely with truck and semi-trailer combination, while containers are used in continental trade. As trucking in general is a small enterprise-driven business and overcapacity in the sector is still the norm, entrepreneurs take all-size deliveries to be transported as fixed costs are so high (due to expensive transportation fleet investment).

Typically in DEA models it is emphasized that correlations between input and output factors are undesirable. It is simply assumed that the used inputs will lead to a desired output, and these are interdependent. This is not entirely the case in the data used. Diesel consumption at sea (litres) has high correlation with CO_2 emissions – they differ basically marginally due to the reason that CO_2 emissions are directly dependent on the used amount of fossil fuels in transportation journey, and in this research work CO_2 emissions take also into account the emissions of hinterland operations on both sides of the gulf. However, two other inputs, lead time and total costs, are not that connected neither with each other nor to two other inputs being used. Surprisingly, and mostly due to high handling volume, very short lead time, RoPax vessels do not charge that much higher prices as compared to others (no trade-off).

From the perspective of the DEA method, it was chosen to use constant returns on scale in this research work (used abbreviation CCR, originating from the surnames of its inventors, [20]). As output values in this research work there are only two possible alternatives, and the differences between these two numbers are relatively small. It could be assumed that scale economics is constant. Other alternative would have been to use variable returns on scale (having abbreviation of BBC), which uses non-linear scale economics function to measure the efficiency. In this case semi-trailers having lower freight weight in outputs would have received a bit better treatment than what is the situation in CCR. Of course, it is a matter of open debate, which approach from these two is more accurate – at least CCR is the original evaluation method and as differences in this research work are so marginal (between different options), it was decided that this method is the only one used.

As a caveat, the evaluated amount of different transportation chain options is twelve, which is below three times of the total amount of inputs and output used in this research work (limit recommended by [21]. However, another smaller DEA model is also used in this paper, where only two inputs and one output are used to establish the actual model. This three-parameter model leads to a minimum requirement of observations to nine (as container ship options are in smaller model the same as price and lead time are the same in 500 TEU and 1,000 TEU cases, then the actual amount of analyzed options is eleven). It could be argued that this arrangement ensures that the results are valid from a larger model too, if they have a similar kind end interpretation with a smaller model.

In the following DEA efficiency evaluation is completed with ordinary 0-100% scale, but also using the super-efficiency scale (where the highest performers could have performance substantially higher than 100%). This is completed due to the fact that the differences in performance of different transportation chain options could be better detected. As typically in transportation models and service sector models, the efficiency differences are rather marginal among good and best performers and it is hard to judge, which option is the best one in performance (empirical studies such as [22-25]). Super-efficiency gives opportunity for this (it is actually a two-staged process, where the ordinary frontier is at first estimated and then the highest performing options are removed from the data and the frontier is recalculated) as variance grows between the options and the highest performing is clearly detected (e.g. [26]).

4. EMPIRICAL DATA ANALYSIS OF TWO DEA MODELS USED

Even if a container ship is having an extremely long lead time as compared to other shipping options in short sea route from Helsinki to Tallinn, this low performance does not show up that significantly in larger DEA model results (*Figure* 5). Other positive issues of container shipping, like low environmental harm caused (CO_2) and low diesel oil consumption (per FEU), are rewarding factors together with competitive price. Actually the results illustrate that if no change is implemented in total transportation lead time (in hinterlands or at sea), then this connection should use the largest ship possible (in order to reach the efficiency frontier). However, a smaller ship of 500 TEU will lack only 1.84% percent points from frontier – so not that poor performance either.

Other best performing options in RoRo and RoPax vessels are transportation chains, where container is used in the freight transports. In RoRo it is most efficient to have FEU container either in semi-trailer platform or in Mafi roll trailer (this saves loading time and time spent in the seaport areas). For RoPax FEU could be loaded even together with truck cabin – this mostly because it is again faster to handle at seaport and also due to competitive overall price of operations.

