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Relative Technical Efficiency of European Transportation Systems

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ABSTRACT

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As economy grows also the amount transported goods increases. Transportation systems and their smooth functioning have a great importance for economic growth, and in future their role will still increase. In future a much more efficient holistic transportation system is needed; if we want conduct the traffic flows of future in a sustainable way. This thesis uses data envelopment analysis (DEA) as a method to evaluate individually the current relative technical efficiencies of three European transportation systems: rail, maritime and air.

Significant performance differences were found between the consistency of efficiency performances of transportation modes, when comparing railway companies, airlines and liner shippers in container shipping. Airlines are performing much more solidly and there are no big differences between the efficient ones and the inefficient ones. Railways show huge variations between different countries and also between different years within same company in relative technical efficiency. A brief examination of global liner shippers and their container shipping operations show also only little variation between the efficiencies. Ownership considerations of airlines strongly suggest that privately owned companies are significantly more efficient in operating their passenger services. On the freight operations there are no significant differences. The significant correlations between different models give some implications to transport policy planning. Such as, investments in passenger transportation on rail will improve the technical efficiency of rail operations in general as well as the passenger transportation by air.

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Talouden kasvaessa myös tavarankuljetusmäärät kasvavat. Kuljetusjärjestelmät ja niiden sujuva toiminta on erittäin tärkeää taloudellisen kasvun kannalta tällä hetkellä, ja se tulee olemaan yhä tärkeämpää tulevaisuudessa. Tulevaisuudessa tarvitaan kokonaisvaltainen ja selkeästi tehokkaampi kuljetusjärjestelmä, mikäli tulevaisuuden kuljetusvirrat halutaan hoitaa kestävästi. Tässä opinnäytetyössäni tutkin kolmen eurooppalaisen kuljetusjärjestelmän (rautatiet, lentoliikenne ja konttiliikenne meritse) suhteellista teknistä tehokkuutta ja menetelmänä on data envelopment analysis (DEA).

Vertailtaessa kuljetusjärjestelmiä löytyi suuria eroja kuljetusmuotojen välille. lentoyhtiöt suoriutuivat huomattavan tasaisesti eli tehokkaiden ja ei-tehokkaiden toimijoiden välillä ei ollut suuria eroja. Rautatiepuolella erot venyivät huomattavan suuriksi niin eri yritysten välillä kuin jopa saman yrityksen sisällä eri vuosina. Pikaisemmassa laivayhtiöiden tarkastelussa erot niiden välillä olivat lähes yhtä pieniä kuin lentoyhtiöiden välillä. Tarkasteltaessa omistajuuden vaikutusta lentoyhtiöiden toiminnassa huomattiin, että yksityisessä omistuksessa olevat yritykset olivat huomattavasti tehokkaampia matkustajien kuljettamisessa. Rahtipuolella merkittäviä eroja ei havaittu. Merkittävät korrelaatiot eri mallien välillä antoivat joitain viitteitä myös kuljetuspoliittiseen päätöksentekoon; investoinnit matkustajienkuljetuksiin raiteilla parantaisivat koko rautatiepuolen teokkuutta, mutta myös samalla lentopuolen matkustajakuljetuksen tehokkuutta.

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1 INTRODUCTION

1.1 Background

Transportation systems and their smooth functioning have been recognised to be important issues for economic growth, and their role will be increasingly important also in the future. European Union (EU) has also noticed the development and started to tackle its negative effects with a white paper on transport in 2001. Later transport policies were re-examined in 2006 with the mid-term review of the white paper. The original white paper tried search answers for the following challenges: (i) congestion of roads, (ii) environmental pressures and (iii) safety and life quality issues. The paper suggests that all these issues are derived from the link between transportation growth and economic growth. As the three remedies for breaking this link the white paper proposes the following actions: shifting the balance between transportation modes (e.g. from truck to rail), eliminating the bottlenecks in transportation, and place great emphasis on safety and quality issues in transport policy planning (European Commission 2001)

The mid-term review sees the problem of transportation in the EU zone as two-fold: EU-15 is suffering from road congestion and pollution, while accessibility is the main problem for many new member countries. The review also suggests that at the same time context of transport policy has evolved; globalisation (longer leads and bigger companies), surge in oil prices, more strict emission regulations (the Kyoto Protocol) and increased threat of terrorist attack are making the situation more complex (European Commission 2006). It is obvious that the logistics operators are the ones holding key to a well-working holistic transportation system. EU sees its role as the remover barriers and bottlenecks e.g. through increased funding on transportation in 7th Framework Programme for years 2007-2013. A clear shift in EU's attitude towards this problem has taken place: original white paper mentioned decoupling transportation demand growth from economic growth as its main objective. Midterm review does not mention anything about the goal of breaking the link between economic growth and transportation growth by e.g. moving traffic away from roads. (European Commission 2001; 2006)

From the previous paragraphs, we can conclude that in the future a much more efficient holistic transportation system is needed. Problem of transportation industry is that there has been and still exists very few global, or even continental, all-round logistics operators. During the last years global operators have been emerging through mergers and acquisitions. But whether this development shifts the modal split away from the congested roads depends on operational abilities of the alternative modes, particularly railways. This study concentrates on evaluating individually the relative technical efficiencies of two European transportation systems: rail and air. Also efficiency of maritime transportation is examined briefly through of container transportation efficiency of global liner shippers.

1.2 Research Problem

Research problem for this study is how efficiency of transportation systems has evolved, and which things have affected this development. To gain some information regarding the presented problem, three more specific research questions were formulated as follows:

- “How has efficiency developed in Europe during the investigated time period among the different transportation systems and countries?”,
- “Are there significant differences between the efficiencies of privately and publicly owned companies?” and
- “Does there exist increasing or decreasing scale inefficiencies?”.

1.3 Research Method

1.3.1 Methodical Considerations

The idea of measuring efficiency of European transportation systems itself limits the choice of methodology. First thought of technical efficiency measurement was using data envelopment analysis (DEA). Further on exploring the subject, another method that emerged from the technical efficiency measurement literature was the use of stochastic frontier analysis (Coelli 1996). DEA itself is very sensitive to errors in data, but stochastic frontiers and their production function have error correction term within. One advantage of DEA compared to stochastic frontiers is the fact, that it does not require specification of relation between inputs and outputs to be established (Cooper 2000). Of course the relation should be there, and its reasoning should be clear to the researcher applying the method.

One other limiting factor is the fact that this is master's thesis work and it should conclude the things I have learned during my studies. As I am not a mathematics student, assessing technical efficiencies of European transportation systems through stochastic frontiers would be far too mathematical considering my studies of logistics and industrial engineering. However, as I have studied basic course in linear programming utilisation DEA is justified in this context.

So, what is the used theoretical approach in this research? Neilimo and Näsi (1980) have identified four research approaches: nomothetical, conceptual, decision-oriented and action-oriented. Kasanen et al. (1993) presented the following classification (Figure 1) for the established research approaches, and added constructive approach to the framework (hereafter: framework A).

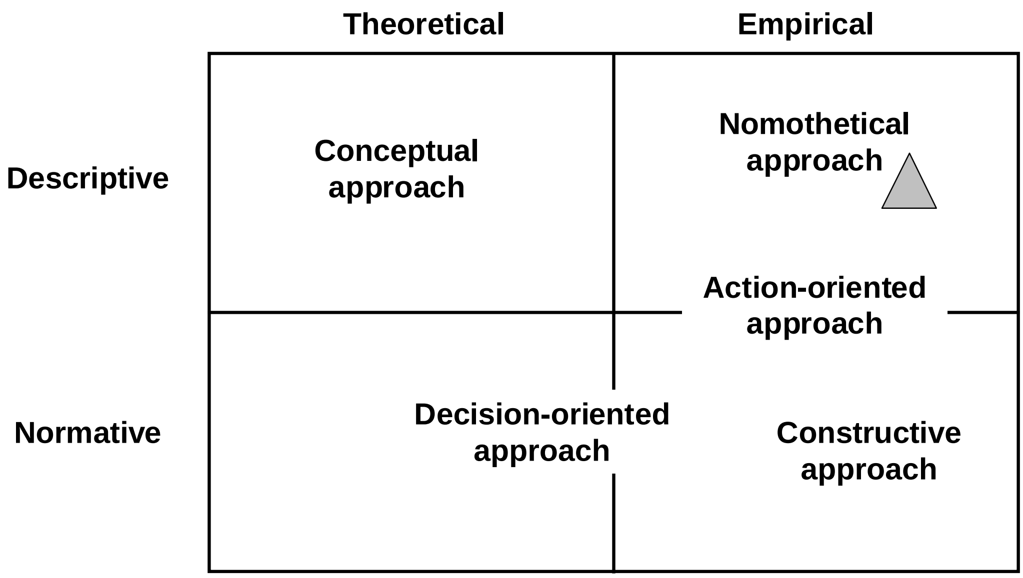

Figure 1. Research approaches classification framework A, and positioning of this study (Kasanen et al. 1993).

