OPTIMIZATION OF RELATIVE TRANSPORT COSTS OF A HYPOTHETICAL DRY PORT STRUCTURE

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Decreasing environmental emissions originated from transportation sector plays a big role in the strategies of EU. One way to decrease emissions is to shift freight transport from unimodal road transport to intermodal solutions. Dry port concept aims at increasing rail transport between seaports and inland intermodal terminals, which are called dry ports. Such a concept is in infancy in Finnish transportation network. The main transport mode used in Finland is unimodal road transport. The aim of this research is to study the effects of a hypothetical dry port structure in Finnish transportation network. The effects are researched with different gravitational models. They apply linear integer programming, and heuristics to find relative transport costs in each situation. Differences in road and rail network, and road and rail transport modes are taken into account. The results of the models argue that Finland could benefit from dry port network. Cost-efficiency of the Finnish transportation network could be enhanced by using up to five or six dry ports. In addition, by replacing road transport with rail transport the environmental impacts can be lowered considerably. However, by alternatively utilizing within wider scale dense seaport network of Finland, we could achieve even better environmental results – approach which has been neglected so far in the dry port literature.

Keywords: Dry port concept, Finnish transportation network, gravitational models, costs of transport, intermodal transport, optimization, linear integer programming

1. Introduction

Transportation is one of the major polluting sectors [1]. The difference between transportation sector and other polluting sectors is that emissions originated from transportation have risen steadily during the last decades, whereas other sectors have been able to decrease or at least stop the increase of their pollution [2, 3]. The aim of the EU is to encourage and increase the use of intermodal transport [4, 5]. One important reason for this is environmental friendliness of intermodal transport, if compared to road transport [6, 7].

Dry port concept is one way to increase the use of intermodal transport. Because the implementation of dry ports increases the use of intermodal transport, especially rail transport, it can decrease the environmental impacts of the whole transportation system. Many studies support the assumption that rail transport is environmentally friendlier mode of transport than road transport [6, 7, 13-17]. The main transport mode between seaport and dry port (inland intermodal terminal) is rail transport in dry port concept [8, 9]. The possible advantages of the concept are the decrease of environmental emissions, and improved cost-efficiency of transportation system [8, 9]. Dry port concept is still in its infancy in Finland. Based on tons being transported (domestically), road transports holds roughly 85 % share in transportation market of Finland, and railways have 11 % (year 2010). However, situation is a bit better, if tonnekms are used as then road transports have share of 67 %, and railways 21.7 %. [10-12]. The aim of this manuscript is to research, what effects a hypothetical dry port network in Finland could have in terms of relative transport costs, and literally improving railways competitiveness.

Gravitational models of distribution based on population areas in Finland are used as main research method. Models are based on populations of chosen cities, rail and road network distances between chosen seaports, chosen dry ports and chosen cities. Models are quantitative, because all the different inputs are numerical. The aim of the gravitational models is to research, how relative costs evolve by using different number of dry ports and different settings concerning choosing of dry port locations in Finland. Linear integer programming is used to find out optimal routes and locations for each setting and for each model. First model uses heuristic approach, when choosing what dry port is dropped out of the model. Other models utilize optimization software package called IBM ILOG CPLEX Optimization Studio (CPLEX) to optimize the model and choose what dry port is dropped out i.e. no heuristic decision-making is then used.

2. Research Environment and Methodology

Physical research environment includes domestic Finnish inland transportation. Different actors that are taken into account are 50 largest cities of Finland with population, different chosen seaports and different chosen dry ports. The chosen dry ports in different models are chosen from the group of 50 largest Finnish cities. Transportation between seaports and dry ports is accomplished by rail transport, whereas transportation between dry ports and the largest Finnish cities is accomplished by road transport. The difference in costs between road and rail transport in Finnish transportation network is taken into account. Henttu et al. [7] calculated cost estimations for both the road and the rail transport modes in Finnish transportation network. Relative road and rail transport costs calculated my gravitational models are multiplied with costs estimations by Henttu et al. [7], so that difference in road and rail transport in gravitational models is detected.