All different options become more equal in performance (*Figure* 6), if utilization rate of ship is increased

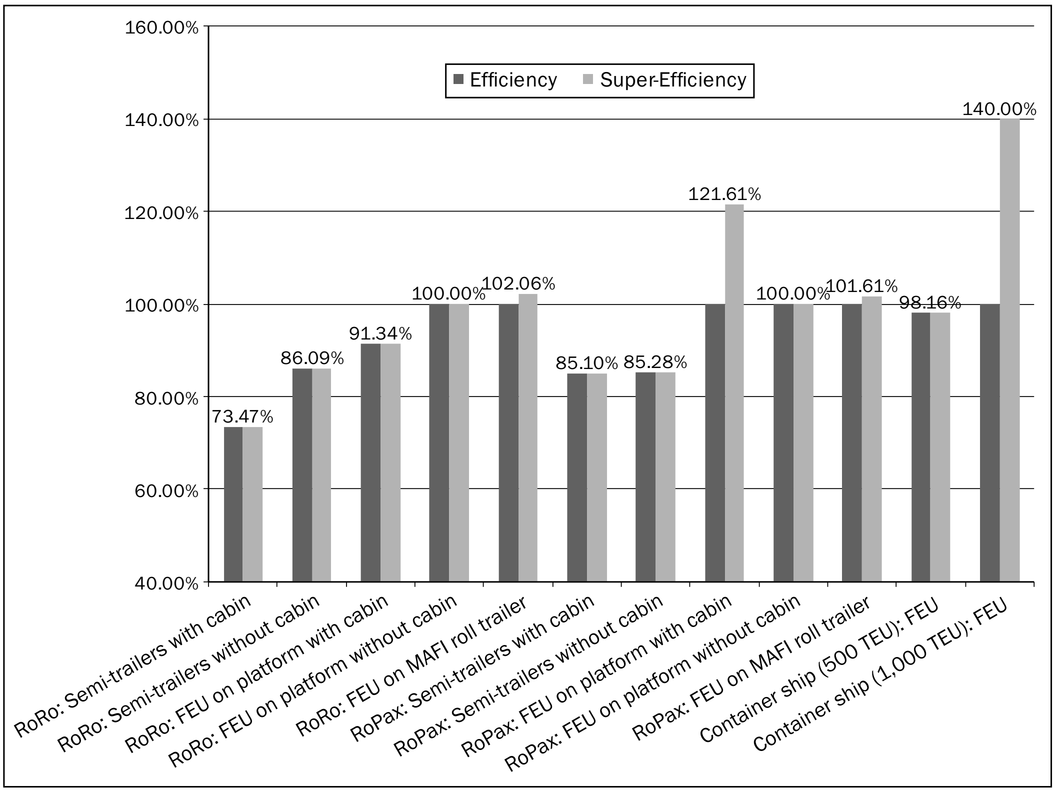

Figure 5 - Larger DEA model efficiency evaluation results (one stage CRS, super-efficiency values shown), where diesel consumption and CO_2 emissions are based on sea vessel utilization level of 50%