Conceptual research approach has been traditionally considered as the oldest one and as the name indicates this approach is pursuing to form and analyse concepts mainly by reasoning. Decision-oriented approach is aiming to create a method to solve a certain problem, and testing of a solution is made by proofing; possible empirical data is presented in form of an applying example. Action oriented approach is striving for understanding of the studied subject often through teleological explanatory models; empirical material is usually provided through only a few cases. Nomothetical approach is often considered as counterpart to action-oriented approach. The one definitive difference between these approaches is that when action-oriented approach aims to understand, nomothetical approach aims to explain. Additionally, nomothetical approach differs from action-oriented by having e.g. far greater empirical material, causality and objectivity. (Neilimo & Näsi 1980) Constructive research approach could be described as a step by step process within a specified framework which results in producing a solution to a real-world problem (Kasanen et al. 1993)

Arbnor and Bjerke (1997) have proposed another classification for research approaches. They came up with a framework which divides methodological research approaches into following three categories: analytical approach, systems approach and actors approach. In studies using the analytical approach the observed reality is considered as objective, rational and its structure to be independent of the observer. The actors approach is somewhat the opposite of the analytical, as its view on epistemology is more subjective and relativistic. The systems approach could be seen as an intermediate form of the two previously introduced approaches, and its characteristics are: holistic view on the observed phenomenon and its problem-oriented nature. In Figure 2 the framework (hereafter: framework B) is introduced with an additional dimension which adds the division between quantitative and qualitative research (Häkkinen & Hilmola 2005). This addition was first introduced "by Britta Gammelgaard in a Nordic logistics doctoral workshop in Copenhagen in January 2000" (Vafidis 2007).

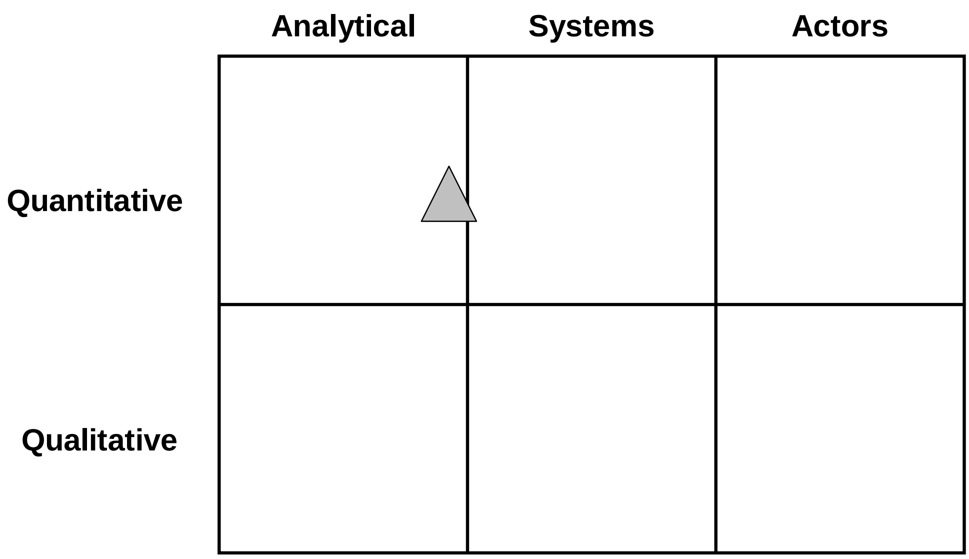

Figure 2. **Research approaches classification framework B, and postioning of this study (Arbnor & Bjerke 1997; adapted from Häkkinen & Hilmola 2005).**

Häkkinen and Hilmola (2005) examined the methodological pluralism of case studies in the field of logistics research by a sample of 114 academic journal articles published during 2000-2003. They used the same two previously presented frameworks. Within the framework A most of the research approaches were action-oriented (27 percent), nomothetical (23 percent), decision-oriented (22 percent) or constructive (20 percent). Only conceptual approach seems to be much more unusual (8 percent) in logistics case research than the other approaches. Vafidis (2007) examined in his dissertation Finnish and Swedish doctoral dissertations on logistics. His analysis of dissertations published during 1999-2003 had a sample of 29 and had somewhat similar division of approaches when the journal articles were classified according to the framework A: action-oriented approach was the most popular dominant research approach (28 percent) closely followed by nomothetical and decision-oriented approaches (24 percent both), while constructive (14 percent) and conceptual (10 percent) approaches were not as widely applied throughout the sample. Regarding the framework B, Häkkinen and Hilmola find that in total over 90 percent of logistics case research is made using the systems approach or analytical approach while actors approach is not widely applied. On the dissertations during 1999-2003 Vafidis (2007) finds the systems approach to be dominating very clearly (64 percent), and the analytic (28 percent) and the actors (24 percent) approaches have the rest of the share divided rather evenly. Both of the studies also reveal that recent logistics research has been both quantitative and qualitative, and not concentrated on either one of them.

On the basis of both the previous categorisations, one could argue that this particular research work falls into category of nomothetical research due to approach which tries to explain efficiency of transport systems from rather large empirical data. According on the latter framework B, this study could be classified as being quantitative and analytical, although it has some features of the systems approach. The used research approach is symbolised by a gray triangle in Figure 1 and in Figure 2. Furthermore, it can be stated that this particular research is conducted mainly by deductive reasoning coming down from theory towards confirmation, rather than building up new theory from observations and patterns by inductive reasoning.

1.3.2 Data Collection

Data of European railways and airlines were collected from official statistics of associations (International Union of Railways, UIC 2004; Association of European Airlines, AEA 2006), and so it could be said to be coming from the most reliable sources available. In railways the figures were also added up from company basis to country basis (i.e. if country had more than one railway operating company, their inputs and outputs were calculated together). Although remark could be made that not all the airlines are taken into consideration, but we believe that sample is very well representative, as the largest airlines from almost all European countries are represented. Data for analysis of container shipping efficiency was more complicated to collect, as availability of uniform data is very weak. Data had to be collected from two main sources: from Containerisation International Yearbook 2006 and annual reports of shipping companies. Data collection from annual reports proved to be very difficult, as not every company provided the data for separately container shipping.

1.4 Limitations of the Study

Study has limitations which are very much connected with the used research method. Data Envelopment Analysis (DEA) is very much limited by the fact that it is an extreme point method and possible mistakes in data can have major influence on the results. Data sets of railways and airlines are from reliable sources, but the data set of the third transportation system, container shippers, suffers from partly interpreted data from e.g. annual reports. This is because not all shippers review by their operations divided separately in bulk and container operations. As a result, data analysis of efficiency of container shipping withered to mere research remark, as data was collected from only one year and from varied sources. For future research of technical efficiency of container shipping, model should be build solely on non-financial data (inputs and outputs) or at least they should be strongly identified representing only container shipping. Of course the choice of method itself limits examination of efficiency to relative efficiency. Also the railways and airlines models are, as always, generalisations of the real world situation and it can be can be argued whether they give accurate enough view on efficiency of different operators in different transportation systems.

1.5 Structure of the Study

The study structured as follows: in Chapter 2 a general outlook is given on the three examined transportation systems and their recent development regarding deregulation is reviewed. In Chapter 3 DEA, the research method, is introduced by a brief literature review and illustrative theory examples. Empirical part of the study begins with Chapter 4 in which results of data envelopment analysis are presented in form of technical efficiencies and returns to scale of transportation systems. On railways technical efficiencies are found to be varying while airlines perform much more solidly. In Chapter 5 correlations between different models are examined, and some interesting connections are found. In the last chapter the main results of the study are gathered into conclusive remarks, and also some suggestions for the future research topics are presented.

2 TRANSPORTATION SYSTEMS

Transportation systems and modes are usually divided into three types by the surface they travel: land (road, rail and pipelines), water (maritime shipping) and air (aviation). This research concentrates on rail, maritime and air transport. Fourth main transportation system, road transportation, is excluded because it is would have been very troublesome to collect and analyse the data on company basis. This a consequence of the fact that most of the road transportation companies are small or medium sized, contrary to the other main transportation modes in the study.

Amount of transported goods in Europe has been growing annually for the last decade significantly faster than GDP (Figure 3). Situation has been different with passenger transport which also has grown, but slower than freight transportation and GDP even as fast as GDP.

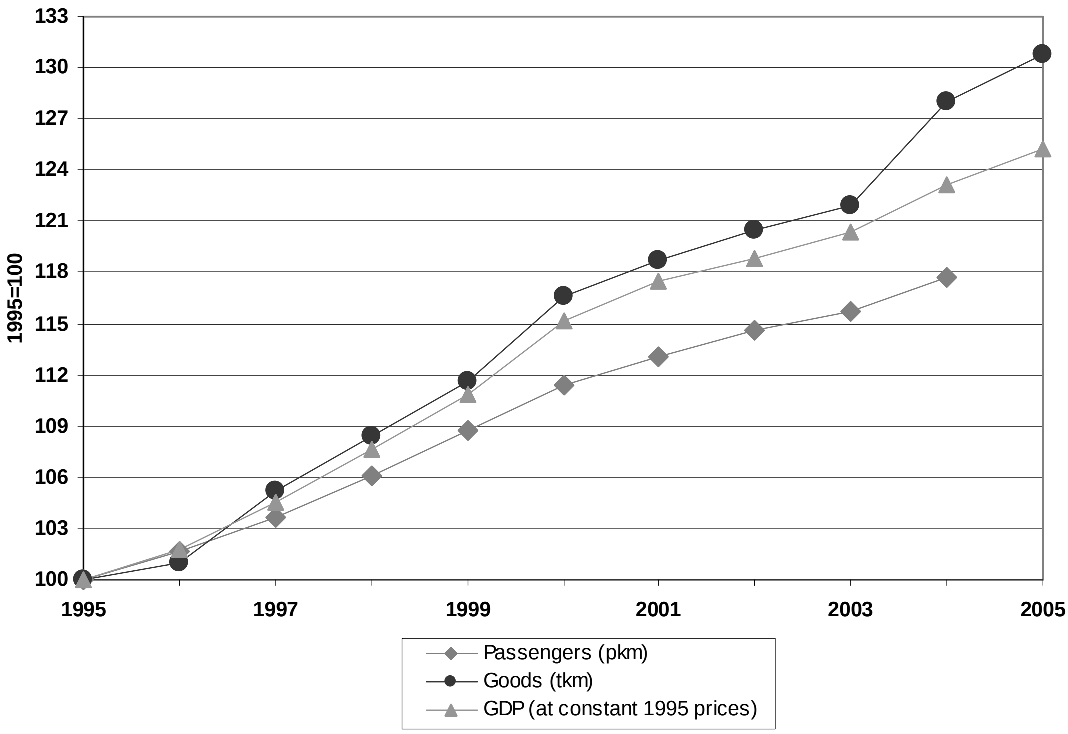

Figure 3. Transport growth in EU-25. (European Union 2007)

From Figure 4 we can see more clearly the before mentioned trend that when in comparison to GDP and its growth, freight transportation has grown substantially and passenger transport has declined.