In our approach gravitational models start with nine different dry port cities. After that models drop one dry port out of the model, so that there are now eight different chosen dry port cities. This process is continued until there is only one dry port city left to serve the entire country. In the first model the dry port cities are dropped out by with heuristic decision-making. Logic in selecting, which dry port location "drops from the list" at each time, is relatively straight forward: dry port, which is serving the lowest amount of TOP50 cities, and has the least transportation activity (distance times population). Three other gravitational models are optimized with CPLEX, which makes decision on what dry port is eliminated.

Nine different cities are chosen according to their geographic location and attractiveness in the first two gravitational models. Chosen possible dry ports in first model are cities of Jyväskylä, Kokkola, Kotka, Kouvola, Oulu, Rovaniemi, Tampere, Turku and Vantaa. Dry port cities were selected basing on their locations to serve 50 largest Finnish cities as well as with appropriate access to railway network as well as preparedness for needed infrastructure. The first model includes four different seaports, and they are ports of Helsinki, Kotka, Oulu and Pori. These ports are chosen, because they have high capacity for intermodal transport and they cover Finnish coastal efficiently. This group is studied with both the heuristic approach and optimization software CPLEX. Both the heuristic and CPLEX optimized approaches use linear integer programming to achieve the most cost-efficient environment. Heuristic approach is used, when dry port amount is reduced. Figure 1 clarifies physical environment of two first gravitational models (upper part).
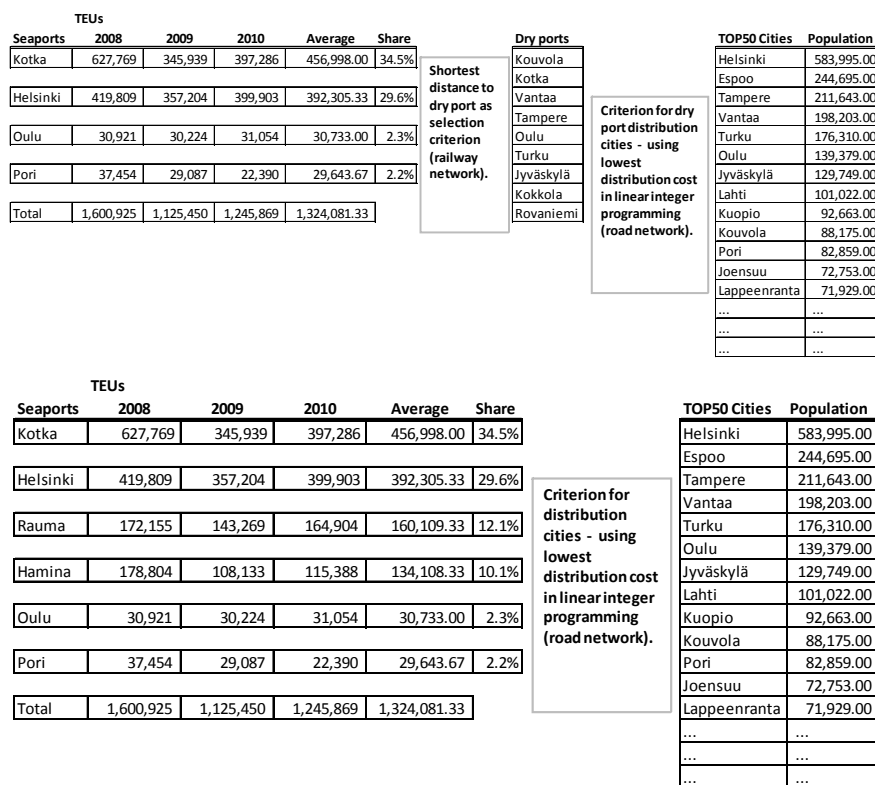
	TEUs											
Seaports	**2008**	**2009**	**2010**	**Average**	**Share**		**Dry ports**			**TOP50 Cities**	**Population**
Kotka	627,769	345,939	397,286	456,998.00	34.5%	Shortest distance to dry port as selection criterion (railway network).	Kouvola	Criterion for dry port distribution cities - using lowest distribution cost in linear integer programming (road network).		Helsinki	583,995.00
							Kotka			Espoo	244,695.00
Helsinki	419,809	357,204	399,903	392,305.33	29.6%		Vantaa			Tampere	211,643.00
							Tampere			Vantaa	198,203.00
							Oulu			Turku	176,310.00
Oulu	30,921	30,224	31,054	30,733.00	2.3%		Turku			Oulu	139,379.00
							Jyväskylä			Jyväskylä	129,749.00
							Kokkola			Lahti	101,022.00
Pori	37,454	29,087	22,390	29,643.67	2.2%		Rovaniemi			Kuopio	92,663.00
										Kouvola	88,175.00
										Pori	82,859.00
Total	1,600,925	1,125,450	1,245,869	1,324,081.33						Joensuu	72,753.00
										Lappeenranta	71,929.00
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						Criterion for distribution cities - using lowest distribution cost in linear integer programming (road network).	Vantaa	198,203.00
Rauma	172,155	143,269	164,904	160,109.33	12.1%		Turku	176,310.00
							Oulu	139,379.00
Hamina	178,804	108,133	115,388	134,108.33	10.1%		Jyväskylä	129,749.00
							Lahti	101,022.00
Oulu	30,921	30,224	31,054	30,733.00	2.3%		Kuopio	92,663.00
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Figure 1. Modelled hypothetical dry port structure of Finland using four seaports, nine alternative locations for dry ports and 50 largest cities as consumption places (upper part) and alternative hypothetical structure, where six different container sea ports are used as dry ports (lower part). Source: (TEU volume): [18]