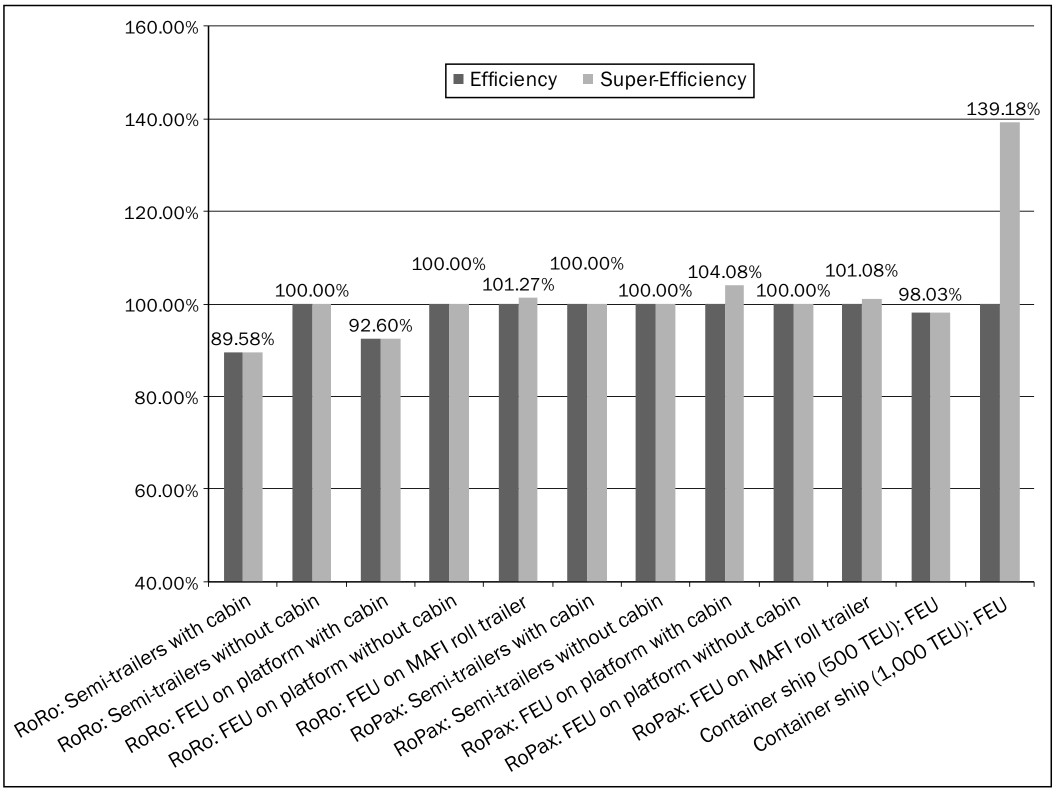

Figure 6 - Larger DEA model efficiency evaluation results (one stage CRS, super-efficiency values shown), where diesel consumption and CO2 emissions are based on sea vessel utilization level of 80% as well as with assumption that semi-trailers carry equal amount of freight with FEU containers

up to 80% (from freight side) and cargo weight of semi-trailers is increased to the same level with FEU containers (20.5% or 2.84 tons more cargo). Increasing of cargo in semi-trailers will have direct impact on freight costs as bunker fee and seaport handling fees increase (both ton based). It is assumed that fuel consumption and CO_2 emissions are not affected by this small weight increase. Based on the analysis of simply increasing utilization rates of ships (80%) or adding cargo weight on semi-trailers, it could be concluded that latter change is much more powerful and significant for DEA efficiency analysis results. However, it should still be noted that "with cabin" options in RoRo shipping are not within the frontier – in other words not being efficient.

As both configurations in Figures 5 and 6 are observed, it could be noted that in super-efficiency measurement container ship with capacity of 1,000 TEU will produce the best possible performance. In both cases the efficiency is approx. 140%. Similarly, in super-efficiency measurement RoPax option of FEU on semi-trailer platform accompanied by truck cabin, shows good performance as compared to others. If utilization of ship is about to increase together with cargo weight increase in plain semi-trailers, this option will understandably lose its competiveness as compared to other RoRo and RoPax transportation chains.

In smaller DEA model only inputs of total costs and lead time were used, while only one output of transported tons remained the same. *Figure 7* shows the results in default parameter setting, and in *Figure 8* the performance of semi-trailers has been correspondingly increased to the same level with FEU containers. Again, in general, it could be said that FEU transported in RoRo or RoPax ship will perform with the highest efficiency. This in situation, where truck cabin is not put in the ship together with the transported cargo. An exception for this exists in RoPax vessel. Notable are container ship options, which follow the efficiency frontier with approx. 7.5% points. This is explained just by a too long lead time for transportation.

In super-efficiency models of Figures 7 and 8 the same higher performer could be identified again, FEU transported in semi-trailer accompanied with truck cabin. This option has efficiency of 120.5% in default setting (*Figure 7*), but again an increase of weight (similarly with larger DEA model) will cause its exceptional performance standard to be lost.