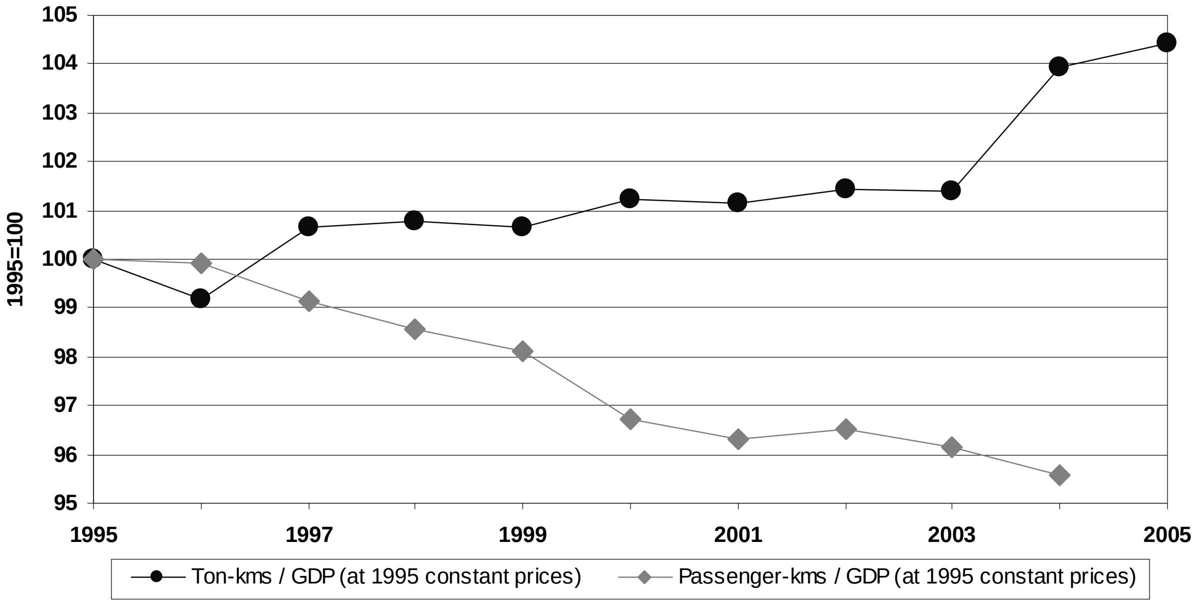

Figure 4. Transportation growth in comparison with GDP (European Union 2007, Eurostat 2007).

As we can see from Figure 5, during time period of 1995-2004 in Europe road and sea transportation have increased their, already very high, amount of transported goods and other modes have somewhat maintained their levels. So, we can conclude from Figure 5 that during last decade the amount of transported goods has grown significantly. Additionally, it can be stated that the growth has been almost solely down to road and sea transportation.

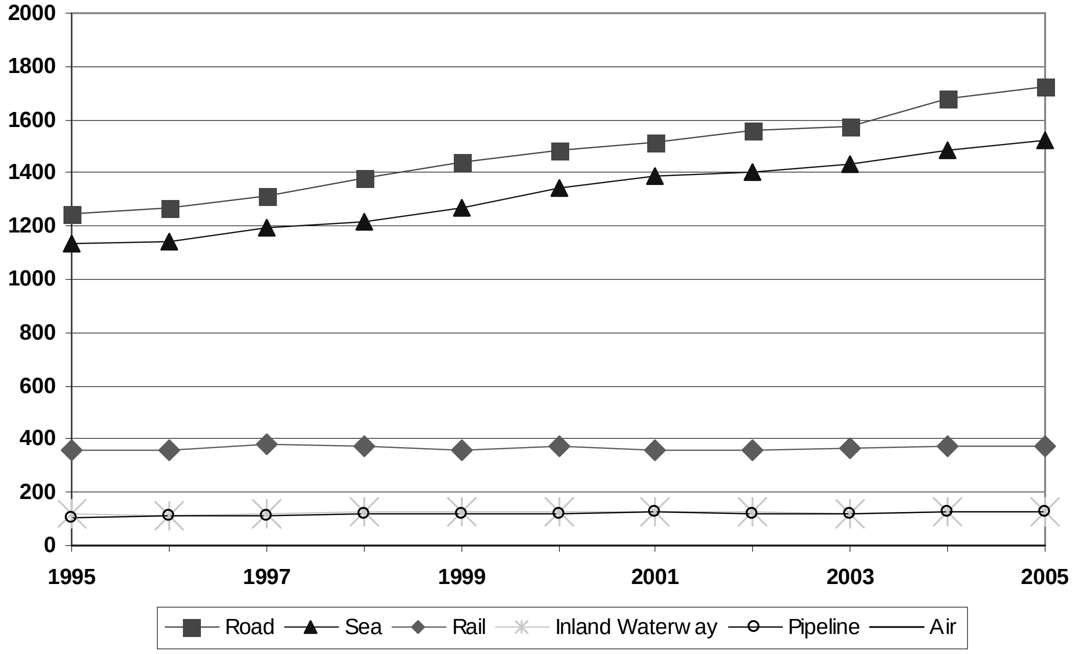

Figure 5. **EU-25 performance by mode for freight transport 1995-2004, billion tonne-kilometres. (European Union 2007)**

2.1 Rail Transportation

Rail transportation has been a product of industrial revolution and a vital part of economic development in Western Europe, North America and Japan since its full utilisation in the 19th century. It presented great improvement in land transportation as well as in transportation altogether. First time it was possible to move considerable amounts of goods relatively fast. It had already been possible to move heavy loads by maritime transportation, but the real breakthrough in transportation was the considerably improved travel time. (Rodrigue 2006)

Traffic on rail has some unique characteristics when compared to other kind of traffic. First of all, is the liability to the rails which enables, due to small friction, fast transportation of heavy loads with relatively small tractive power. Secondly, as the locomotives and the other stock are separate units, very long trains can be assembled, due to small friction and security devices. Thirdly, trains have to be shunted in a way that stock going to different destinations can not be connected to the same train. Also traffic control is a limiting factor due to the fact that only one train at a time can be on a track section. Lastly, trains are scheduled and so called tramping, similar to less physiographically restricted ships, is not taking place in rail transportation. (Mäkelä et al. 2005)

Rail transportation is characterised by a high level of economic and territorial control since most rail companies are operating in a monopoly (as mostly in Europe, although deregulation is somewhat progressing) or in an oligopoly situation (as in North America). The rest of the paragraph deals with some rather awkward characteristics of rail transportation. Firstly there is space consumption demand which is high when building stations and terminals (but not very high along the lines), especially in urban area. Secondly issues concerning gradient and turns. Rail transportation can support a gradient up 4%, but e.g. freight trains rarely tolerate more than 1% (meaning that an operational rail freight line requires 50 kilometres to climb 500 meters in altitude). For the turns, minimum of curvature radius is 100 metres, but radii of 1 kilometre for a speed of 150 kilometres per hour and 4 kilometres for a speed of 300 kilometres per hour. Thirdly, there is vast amount of different vehicles and cars, as well as two different locomotive types by tractive power (diesel, mostly for freight, and electric, mostly for passengers). (Rodrigue 2006) Lastly, there is the issue of gauge. The standard gauge (1435 millimetres) is dominating in most parts of the world, but there are difficulties especially between France and Spain (Table 1), Eastern and Western Europe, and between Russia and China. This is also limiting factor when considering utilising the Eurasian landbridge with its full potential. (European Union 2007; Rodrigue 2006) In Europe there are also problems with different signalling and electrification standards (see Table 1). For example, high speed train Thalys between Paris and Brussels had to be installed with seven different signalling systems. It is clear that this kind of variety in signalling systems adds up costs and breakdown risks as well as travel time. European Union (EU) is attempting to unify signalling standards with its ERTMS (European Rail Traffic Management System) which consists of GSM-R and ECTS. GSM-R is a system based on GSM standard and it is used to exchange information between trackside and on-board. ECTS is system, where a train-based computer controls the speed of train by train's current speed and by the tracks maximum permitted speed. ERMTS is slowed down especially by the long service life of existing signalling equipment. Investment and maintenance costs of ECTS are not significantly higher than for the current system (European Union 2005).

Table 1. Rail gauges and electrification in Europe (European Union 2007).