By using the chosen ports (Ports of Helsinki, Kotka, Oulu and Pori), the coastline of Finland is effectively used. Most of the chosen dry port locations are situated in the south, because population is concentrated over there. The Northern Finland is very sparsely populated. Figure 1 above illustrates research environment only for two first gravitational models (upper part). Two other gravitational models have different settings concerning the chosen seaports and dry ports, and they are described more carefully later in this Section. Rail network distances from seaports to different dry ports are gathered from Finnish Transport Agency sources [20]. Distance to each dry port is from the nearest seaport. Road network distances from different possible dry ports to 50 largest Finnish cities are gathered from Google Maps [21] and ViaMichelin [22]. Populations of the 50 largest Finnish cities are gathered from Finnish population register centre [23].

Third gravitational model does not include any inland cities as dry ports. Only Finnish most used container seaports are used for export and import (Figure 1 lower part). Inland transportation in Finland is performed by the road transport in this model. The chosen Finnish container seaports in this group are ports of Hamina, Helsinki, Kotka, Oulu, Pori and Rauma. This group is researched only by using CPLEX. The fourth and final gravitational model includes all the largest Finnish cities as possible dry port solutions. Only those cities are included that has railway connection. This group is the most versatile due to many possible dry port locations. This group is researched only with CPLEX. The aim of these gravitational models is to study if Finnish transportation network could achieve cost saving by implementing dry port network, which is having entirely flexible setting (optimization is allowed to make selection). Furthermore, models include different number of dry port locations to find out, what is the effect if dry port amount is decreased or increased i.e. to research, if there is an optimal amount of dry ports in Finnish transportation network according to gravitational models.

In the used CPLEX model the model is done using integer programming (various optimization methods, see [28]). The model is optimized by modifying variables s_{ij} and d_j. They are binary variables, which represent whether a city is using a particular dry port and whether a specific dry port is used. The model minimizes the total costs, which consists of road costs, road environmental costs, railway costs, and railway environmental costs.

In their research, Henttu et al. [7] calculated the total cost estimations for road and rail transport in Finnish transport network. Costing includes both the internal and external costs of both transport modes. Internal costs are further divided into fixed and variable costs. External costs contain accidents, noise, congestion and CO_2 emissions. Estimated internal costs of road and rail transport calculated by Henttu et al. [7] are based on various sources e.g. Finnish Transport and Logistics [24], Finnish Transport Agency [25] and LIPASTO [26], which is a calculation system for traffic exhaust emissions and energy consumption in Finland. Estimated external costs for both the road and rail transport are based mainly on calculations by Maibach et al. [27] and LIPASTO [26]. Estimated total costs by Henttu et al. [7] are 0.0506 € per ton-kilometer for road transport and 0.0270 € per ton-kilometer for rail transport. Increasing use of rail transport can decrease the total costs of the transportation, because the total costs of rail transport are less than same costs of road transport. These costs are used in all groups of gravitational models.