5. DISCUSSION

Based on the findings of this research work, it could be argued that current modus operandi at Helsinki-Tallinn route, using mainly RoPax ships and semi-trailers with cabin, is far from optimal. This basically arises

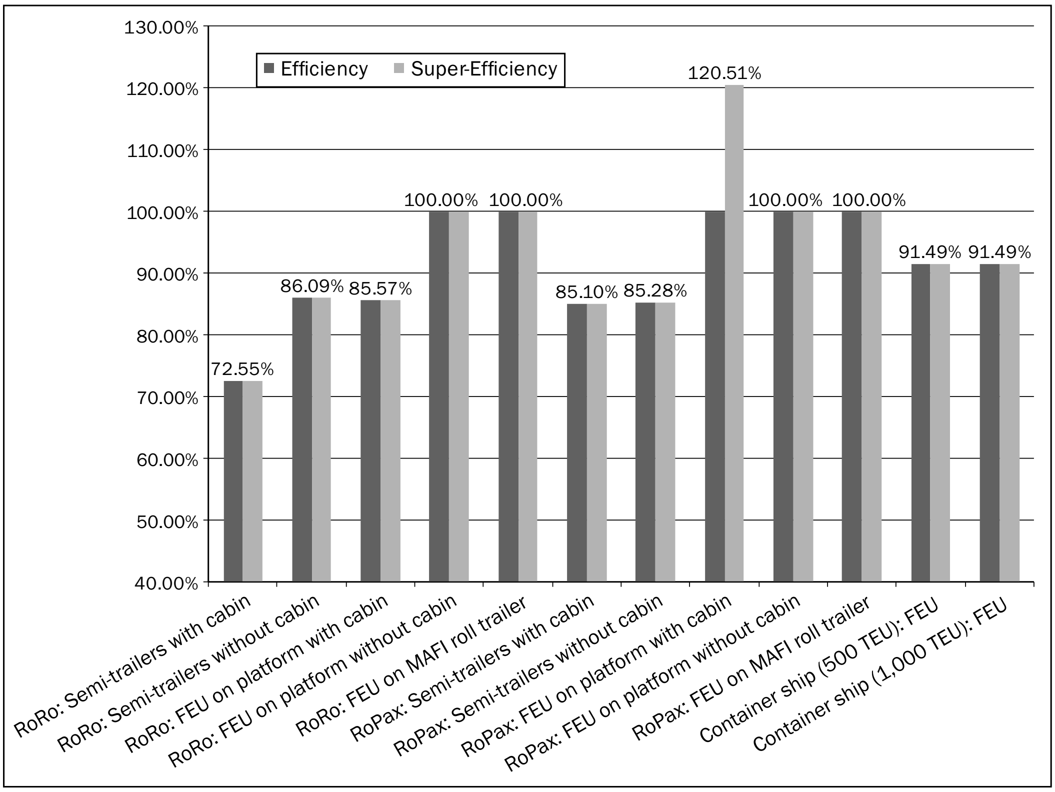

Figure 7 - Smaller DEA model efficiency evaluation results (one stage CRS, super-efficiency values shown), where total costs and weight are as they are today