	Track Gauge	Electric current	
	mm	dc volts	ac volts
Belgium	1435	3000	25000 50Hz
Czech Republic	1435		15000 16,7Hz
Denmark	1435	3000	25000 50Hz
Germany	1435	800-1200 (contact rail)	15000 16,7Hz
Estonia	1524		15000 16,7Hz
Greece	600 1000 1435		 25000 50Hz
Spain	1000 1435 1668	1500 3000	 25000 50Hz
France	1000 1435	750-850 (contact rail) 1500	 25000 50Hz
Ireland	1600	1500	
Italy	1435	3000	
Cyprus	-		-
Latvia	1524		15000 16,7Hz
Lithuania	1524		15000 16,7Hz
Luxembourg	1435		25000 50Hz
Hungary	1435		15000 16,7Hz
Malta	-		-
Netherlands	1435	1500	
Austria	1435		15000 16,7Hz
Poland	1435		15000 16,7Hz
Portugal	1000 1668		 25000 50Hz
Slovenia	1435		15000 16,7Hz
Slovak Republic	1435		15000 16,7Hz
Finland	1524		25000 50Hz
Sweden	1435		15000 16,7Hz
United Kingdom	1435 1600 (N-IRL)	750 (contact rail)	25000 50Hz

The initial capital costs in rail transportation are very high, because the building and maintaining of rail lines is very expensive. This creates important entry barriers and therefore tends to limit the number of operators. The expensiveness together with long service life of rolling stock also delays the innovation, e.g. compared to road transportation. On the other hand, constructing rolling stock is not very expensive. For example, building simple freight wagons is relatively cheap. All in all, railroad companies need to invest about 45 percent of their operating revenues every year in capital and maintenance expenses of infrastructure and equipment. Capital costs alone account for 17 percent of revenues, when in manufacturing equivalent percentage is about 3-4 percent. Traditionally in Europe rail transportation, and especially passenger transportation, has been very important, but at the same time it has been declining over the last decades. In North America rail transportation is almost solely related to freight, with passenger side is playing only a minor role along major urban corridors. The impacts of globalisation on rail transportation, especially on freight transportation, can be divided as follows. At the macro scale, new long distance alternatives are emerging in the form of landbridges in North America, and between Europe and Asia. North American landbridge is already well utilised (Rodirigue 2006), and Eurasian Landbridge tries to follow the same path (see. e.g. Lee 2004; Vellenga & Spens 2006). At the meso scale it can be seen, that increasing number of countries are relying on foreign energy sources and therefore building major fuel transport arteries. Another trend is the integration between rail and maritime transportation systems. Overall, at the meso scale the key issue is concentrating the investments in shaping rail corridors. At the micro scale the railways are also concentrating more and more on container traffic. In future of railways intermodal transportation is a key issue. (Rodrigue 2006)

Technical changes of railways have not been very dramatic in rail transportation. Only more or less significant development has been the high speed (HS) passenger services which have been over average distances a viable alternative to even air transportation. HS traffic is traffic where the speed of the train exceeds 250 kilometres per hour at some point of the journey. France has been a pioneer with HS railways in Europe since the start of its TGV train operations in 1981. For example, 55,9 percent of its passenger traffic (in passenger-kilometres) was conducted by HS rail in 2004. In Europe (EU-25) the same figure was 21,5 percent. All in all, when measured by passenger-kilometres HS traffic in Europe has increased to five-fold from 1990 to 2004. Other technical improvements in rail transportation include variable wheel-base axles (to permit transport between different gauges), engineering of long tunnels and double-stacking of containers (at the moment only used in the US). (Rodrigue 2006, European Union 2007)

2.2 Maritime Transportation

Maritime transportation is the single most important form of transportation, e.g. it is carrying 96 percent of world trade in terms of weight, and it can be said that maritime shipping is one of the most globalised industries in the world. (Rodrigue 2006). In Europe ports handle over 90 percent of the trade outside European Union and 40 percent of intra-EU traffic. Additionally, 40 percent of the maritime shipping fleet is in European ownership (European Commission 2006b).

Maritime transportation very much rests on the existence of regular itineraries. Routes are most of the time few kilometres in width and trying to avoid discontinuities of land transport by linking sea ports. Maritime routes can be described as function of obligatory points of passage, of physical constraints (coasts, winds, reefs, marine currents, depth and ice) and of political borders. There are different maritime routes; e.g. pendulum routes which tend to be very flexible in terms of which ports are serviced and hence are very popular form of containerised maritime circulation, and feeder routes, on which feeder ships are converging cargo from smaller ports to a major hub. (Rodrigue 2006)

Ports are the point in the transportation system where goods transferred from land carriers to ships water carriers or vice versa. Also warehousing of goods is an important part of port operations. Karvonen and Tikkala (2004) have presented the following three different definitions of a port. Firstly, port can be seen as a physical area consisting of harbour area, fields, berths, and both waterways and transportation passages on land. By the second definition, port consists of the defined physical area together with all the buildings and machinery (warehouses, cranes and terminals). The third and the broadest definition sums the port definition as all the area, all the infra- and superstructure, and in addition all the services produced by organisations operating in port area. (Karvonen & Tikkala 2004).

Maritime freight is measured in deadweight tons (that is amount of cargo that can be loaded into empty ship) and it is usually considered in two categories. Bulk cargo is non-packaged dry or liquid freight; usually this kind of cargo is has a single origin, destination and client. Economies of scale can be achieved easily using bulk cargo. Break-bulk cargo refers to general cargo that is packaged using e.g. bags, boxes, drums or containers; usually this kind of cargo tends to have numerous origins, destinations and clients. Before containerisation economies of scale were difficult to achieve with break-bulk cargo. (Rodrigue 2006)

Development towards bigger vessels in size and capacity is driving the whole industry towards major transformations in vessel technology (twin engines and specialisation) and especially in port infrastructure development (deeper berths and improved handling systems) (Yang 2004, Rodrigue 2006). Most major maritime infrastructures involve maintaining or modifying waterways to establish more direct routes. This strategy is very expensive and undertaken only when necessary. Ports are heavy consumers of space because of their great need for transshipment capacity. Several technical innovations aiming to improve performance of ships and their access to port facilities have been introduced in the 20th century. Along with growth of the number of ships, also the average size of the ships has grown substantially. Every time the size of a ship is doubled, it can be said that capacity will triple. So, now the only remaining constraints in ship size are the capacity of ports, harbours and canals to accommodate them. (Rodrigue 2006). However, Stopford (2002) argues that the economies of scale in total transportation costs diminish beyond capacities of 3000 TEUs and become immeasurably low after 8000 TEUs. Furthermore, Stopford points out that there are significant diseconomies in dredging, congestion and redirecting the goods from ports. He also states that greater economies lie in replacing small and medium ships with ships in size class of Panamax and post-Panamax containerships. Smaller ships mean more flexibility which is traditionally greatly appreciated by the logistics operators (Stopford 2002). Conventionally, the average speed at sea has been 15 knots (or 28 km per hour), but nowadays ships can reach top speeds of 35 to 30 knots (45 to 55 km per hour). The challenge of reaching even higher maritime speeds excessively costly to overcome and it limits the future improvements in maritime speed (Rodrigue 2006).

Maritime traffic is almost exclusively concentrated on freight traffic; passengers are only a marginal leisure function serviced only by the cruise shipping. The systematic growth of maritime shipping is fueled by several things. First of all, increase in energy and mineral cargoes which has been derived from the growing demand of the developed economies, and also increase in importing raw materials to China. Secondly, containerisation has permitted marine transportation to still have economies of scale and low-cost status when compared to e.g. railways. Thirdly, technical improvements in ships (e.g. bigger container vessels) and maritime terminals have facilitated the flows of freight. Lastly, globalisation, along with international division of production and trade liberalisation, has also been an important factor in the growth of maritime transportation. (Rodrigue 2006). It should also be noted that the trend of building container vessels with larger capacities (see e.g. Mikkelsen 2006) is accelerating the already very competitive container transportation market even more (Yang 2004), and so the prices in the future at least maintain their competitive levels if not get even lower.

Different kinds of trends in container port concentration can be seen: in USA traffic is concentrating to fewer ports and in Europe traffic is getting less concentrated. In world scale the biggest container ports are nowadays concentrating to East and South-East Asia. This to a large extent is result of manufacturing moving to China and newly industrialised countries in Asia (Knowles 2006). In Europe the four biggest container handling ports have been since 1975 to year 2003 the same: Rotterdam, Hamburg, Bremen/Bremerhaven and Antwerp (Knowles 2006; see Table 2). If we examine overall biggest ports in Europe (Table 3); Rotterdam, Hamburg and Antwerp still are the major hubs. In fact, amounts of freight Rotterdam handles per year are two times the equivalent of Antwerp and three times the equivalent of Hamburg (European Union 2006).

Table 2. **Ten biggest ports in Europe by container traffic in 1000 TEUs (European Union 2007)**

Port, Country		1990	1995	1999	2000	2001	2002	2003	2004	change 04/03 %
Rotterdam	*NL*	3 667	4 787	6 245	6 268	6 102	6 526	7 107	8 271	+16,4
Hamburg	*DE*	1 969	2 890	3 750	4 281	4 684	5 401	6 140	7 003	+14,1
Antwerp	*BE*	1 549	2 329	3 614	4 082	4 218	4 777	5 445	6 064	+11,4
Bremen/B'h.	*DE*	1 198	1 524	2 201	2 752	2 974	3 032	3 190	3 469	+8,7
Gioia Tauro	*IT*		16	2 253	2 653	2 488	2 955	3 149	3 261	+3,6
Algeciras	*ES*	553	1 155	1 835	2 009	2 152	2 229	2 516	2 936	+16,7
Valencia	*ES*	387	672	1 161	1 308	1 507	1 821	1 993	2 145	+7,6
Le Havre	*FR*	858	970	1 378	1 465	1 523	1 720	1 985	2 132	+7,4
Barcelona	*ES*	448	689	1 235	1 388	1 411	1 461	1 652	1 916	+16,0
Dublin	*IE*	215		1 304	1 380	1 445	1 503	1 596	1 719	+7,7

Table 3. Ten biggest ports in Europe by amount of loaded / unloaded freight in million tonnes. (European Union 2007)