3. Results of Gravitational Models

All the results of different gravitational models are illustrated in Figures 2-7. Relative transport costs incurred by varying number of dry ports or seaports are described in y-axis. Costs are relative, because they are calculated by multiplying population and distance with each other. They are not real costs of transportation. The aim of the relative costs is to find out different possible benefits or disadvantages. X-axis describes the number of dry ports or seaports being used depending on the model (the third model uses only seaports as terminals). Relative rail costs between seaports and dry ports are represented with the lightest line, which has continuously increasing tendency, if additional dry ports are being added into system. Possible positive tradeoff from this increase could be detected from the darkest line, in which the relative road transport costs decrease by adding dry ports. The line in the upper part of Figure 2 represents the total relative transport costs of the dry port system.

Figure 2 illustrates the results of the first group of gravitational models using heuristic approach, when choosing what dry ports are eliminated from the model. In this group, as in all other groups, the difference of costs between road and rail transport is taken into account. The relative road transport costs calculated with gravitational models are multiplied with 0.0506. The relative rail transport costs are multiplied with 0.0270. These multipliers are estimated total costs per ton-kilometer (internal and external costs) for Finnish road and rail transport calculated by Henttu et al. [7]. Cost estimations include internal and external costs i.e. models take the most important environmental impacts into account. Different environmental impacts are accidents, CO_2 emissions, noise and congestion.

The first model was created mainly with Microsoft Excel. Solver of Microsoft Excel was used for linear integer programming. The model starts with settings of nine different dry ports. Solver is used to optimize the most inexpensive routes between seaports and dry ports and dry ports and 50 largest Finnish cities. After that one dry port location is eliminated from the model to research the effect of smaller amount of dry ports. Elimination is based on heuristic approach. Dry port that has the least connections is dropped out of the model. In future this city is counted as one of the consignees or consignors. This process continues until there is only one dry port left in the model. Figure 2 summarizes the results concerning the costs of the first gravitational model.
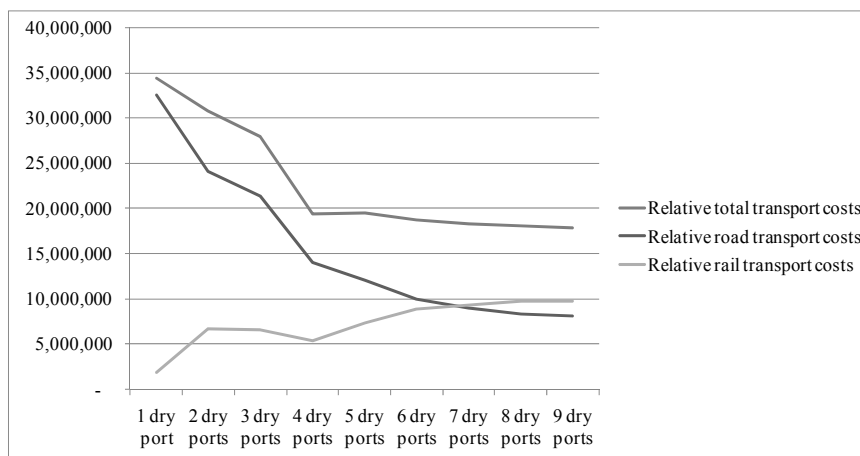
Figure 2. Relative transport costs of a dry port network with different number of dry ports (Heuristic approach)

As Figure 2 shows, the relative total transport costs can be decreased by using dry port network according to the first gravitational model. Significant cost reductions can be achieved by adding up to four dry port solutions. By adding more than four dry ports in the Finnish transportation network, cost saving becomes much less i.e. according to this model, four to six dry ports in Finnish transportation network allow the most cost-efficiency for the whole transportation system. As can be seen from Figure 2, the slope of the relative total transport costs line does not become smaller evenly. The reason for this is the heuristic approach, when choosing that dry port is dropped out of the model.