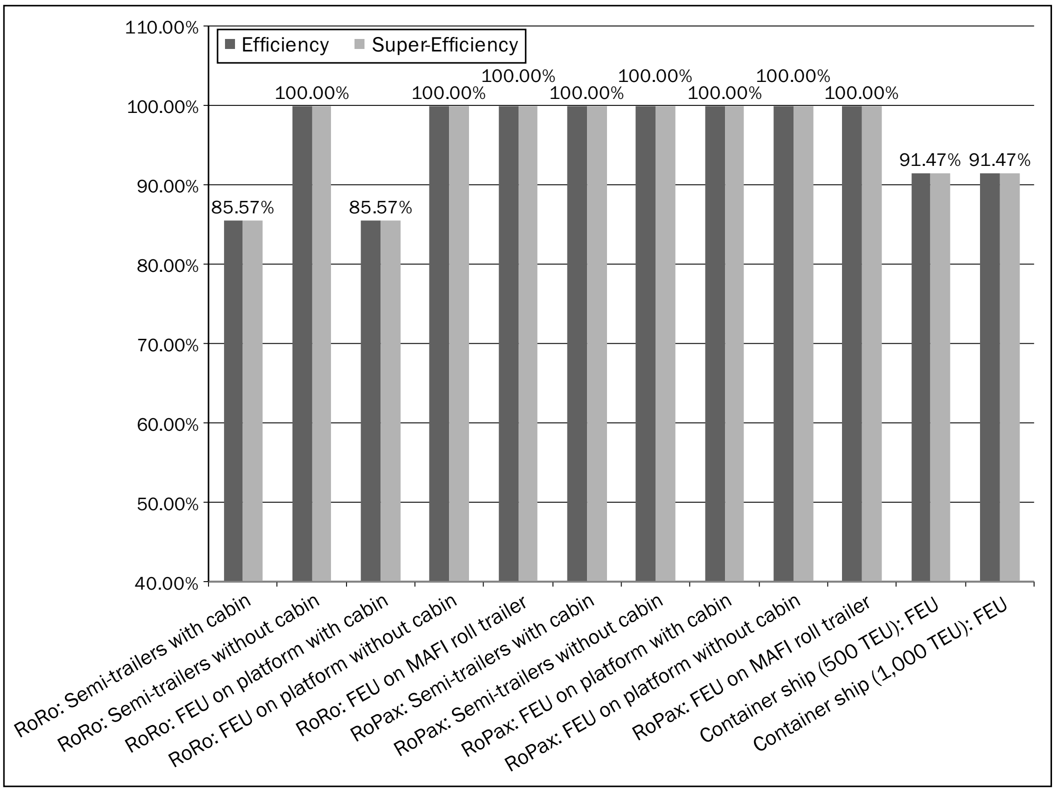

Figure 8 - Smaller DEA model efficiency evaluation results (one stage CRS, super-efficiency values shown), where weight of semi-trailers is increased up to level of FEU containers and total costs are increased due to this

from CO_2 emissions and fuel economy. Current RoPax ships could be used, but their fillrates should be higher and cargo load on semi-trailers ought to be higher – both would reduce the environmental load and diesel