Port, Country		1970	1980	1990	1999	2000	2001	2002	2003	2004	change 04/03 %
Rotterdam	*NL*	226,0	276,0	288,0	299,5	320,0	313,7	320,9	327,0	352,8	+7,9
Antwerp	*BE*	78,0	82,0	102,0	115,7	130,5	130,1	131,6	142,9	152,3	+6,6
Hamburg	*DE*	47,0	63,0	61,0	81,0	85,9	92,7	98,3	106,5	114,5	+7,5
Marseille	*FR*	74,0	103,0	90,0	90,3	94,1	92,4	92,3	95,5	94,1	-1,5
Le Havre	*FR*	58,0	77,0	54,0	63,9	67,5	69,0	68,0	71,5	76,2	+6,5
Amsterdam	*NL*	21,0	34,0	47,0	56,2	64,1	68,3	70,4	65,5	73,2	+11,8
Algeciras	*ES*	8,0	22,0	25,0	41,9	44,0	49,0	51,3	56,8	61,3	+8,0
Grimsby & Imm.	*UK*			59,7	47,0	50,0	51,4	52,2	51,3	57,6	+12,3
Genova	*IT*	53,0	51,0	44,0	45,9	50,8	50,2	51,7	53,7	55,8	+4,0
Tees & Hartlep.	*UK*	23,0	38,0	40,0	49,3	51,5	49,7	50,4	53,8	53,8	-0,0

Most of the maritime freight (72,6 percent in ton-miles in 2000) is still bulk cargo, but the share of break-bulk cargo is steadily increasing, mostly because of containerisation. Technical improvements blur the division between bulk and break-bulk cargoes, as both can be unitised on pallets and also in containers. The amount of containerised freight has grown significantly, from 23 percent of all cargo in 1980, to 40% in 1990 and to 70% in 2000. The biggest drawback of maritime shipping is its slow speed. At the sea the speeds average 15 knots (26 kilometers per hour). There are also delays up to several days in ports where loading and unloading of ships is conducted. The strength of maritime shipping is clearly its large capacity and the continuity of its traffic. The average haul length of maritime transportation is even as much as 4200 miles which is e.g. about 10 times as much as the equivalent for rail transportation in Europe. (Rodrigue 2006)

Four general types of ships are employed around the world. Firstly there are passenger vessels which can be divided to passenger ferries and cruise ships. Second category is bulk carriers which carry either dry (typical size is from 100 000 to 150 000 dwt) or liquid bulk (typical size is 250 000 to 350 000 dwt). Traditionally general cargo ships have been less than 10 000 dwt in capacity, because of their very slow loading and unloading. Nowadays these vessels have been mostly replaced by much larger container ships which can also be loaded much more efficiently. Roll on-Roll off (RORO) vessels are designed to allow cars, trucks and trains to be loaded directly on board. The largest RORO vessels are used to transport cars from assembly plants to main markets. (Rodrigue 2006)

Maritime shipping is very capital intensive because of the expensive ships and port fees. Container shipping requires large fleet to maintain regular service, e.g. 14 ships in case of a typical Far East – Europe service. This poses a severe constraint to the entry of new operators. (Rodrigue 2006)

2.3 Air Transportation

Air transportation theoretically gives great freedom in choice of route. In practice the mode is much more constrained than one might suppose; air traffic has specific corridors which are used to facilitate navigation and safety. Also usually aircraft seeks to exploit (or avoid if "head wind") upper atmospheric winds and especially jet streams which allow enhancing speed and reducing fuel consumption. (Rodrigue 2006)

Maritime transportation mainly concentrates on freight services; the situation is vice versa in air transportation. Passenger services are major part of air transportation, but the amount of especially valuable cargo has been in growth. Some reasons for the growth are the entry of express freight companies into the market and especially the remarkable accumulation in use of their services (Varjola et al. 1999). Overall, in the last decade air transportation has grown annually 5 to 10 percent until the terrorist attack on 11th of September 2001 and the SARS epidemic in the late 2002, which both had a direct negative effect on growth for about a year (Airbus 2004; Boeing 2004). Since the Second World War quantities of shipped freight by air have increased remarkably. If we look the value of world trade, air transportation handled 7 percent of it in 1965, but in 1998 the figure was 30 percent, and already 40 percent in 2003 (Rodrique 2006).

International air traffic had significant growth after Second World War, until the oil crisis during the year 1973. Technical innovations have always played a focal part in development of air transportation; e.g. turboprop engine in the early 1950s, intercontinental jets, wide body aircraft and bypass jet engines in the 1970s. These innovations shortened travel time and increased capacity, in other words lowered costs per unit which eventually led to booming demand (Varjola et al. 1999). Rodrigue (2006) introduces also some other factors than the technical innovations, such as rising affluence, lower airfares and globalisation. The development in air transportation networks is proceeding towards major hubs around which traffic converges. Growth has also its problems; capacity of airports is not keeping up with the demand growth and it has lead to increasing amount of delayed flights (AEA 2003). Aircraft manufacturer Airbus is forecasting the growth on the passenger traffic to be annually 5,2 percent during time period of 2004-2023. Another aircraft manufacturer Boeing is estimating the growth on the freight traffic to be annually 6,2 percent in the time period in the time period of 2003-2023. If these forecasts become reality, the amount of traffic, both passenger and freight, will more than triple by 2023 (Airbus 2004; Boeing 2004).

Three main reasons to use air transportation to transport freight can be identified. First, there is the marketability of products is quickly expiring (e.g. some foodstuffs, living animals and plants, and products similar to newspaper). Secondly, air transportation is viable option when transportation costs represent only small part of total costs of the product (e.g. products that have to be on the markets quickly as possible, such as electronics and brand apparel). Thirdly, air transportation is a safe way, if not the safest way, to deliver the products to their destination (e.g. products that can not be exposed to wrong conditions during the transportation, such as pharmaceuticals and cosmetics or products that would dangerous in the wrong hands, such as pharmaceuticals). (Mäkelä et al. 2005)

Passenger transportation is very competitive business and the competition is getting tougher every year. It is easily understandable why airlines have always competed with price, because the fixed costs of airlines are high and the temptation of filling empty seats with discount pricing is huge (see e.g. comments by Warren Buffett, Edmonds 2003). This development together with raise of the fuel prices has led the industry to seek for new solutions and even new business models: hub-and-spoke, emergence of no-frills airlines and forming of alliances. Firstly, hub-and-spoke networks have emerged, and this has led to traffic to converge from smaller airports on certain larger airports. These hubs are usually situated along important routes, e.g. are located en route from east to west coast in USA (Rodrigue 2006; Knowles 2006). Second trend is emergence of no-frills airlines. No-frills airlines, or also known as low-cost carriers, aim to have as low cost structure as possible by removing all unnecessary services from its offering. The means by which no-frills airlines cut costs are various: flying only one aircraft type (lower maintenance), instead of hub-and-spoke flying point-to-point, using alternative airports and of course offering only the absolutely necessary services on flights. First successful utilisation of no-frills was by Southwest Airlines in the early 1970s in USA and by 1990 the no-frills wave reached also Europe in form of e.g. Ryanair and easyJet. Another trend in airline business is forming alliances. Alliances are used to gain access to new markets, achieve higher load factor and yield, defend current position in market by optimising seats and achieve economies of scale by combining resources. They also permit carriers that otherwise would be restricted by bi-lateral regulations to offer global coverage. Nowadays partners in alliances have also marketing cooperation (Rodrique 2006; Varjola et al. 1999).

In the world scale biggest passenger airports can be found from the USA (ACI 2006). Those airports, such as Atlanta and Chicago, have somewhat critical geographical location along either east/west or north/south traffic flows (Knowles 2006). In Europe major airports are located in countries with vast population, such as UK, Spain, France and Germany. Alone in the UK there is three major airports situated in London area: Heathrow, Gatwick and Stansted. Biggest non-domestic passenger flows in Europe are between UK and Spain (European Union 2006).

Like maritime shipping, airline companies are a very capital intensive segment of transport services. However, unlike in maritime transportation, air transportation is also labor intensive. Air transportation had total annual income of 320 US$ in 2000 and total economic impacts are estimated to be about 1300 billion US$ which accounts for 3,5 percent of world's GDP. (Rodrique 2006)

In the early days of commercial aviation, airlines were seen as means of providing a national air mail service in United States and of establishing long haul air services in United Kingdom and France to their colonies and dependencies. This trend of pursuing these national goals continued in the post-colonial period of the 1950s to the 1970s. In 1978 United States opened air industry to competition by Air Deregulation Act. After that the liberalisation process spread out to many other countries. Many firms that used to be heavily subsidised and protected went bankrupt or have been absorbed by larger ones. A key outcome of the airline deregulation has been the emergence of hub and spoke networks which are often dominated by a single carrier. Internationally, air transport still is dominated by bi-lateral agreements (e.g. regulation between US and EU). (Varjola 1999; Rodrique 2006)

2.4 Deregulation

In the past transportation systems were seen as a public service that had to be guaranteed for as many people as possible. Air deregulation act was introduced in the United States (US) in 1978 and as a result airline fares went down 30 percent in real terms between years 1976-1990 (Kahn 2006). Other clearly positive outcome in US that Kahn (2006) introduces was increase in productivity, when measured with increased seat fill rate while the average amount of offered seats on flights increased. After introducing these examples it is not surprising that governments around the world started to consider deregulation and privatisation as viable option for expensive-to-maintain publicly run services, such as transportation systems. A wave of transportation deregulation started in a bigger scale from United States in form of air deregulation act of 1978 and railways followed with Staggers act in 1980. Although it has to be mentioned that passenger operations in United States are still heavily subsidised (see e.g. Rhoades et al. 2006). Europe was somewhat lagging behind in transportation deregulation until late 1980s when some of the airlines and railways (United Kingdom and railways in Sweden) led the way.