Next model uses the same possible dry port cities as the previous model. Difference between these models is that next model uses optimization software CPLEX for the whole process. No heuristic decision-making is used in this model. The results are shown in Figure 3.
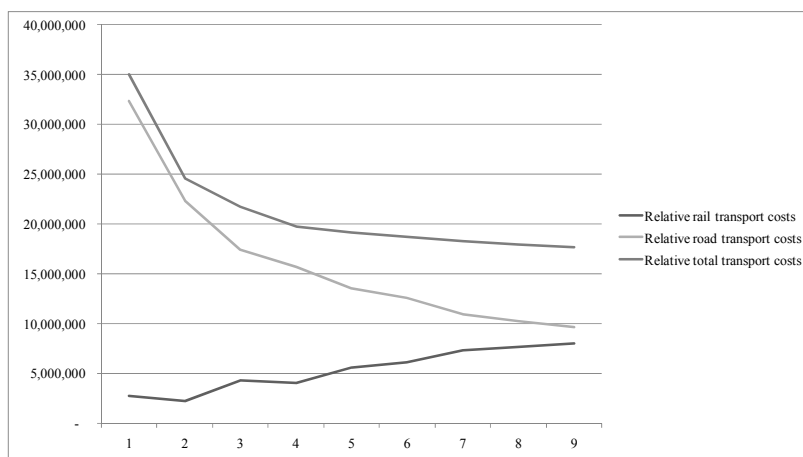

Figure 3. Relative transport costs of a dry port network with different number of dry ports (CPLEX optimized)

According to CPLEX optimized gravitational model, the relative transport costs can again be decreased. The major cost savings can be achieved by adding up to four to six dry ports. By adding more than six dry ports, costs can further be decreased, but decrease in costs becomes smaller. With nine dry port implementations, the total relative costs of road and rail transport are near each other.

Figure 4 summarized differences between two previously presented models. Both models have the same chosen possible dry ports and seaports, but the method for dropping a dry port is different. The first gravitational model uses heuristic decision-making, whereas the other usefull software optimization (CPLEX).
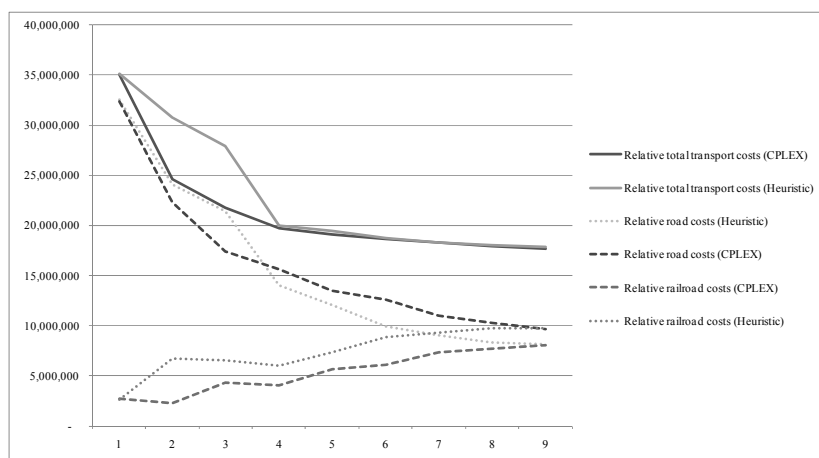

Figure 4. Comparison of relative transport costs between two similar gravitational models with different decision-making method

Figure 4 illustrates that CPLEX optimized model is having lower costs with two and three dry ports. If models use one, five, six, seven, eight or nine dry ports, then the relative total transport costs are similar in heuristic and CPLEX optimized models. So, it seems that total software optimization does not give much benefit, if different possible dry ports are restricted to nine pieces. There is almost no difference in relative total costs between models at number of four to nine dry ports. The main difference in researching hypothetical dry port network with heuristic approach and CPLEX optimization software is the amount of work that has to be done. Both models need both road and rail distances between dry ports, seaports and 50 largest cities of Finland, and population of these cities. After collecting these input data, the heuristic approach took one to two work days to create models. CPLEX optimization was able to run in one or two hours. After first CPLEX model, the others can be run in considerably less time (new models can be created in less than five minutes). The main difference in used dry ports between these models is that one with heuristic decision-making utilized city of Kouvola between three to nine dry port networks, whereas CPLEX optimized model utilized Kouvola only with nine dry port network. CPLEX optimized model utilized cities of Oulu and Kotka instead of Kouvola.