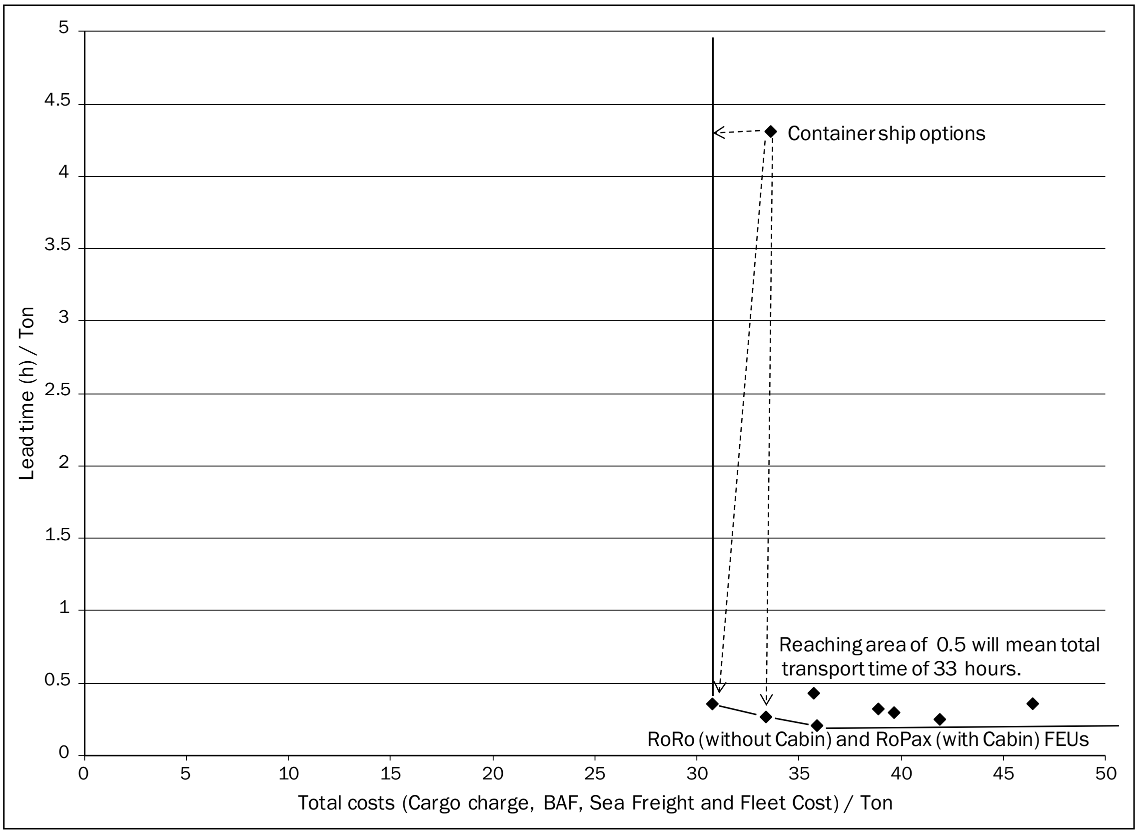

Figure 9 - Improvement of container shipping options in smaller DEA to reach the frontier

consumption per ton. The role of higher weight was already detected in lower fillrates and preference of loading semi-trailers with FEU containers.

Of course, in the current environment RoPax based chain is performing well, if compared to main competitors (small DEA). As price differences between different chains are basically very small, and RoPax offers much better frequency, shorter lead time and convenient price for semi-trailer with cabin, it is not surprising that most of the transportation flows are completed through this chain (even if the driver with the entire semi-trailer truck adds "hidden" indirect costs). Typically, the importance of the frequency of short sea shipping connections is forgotten; based on recent North American empirical study, it was found that customers were willing to pay a significantly higher price from higher frequency of short sea shipping alternative [5]. In this study, the impact of frequency on the efficiency was not analyzed at all, since it is a problem to have it included as input factor: The higher the frequency, the better it is for the users, but in DEA model it is the opposite as it is taken as an input. However, one option is to have it as output. This is not problem-free either as it is the output of shipping operations, not the transportation chain.

In larger DEA models plain container ship options did not experience lack of efficiency as compared to other options. Actually, it was so that larger container ship was remarkably more efficient than others in super-efficiency measurements. However, this is only one part of the story and situation, where four factors are used together in the evaluation. In real-life it could be so that a container ship's lead time is outside any practical requirement, and although performing extremely well in other dimensions, it is the reason why container ship volumes are practically nonexistent between Helsinki and Tallinn. This raises, of course, the following question: How much better should container transportation chain be in lead time performance? Graphical examination of this issue is performed in the frame of a smaller DEA model (no changes in the weight implemented) in *Figure 9*. It is evident from the figure that a container ship requires considerable improvement in lead time performance. This could be implemented e.g. by slightly reducing the total cost of transportation as well as reducing the y-axis performance around the 0.5 area (corresponds to 33 hours of lead time). If cost reduction is not possible, then the container ship option is forced to try to reach the performance level of RoRo and RoPax options (without truck cabin).

In container ship transportation chains lead time reduction need not necessarily be implemented at sea as hinterland operations take two thirds of the total lead time. In the research project, it was identified that the customs free zones are one constraint factor for shorter lead time at terminals. As nowadays most of the containers arrive from different continents, containers enter e.g. the Tallinn seaport and its Muuga container terminal first customs free zone. All paperwork and processing take a long time and container simply cannot be handled over for hinterland transportation device that smoothly. Based on three meetings with the concerned stakeholders of Tallinn over the lead time issue, clear improvement paths were identified. Dedicated quays e.g. for short sea shipping and international transit operations need to be established (container), and possibly to virtually (using RfIDs) as well as physically make the barriers to clearly separate the area for the EU area originating container transportation and inter-continental one. These changes would reduce considerably the current lead time requirement of 24 hours at the Tallinn seaport; the time needed at hinterland could drop down to a level of two to six hours.