2.4.1 Railways

EU has laid foundations of its rail reform in several directives[1]. Carbajo and Sakatsume (2004) summarised these directives having the following objectives: "(i) management independence for railway undertakings to operate on a commercial basis; (ii) the sound financial basis of all railway undertakings; (iii) the separation of infrastructure from operations; and (iv) access and transit rights to the rail infrastructure by independent operators".

The development is still behind of plans and objectives in most countries according to rail liberalisation index 2004 (IBM Business Consulting Services, 2004). The study was funded by Deutsche Bahn (DB). According to the index, DB is in schedule with its privatisation process, but reality is said to be somewhat different. DB is still, after many revisions in its pricing methods, accused of having favourable pricing for its subsidiaries compared to their competitors (Link 2004). In addition, Link (2004) states that in Germany there is not any regulative authority for the railway competition and

[1] e.g. EU directives 1991/440/EC, 1995/18/EC, 1996/48/EC and 2001/14/EC.

DB is still practically vertically integrated company. Other privatisations of state monopolies have not been without troubles, e.g. in Britain the process was thorough (infrastructure was also included in privatisation), but conducted rather hastily. Conducting complex process in a very short time ended up having mixed results: growth of traffic has been remarkable, investment on rolling stock is at record levels, and safety records have also been better than old British Railways ever accomplished, but at the same time there has been problems with getting infrastructure access charges set so that incentives of operating passenger franchises and the infrastructure manager Network Rail are aligned (Thompson 2004). Overall rail privatisation, at least on the freight side, has eventually become a successful one (Logistics & Transport Focus 2005).

Sweden has been much more conservative with its process, and still on-going privatisation is conducted with more planning and in smaller scale. Reform started with separation of accounting in 1985 and the actual separation of infrastructure from operations followed in 1988. At the moment there is free access to the Swedish railway market also for foreign operators for tendered passenger services and freight services. This market access consists of the right to organise rail traffic and of the right to operate trains. Foreign companies can apply for access on the condition that Swedish companies are given the same right to apply in their native country (reciprocity). Swedish companies have access to whole Swedish railway network to run freight services, while foreign companies from European Economic Area have the same access for running international freight services. (European Commission 2005) Sweden National Railways (in Swedish Statens Järnvägar, abbreviated SJ) is still at the moment having legal monopoly in passenger services on the routes it considers profitable, while often shorter and unprofitable routes are open for competition (Swedish Competition Authority 2004).

2.4.2 Shipping Industry

Shipping industry can be divided into two segments by the nature of the shipping they are conducting: there are liner shippers who have scheduled services and tramp shippers operate on spot deliveries. Liner shipping industry and its regulation is very different compared e.g. to the two other observed transportation industries. This is because the liner shippers have been since 1875 regulating self supply and setting prices in their conferences. This has been widely recognised practice in the past e.g. by the European Union (Benacchio et al. 2007); EU has only recently started to question the block exemption (EU regulation 4056/1986) which allows the conferences between liner shippers. The block exemption has been justified on the grounds that all of the four following cumulative conditions apply (European Union 2006): (i) the exemption should improve "the production or distribution of goods or promoting technical or economic progress", (ii) "consumers must be compensated for the negative effects resulting from the restriction of competition", (iii) exemption "must not impose on the undertakings concerned restrictions which are not indispensable to the attainment of its objectives" and (iv) "conference should remain subject to effective competitive constraints". EU has stated that these conditions do not apply anymore, and the conference system of liner shipping will be abolished. The regulation 4056/1986 is repealed, though some parts of it are still applied during the two-year transition period. Tramp shipping services have not been part of regulation since they have been operating on normal principles of supply and demand. (European Union 2006)

If port privatisation is defined broadly as all actions taken to raise the commercial orientation of port operations, it can be said that it has gained a lot of attention in the world's port industry during the last two decades (Cullinane et al. 2005). This development has been spurred by some encouraging examples of vastly growing private ports (e.g. Felixstowe in UK, see Baird 1999).

2.4.3 Air Traffic

In Europe the first phase of air transportation liberalisation started in 1980s with airline sector getting deregulated and some of the airlines were also privatised. Little by little barriers and regulations hindering competition between the airlines have been lifted. This has led to an increase and diversification of supply which led to lower fares and thus opened air travel for people who previously could not afford to fly. But this development has led to a situation where airlines are in difficult situation; air fare prices are getting lower and e.g. fuel price have been increasing in recent years. This development has lead to constant thrive towards better productivity and efficiency. As means for improving performance airlines have been forming alliances and using hub and spoke systems, as mentioned before. (Gerber 2002)

In the second phase also the airports are going towards privatisation, maybe inspired by the successful restructuring of British Airports Authority (BAA). Interestingly enough, in the United States most airports are still in governmental ownership and operation. (Oum et al. 2006) Infrastructure providers are turning as modern companies, and naturally at the same their business models are developing. Modern airports can get 50 to 70 percent of their revenues from non-aviation business. (Gerber 2002; Oum et al. 2006)

3 DATA ENVELOPMENT ANALYSIS

Data envelopment analysis (DEA) is a method to measure relative efficiency of different decision making units (DMUs) or producers based on their observed inputs and outputs. The most efficient producers have relative efficiency of 1 and others have figures between 0 and 1. There is a fundamental difference between traditional statistical approaches using regression analysis and DEA. The former reflects the average behaviour of the observations, while the latter deals with best performance, evaluating all performances from the efficient frontier line (Cooper et al. 2000). The basic ideas and concept definition of DEA were already introduced by Farrell (1957). On the base of his work, a linear programming model was developed by Charnes, Cooper and Rhodes (1978). Their paper is traditionally considered as the starting point of DEA. In this chapter, first, DEA as a method and two its most applied models CCR (named after Cooper et al. 1978) and BCC (after Banker et al. 1984) are introduced.

DEA has been applied in many fields of research, for example measuring efficiency of public institutions, such as senior secondary schools in Finland (Kirjavainen & Loikkanen 1998) and police in India (Verma & Gavirneni 2006). Other efficiency measurement applications include Portuguese hypermarkets (Barros 2006) and several banking industry cases (e.g. Kirkwood & Nahm 2006; Lim & Randhawa 2005). Nowadays also efficiency measurement of transportation using DEA has gained popularity among academics; some examples of applications are British bus industry (e.g. Cowie & Asenova 1999), Spanish airports (e.g. Martin & Roman 2001), European railways (e.g. Cantos et al. 1999 and Hilmola 2007) and North American container ports (Turner et al. 2003; Cullinane et al. 2005).

3.1 Example: Two Inputs and One Output Model

As introduction an example of simple DEA is presented. The following example consists of two inputs and one output, and it is slightly modified from Cooper et al. (2000). The inputs in this example are number of employees and shop floor area and the output is sales (Table 4). In Table 5 sales are unitised to 1, under the constant returns to scale assumption. This normalised data is used for graphical presentation of DEA. DEA efficiencies can be solved graphically when the model has in total three inputs and outputs or less.

Table 4. Example data.

Store		A	B	C	D	E	F	G	H	I
Employees (10)	x_1	8	18	8	16	10	10	18	22	18
Floor area (1000m^2)	x_2	6	9	1	8	20	4	12	10	8
Sales	y	2	3	1	4	5	2	3	4	3

Table 5. Normalised example data.

Store		A	B	C	D	E	F	G	H	I
Employees (10)	x_1	4	6	8	4	2	5	6	6	6
Floor area (1000m^2)	x_2	3	3	1	2	4	2	4	3	3
Sales	y	1	1	1	1	1	1	1	1	1

In Figure 6 the normalised example data is plotted into a diagram. Because axes are plotted in form of input x_1 and x_2 divided by output y, this is a graphical representation output oriented DEA. From efficiency point of view, DMUs using fewer inputs per 1 unit of output are, of course, identified as more efficient. Graphically, the efficient DMUs are the ones that can be connected to each other so that all the other DMUs are enveloped within those connecting lines (see Figure 6). This area can is commonly called production possibility set, but more accurately it should be called piecewise linear production possibility set assumption, because it is not guaranteed that the true frontier is piecewise linear (Cooper et al. 2000).

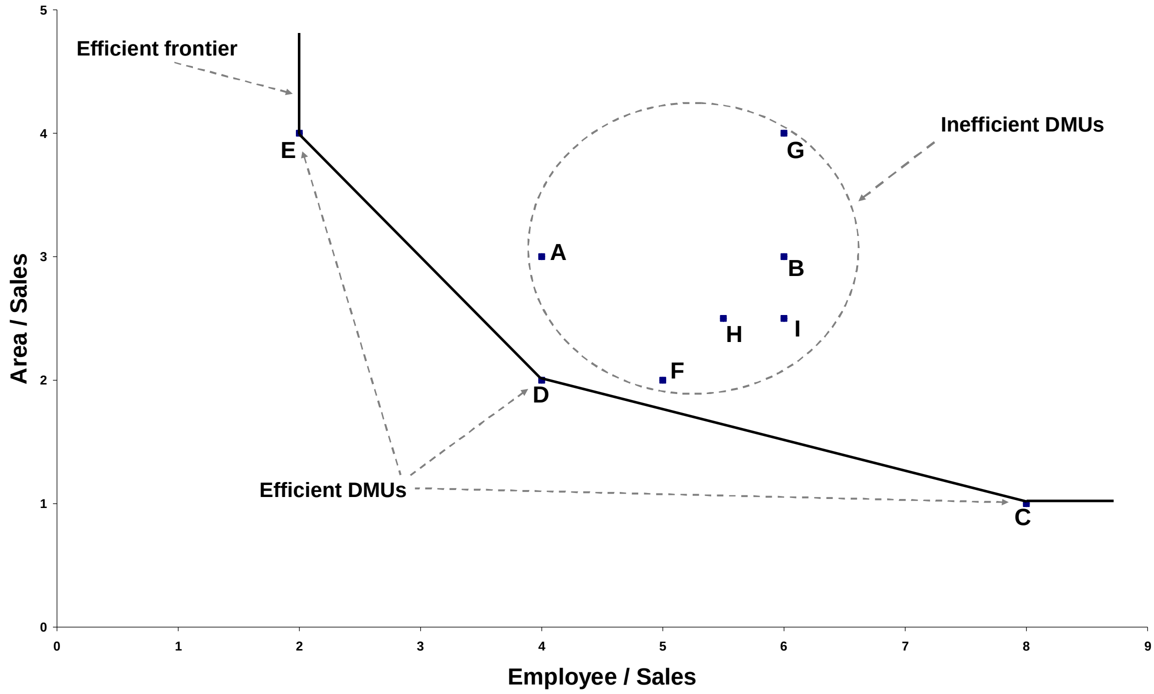

Figure 6. Graphical presentation of normalised example data

With these simple DEA models (total of three or less inputs and outputs) it is also possible calculate the efficiencies of inefficient producers geometrically from figure. For example, efficiency of store A is the following, when calculated geometrically (see figure 3):