Next results are about gravitational model that does not include any dry port solutions i.e. all intermodal terminals are container seaports, and no inland terminal is used. All the inland transportation is accomplished by road transport. Figure 5 summarizes the results of this gravitational model. Numbers at x-axis describe the number of seaports used. Different possible seaports in this model are ports of Hamina, Helsinki, Kotka, Oulu, Pori and Rauma.
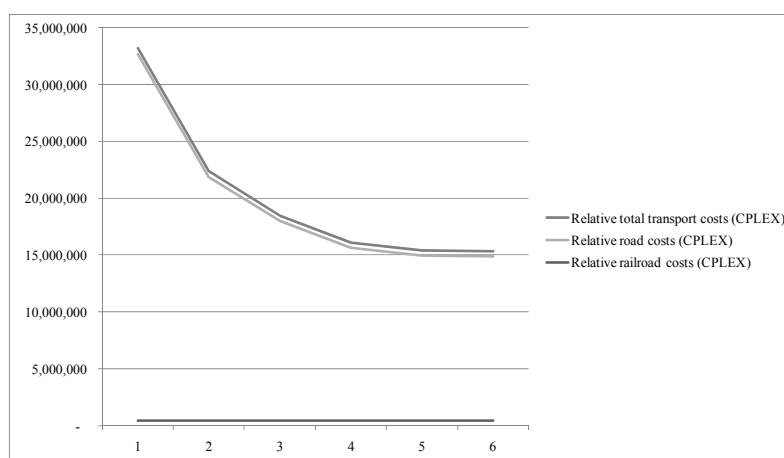

Figure 5. Relative transport costs of a transportation network, which utilized only main Finnish container seaports (CPLEX optimized)

If the main container seaports of Finland are used instead of any dry ports, costs saving can still be achieved by increasing the number of seaports. According to this model, costs saving is even larger in this model. One explanation is the difference of road and rail network structure. Road network distances between different geographical locations in Finland are quite straight, whereas many rail connections between different cities are more distant than road connections.

All the Finnish largest cities are possible dry ports in the last gravitational model, if they have railway connection (not all 50 largest Finnish cities have railway connection). This model is the most versatile one with the most available configurations. The results are illustrated in Figure 6.
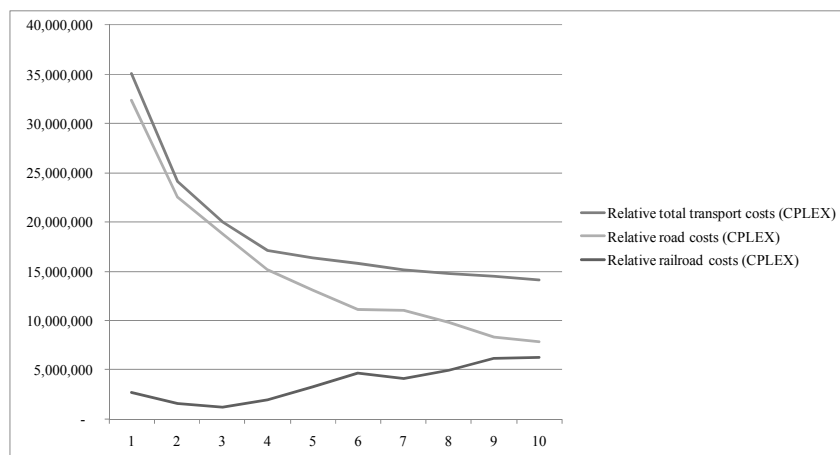

Figure 6. Relative transport costs of a dry port network with all 50 largest Finnish cities as possible dry ports
(CPLEX optimized)