6. CONCLUSION

As illustrated in this research work, the Finnish transportation chains are still based on intra-continental logistics mostly on road transports, and the best suited short sea shipping alternatives to support it. Even if container transports have revolutionized general cargo, and in parts bulk transports, it still has room to go within intra-continent transports. This research work has evaluated the different transportation chain alternatives and has recognized in the larger DEA model that the dominance of RoRo and RoPax may be challenged by container ships. Also containers themselves were identified to be better than pure semi-trailer and truck combinations due to higher cargo load. Still as a caveat, it could be noted that lead time in short sea shipping for container transportation is too long, and in smaller DEA model container ships do have margin as compared to efficiency frontier. It could be that the lead time in the current environment (where e.g. emissions do not play such a high role) is just too long, and this takes all the volumes for RoRo and RoPax options (especially the latter). Also in the analysis it was illustrated that RoRo and RoPax could increase their competitiveness with higher cargo loads of carried semi-trailers, and in smaller part with higher fillrates of ships. The challenge on container transport side is the lead time, which was identified to be the main improvement priority in the near future. Required reductions are large, but could be in parts improved with clearly dedicated areas and logistics flow separation technology at seaports.

There are naturally numerous further avenues for research on this topic area. One of them is the shipping frequency. One possibility to incorporate this in the DEA efficiency analysis models as input would be to make simulations from lead times with actual weekly schedules. These would without doubt improve RoPax performance in DEA analysis as e.g. container connections are very infrequent and continuous transportation need would result in very long wait times. Another factor to be considered is the diesel consumption (and CO_2 emissions) of the future – looking beyond the years 2020 and 2030. Different hinterland operations and shipping alternatives have clearly differing experience curves on energy consumption. It is argued that container ships hold the best possibilities for energy savings [27]. These future scenarios should be modelled and evaluated for efficiency.

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TIIVISTELMÄ

DEA-TEHOKKUUSANALYYSI HELSINKI-TALLINNA KULJETUSKETJUISTA

Itämeren laivaliikenne on murrostilassa ja kustannuspaineessa lähivuosina, johtuen paljolti vuonna 2015 voimaantulevasta rikkidirektiivistä. Lisäksi mahdollinen hiilidioksidikaupankäyntijärjestelmä nostaa myös liikennöin kustannuksia entisestään. Muutoksien johdosta itse meriliikenne tullaan minimoimaan ja korvaajana toimii maaliikenne (kumipyörä ja rautatiet). Tässä tutkimuksessa analysoimme tilannetta yhdellä tärkeimmistä yksiköidyn rahtiliikenteen reiteillä, joka toimii välillä Helsinki-Tallinna. Tarkastelutapamme on kuljetusketjupohjainen, joten lastaus ja purku satamissa sekä itse kuljetus kaupunkien välillä otetaan vertailuissa huomoon eri suorituskykymittareilla. DEA-tehokkuusanalyysin perusteella näyttää siltä, että konttikuljetukset ovat tehokkaampia kuin puoliperävaunut – tämä riippumatta siitä, millä kuljetuskonfiguraatiolla kontteja siirretään. Tutkimuksemme perusteella näyttäisi myös siltä, että Helsinki-Tallinna –reitille olisi tilausta isommalle konttilaivalle. Tällöin kuitenkin läpimenoajat ja satamatoiminnot tulisi tarkastella kriittisesti uudelleen. Vaihtoehtoisesti nykyiset RoRo ja RoPax –laivat voisivat yrittää parantaa omaa suoriutumistaan ympäristöpäästöjen ja polttoaineen kulutuksen suhteen. Lyhyellä aikavälillä korkeammat yksikköpainot ja käyttöasteet ovat avain parempaan suorituskykyyn.

AVAINSANAT

Lyhyt meriliikenne, Helsinki, Tallinna, moniulotteinen suoriutuminen, DEA

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