$$\frac{OP}{OA} = 0{,}8571.$$

As P is on connecting line between D and E (Figure 7), inefficiency of A is evaluated by a combination of these two points; in other words, D and E are reference set for A. The reference set can be different from store to store, e.g. it can be seen from figure 2 that reference set for F consists of C and D. Many stores are around D, in comparison with other efficient stores C and E; and hence it can be said that D is representative and C and E have more unique characteristics in their association with segments of the frontiers that are far away from any observations. There is room for improvement for the inefficient stores. For example A can improve by moving to P, by reducing both inputs; also by reducing only sales area (A_1) or personnel (D) A has possibility to be efficient. Of course increasing output and keeping inputs at the same level would be another route to efficiency improvements (Cooper et al. 2000).

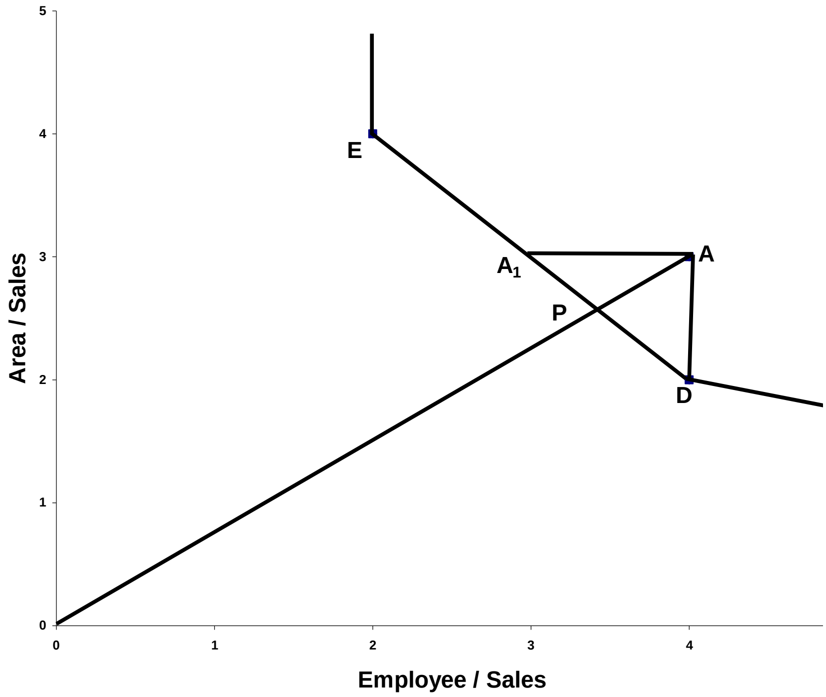

Figure 7. Inefficiency and possible improvement of store A

3.2 Constant and Variable Returns to Scale Models

The basic idea of CRS model is to assume constant returns to scale (hence the name CRS, or alternatively CCR by the authors), so that change in any product combinations is scaled up or down proportionally. Mathematically DEA is conducted by maximising the ratio of virtual output and virtual input using linear programming (LP). The basic multiplier form of CRS LP model which seeks to maximise outputs, is the following (adapted from Cooper et al. 2000):

$$
\text{(1)}\quad
\begin{aligned}
&\text{maximise} && \theta = \sum_{r=1}^{s} \mu_r y_{ro} \\
&\text{subject to} && \sum_{i=1}^{m} v_i x_{io} = 1 \\
& && \sum_{r=1}^{s} \mu_s y_{sj} - \sum_{i=1}^{m} v_m x_{mj} \le 0 \\
& && \quad (j = 1, \cdots, n) \\
& && v_1, v_2, \cdots, v_m \ge 0 \\
& && \mu_1, \mu_2, \cdots, \mu_s \ge 0
\end{aligned}
$$

Where

$\theta =$ sum of virtual outputs

$x_{ij} =$ amount of input *i* used by DMU *j*

$y_{rj} =$ amount of output *r* produced by DMU *j*

$v_i =$ weight of input *i*

$\mu_r =$ weight of output *r*

$n =$ number of DMUs

Subscript *o* refers to the DMU whose efficiency is calculated.

The above model is solved *n* times, so relative efficiency for each DMU is determined. This is a basic DEA model, but there are many different DEA models, such as input and output oriented models, and their different formulations. With more complicated models it is possible to calculate slacks for the DMUs. The slacks can be used in input oriented model to determine the needed reduction per input for the inefficient DMUs to become efficient. Oppositely, output oriented model determines the amount of needed increase in outputs for inefficient DMUs to become efficient. Multi-stage calculation of DEA can also define set of peers (reference set) with similar mix of outputs and inputs for each DMU. (Coelli 1996)

By contrast to CRS model, VRS model allows variable returns to scale (hence the name VRS, or alternatively BCC by the authors) and is graphically represented by piecewise linear convex frontier. From the envelopment form (dual of the multiplier form) of CRS model can be modified as the VRS model. The dual multiplier form of the input oriented VRS model can be formulated as following linear program (Cooper et al. 2000):

$$
\begin{aligned}
&\text{maximise} \quad && z = uy_0 - u_0 \\
&\text{subject to} \quad && vx_o = 1 \\
& && -vX + uY - u_0 e \leq 0 \\
& && v \geq 0,\ u \geq 0, \quad u_0 \ \text{free in sign}
\end{aligned} \tag{2}
$$

Where z and u_0 are scalars, and latter can be positive or negative (or zero). Model differs from CRS only in the adjunction of the condition $e\lambda = \sum_{j=1}^{n} \lambda_j = 1$. Together with the condition $\lambda_j \geq 0$, for all j, this imposes a convexity condition on allowable ways in which the n DMUs can be combined.

With VRS assumption there is more efficient DMUs, because the frontier is fitted through more points than by using CRS assumption. This leads to higher overall efficiency. This can be rationalised by a graphical example of one input and one output model (Figure 8): distance to frontier shortens or is the as before, and there efficiency is higher or at least in the same level. As we can see from Figure 8, A and B are operating within increasing returns to scale part of production function, and D, E and F are operating in decreasing returns to scale area. But as we are assuming VRS, points A, B, C and D are efficient, and thus they are perceived having constant returns to scale. This means that only E and F can be said having really decreasing returns to scale.

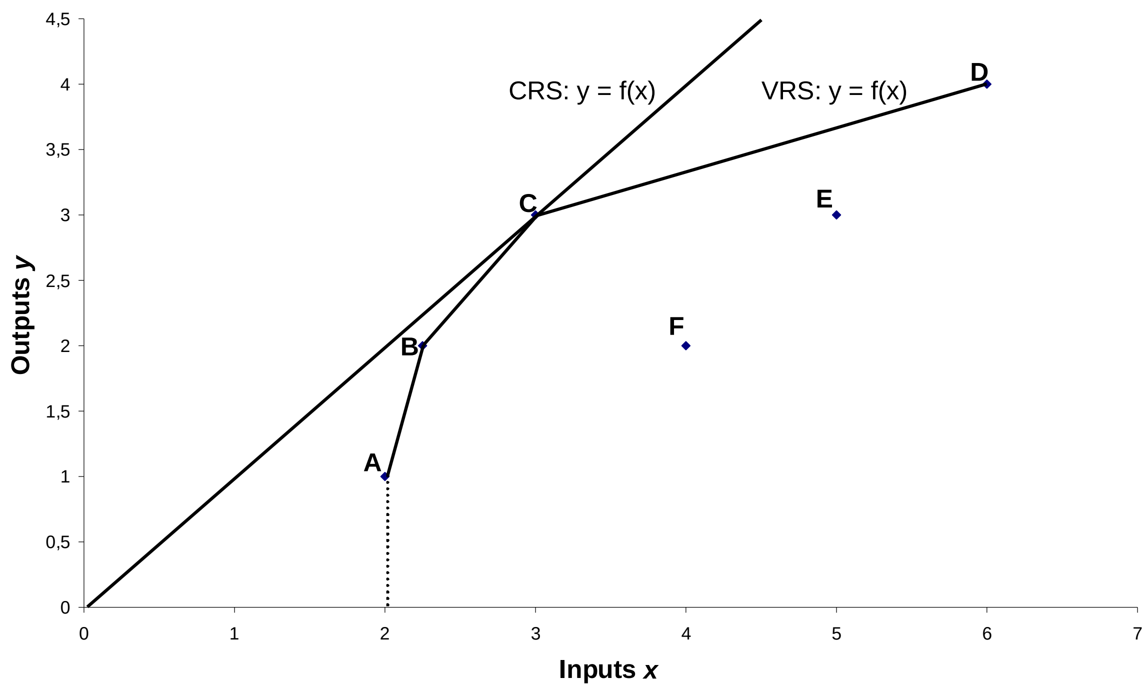

Figure 8. Example of returns to scale: one output and one input

As DEA is conducted by linear programming (LP), it is possible to use any program that can solve LP models e.g. MS Excel Solver. Nevertheless, it is more convenient to use programs solely dedicated to solving DEA and easily available and comprehensive options, e.g. choosing between orientation and type of DEA. In this study a program called Data Envelopment Analysis (Computer) Program (DEAP[2]), developed by Tim J. Coelli, was utilised for calculating the efficiency scores. Calculations were made with both CCR and BCC models, and technique applied was multi-stage DEA, where multiple radial LPs are solved to identify the efficient point. Multi-stage DEA is more computationally demanding, but using it has benefit of identifying the reference set of DMUs (Coelli 1996).