Lines in this model look very similar to the first two models. The difference is that costs can be decreased little bit more than in the first two models by using more possible dry port locations. Final Figure 7 illustrates the total relative transport cost results of all four different gravitational models.
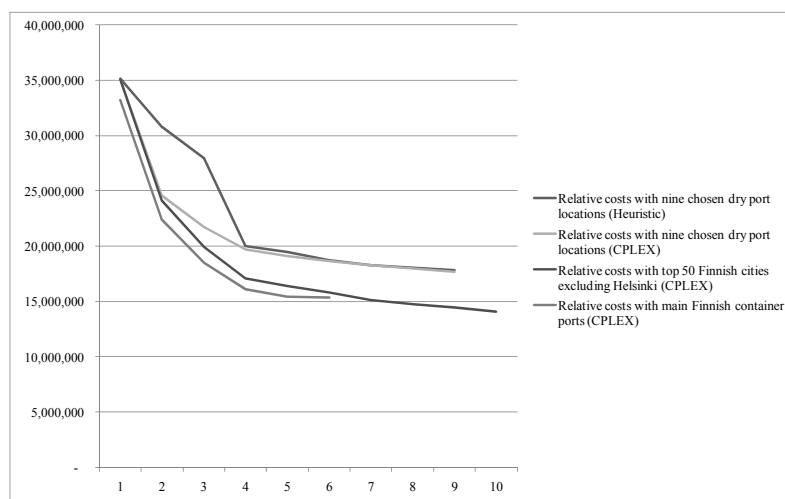

Figure 7. Comparison of all presented gravitational models

According to both heuristic and CPLEX optimized models, the relative total costs of transport can be decreased by using limited dry port network of at most nine different chosen dry ports (Jyväskylä, Kerava, Kokkola, Kotka, Kouvola, Oulu, Rovaniemi, Tampere and Turku). By using up to four or five dry ports the relative costs can almost be minimized. By adding more dry ports, the costs savings become very small. Surprising conclusion is that CPLEX optimized model that uses major Finnish container ports excluding all inland dry ports can reduce costs significantly. The main reason could be a better attainability of the road network. Slight relative cost reductions can be achieved compared to first two models, if number of possible dry ports is increased.

4. Conclusions

CPLEX software can be efficiently used to minimize model creation time. By using heuristic approach, the results can almost be optimized (at least by small number of possible variations), but creating such model takes a lot of time (one to two days). Furthermore, changing heuristic model (e.g. changing seaports, dry ports, number of seaports, number of dry ports etc.) needs much work, whereas changing CPLEX model takes almost no time, once the original model is created (although learning to use the optimization software might take months).

Objective of this research was to research the effect of a hypothetical dry port network in Finland. The research has been conducted with different gravitational models that use linear integer programming to achieve the least possible transport costs. Difference between models is different methods (heuristic approach versus full software optimization), when dropping dry ports out of the models. Other difference is different possible dry ports and seaports between different gravitational models.

The results of gravitational models show that the cost-efficiency of transport system can be enhanced by implementing dry port structure to Finnish transportation network. With four to six dry ports the most cost savings can be achieved. By adding more than six dry ports, costs savings become very small i.e. gaining enough profit to cover possible investment costs of dry port (inland intermodal terminal connected to seaport by rail) will take many years with too many dry port solutions in the system. Surprising result is that unimodal road transport costs can be decreased significantly by using numerous seaports that cover the whole coastal of Finland. By using only one or two seaports, relative transport costs are relatively high. If all 50 largest Finnish cities (cities with no rail connection are excluded) are included, the total relative costs can be decreased. Decrease in costs is not much larger than in other gravitational models that have limited dry ports or seaports. It seems that by choosing possible dry port locations by heuristic approach in Finnish transportation network, the total relative transport costs can be minimized quite accurately. The main reasons for this are small number of appropriate cities that could be dry ports and centralization of Finnish population in the area of capital city.

The practicality of the results shown in this research work establishes a route for further research. For example, using numerous sea ports in decreasing overall emissions could be questionable in the future due to IMO's strict sulphur emission restrictions of sea vessels (e.g. Entec, 2010), which are mostly harmful for Finnish shipping industry (they are taken with the most strictness from in use in northern Baltic Sea). So, this would in turn restrict the use of low volume sea container sea ports. Besides emission control, another question arises from current level of capacity in smaller sea ports, and secondly their readiness to continue investments in the future. Similar lack of capacity and willingness of investing in future concerns selected railway based dry ports of entirely "flexible" optimization model. This does not only include arrangement yards, but terminals with appropriate railway yards, railway connections, loading/unloading places and lifts for container handling.

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