[2] Software is available at URL: http://www.uq.edu.au/economics/cepa/deap.htm (Retrieved: 15.Mar.2007).

The other freeware program developed to calculate DEA efficiencies, EMS[3], is a bit different to DEAP when considering the output of results from the programs. EMS presents just the results, weights, peers (*benchmarks* in EMS) and slacks, while DEAP outputs also input or output targets, regarding on the used model. These targets allow the examination of how much inefficient DMUs have decrease inputs or increase outputs to be on the efficiency frontier. EMS' in turn presents the calculation of super-efficiency which allows the comparison between the efficient ones. The basic idea behind the super-efficiency is that the examined efficient DMU is excluded from the reference set and a new efficiency frontier for the remaining group is calculated. After that the efficiency score of the excluded DMU is calculated on the basis of the new frontier; the score is over 1 (Andersen & Petersen 1993).

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[3] Software is by Holger Scheel and available at URL: http://www.wiso.uni-dortmund.de/lsfg/or/scheel/ems/ (Retrieved: 28 Apr 2007).

4 DEA OF EUROPEAN TRANSPORTATION SYSTEMS

In this chapter we are trying to examine the relative technical efficiency of different European transportation systems by using data envelopment analysis. The used DEA models for calculations are multi-stage, input oriented CRS models; the exception being maritime shipping where both CRS and VRS scores are included. Traditionally, research has concluded transport sector having constant returns to scale (see e.g. Oum and Zhang 1997), and therefore it is justified to use CRS assumption in calculations of this study. Additionally, the returns to scale results are calculated revealing the possible scale efficiencies or inefficiencies. As mentioned before, the actual calculations of efficiencies were done with DEAP software.

4.1 DEA of Railways of European Countries

Rail transportation DEA is different to two other transportation systems DEAs because it was conducted with data consisting of different countries rather than companies. Data was collected from the database of International Union of Railways (UIC 2004) and that database also restricted the time period to the one that was used. The chosen time period is well justified because before 1994 there were many new countries established, but since 1994 Europe has not had so many new countries. There were some gaps in the data especially concerning United Kingdom.

4.1.1 DEA Railways models

Passenger and freight transportation DEA models consist of four inputs and two outputs. All the inputs and outputs are technical by nature, so possible effects of currency fluctuations are avoided. Freight model (Figure 9) is derived from the two freight DEA models[4] made by Hilmola (2007). The major difference between this particular model and Hilmola's, is that he used different models for both quantities (e.g. tons) and quantity-distances (e.g. ton-kilometers), when here both outputs are considered within same model. Also other railway models (Figure 10 and Figure 11) have similar structure to the freight model.

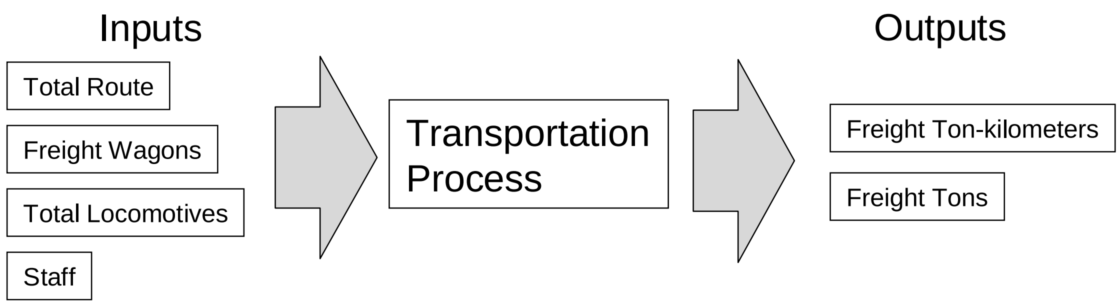

Figure 9. Railways freight DEA model

The chosen outputs were the freight tons and ton-kilometers. The used inputs for railways freight DEA model are total route (rail length) available in country, number owned freight wagons by the companies in the country, total number of owned locomotives by the companies in the country and the number of staff. The chosen outputs were the number freight tonnes and freight ton-kilometres.

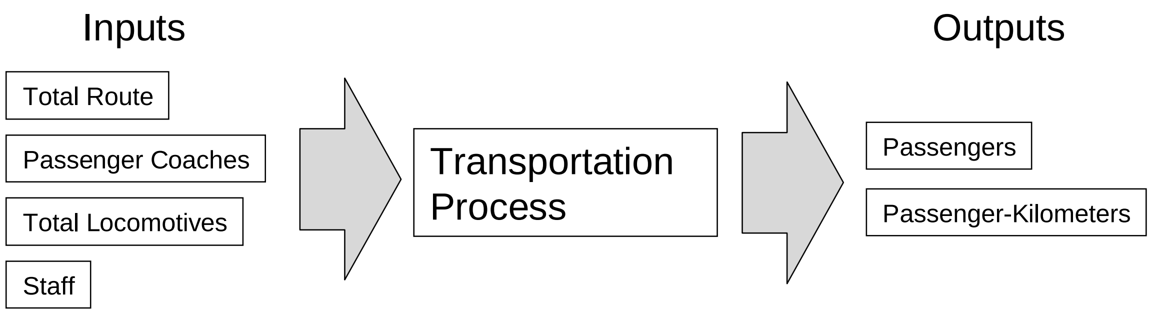

Figure 10. Railways passenger DEA model

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[4] In Hilmola (2007) one output model was used to enable partial productivity considerations in addition to DEA considerations.

Passenger model is very similar to freight model. The used inputs for railways passenger DEA model are total route (rail length) available in country, number of owned passenger coaches by the companies in the country, total number of owned locomotives by the companies in the country and the number of staff.

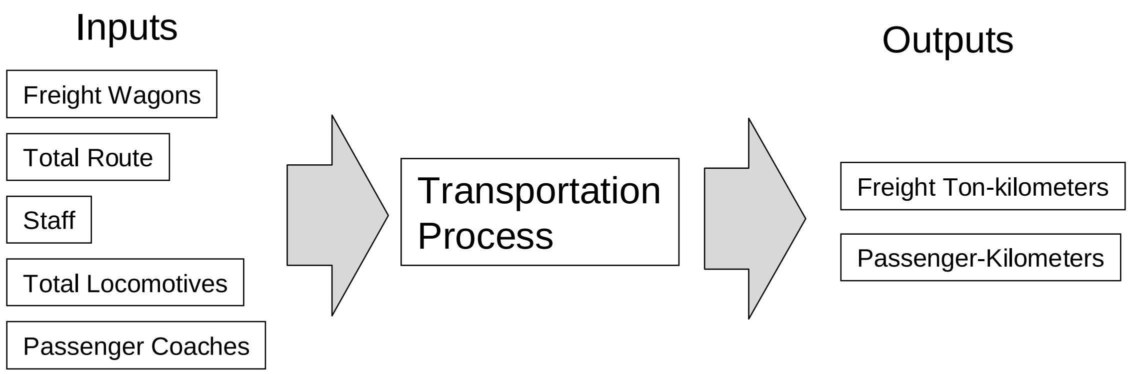


Figure 11. Railways grand DEA model

Also railways grand DEA model was created in order to evaluate the relative efficiency of countries when both railway operations are taken into consideration. It consists of all the three common inputs (staff, total route and total locomotives) and the other inputs (passenger coaches and freight wagons). Two outputs are quantity-kilometer based ones, freight ton-kilometres and passenger-kilometers.

4.1.2 Results of Railways DEA

The Table 6 shows the relative efficiencies of passenger transportation in different European countries throughout the years 1994-2002. From the results it can be seen that the efficiencies between countries vary very much. The only efficient countries in passenger transportation every year are Portugal and Netherlands. Also Denmark, Spain, Turkey, France and Ukraine perform rather well during the chosen observation period. From the first observation year 1994 to last 2002 Sweden has had tremendous performance improvement from 0,614 to 1. On the other hand some countries as Romania, Lithuania and also the well performing Turkey have had downward trend with their efficiency scores. Overall many East-European countries, such as Macedonia, Bosnia-Herzegovina and Estonia, perform very poorly in passenger transportation. Of East-European countries only Ukraine performs quite well and consistently.

Table 6. DEA (CRS) of railways passenger transportation 1994-2002

Country	1994	1996	1998	2000	2002	n
Austria	0,391	0,713	0,44	0,603	0,478	5
Belarus	0,827					1
Belgium	0,376	0,692	0,407	0,806	0,459	5
Bosnia-Herzegovina			0,437	0,038	0,077	3
Bulgaria	0,411	0,495	0,395	0,354	0,286	5
Croatia	0,189	0,475	0,188	0,255	0,366	5
Czech Republic	0,282	0,402	0,27	0,355	0,258	5
Denmark	0,815	0,856	0,964	1	1	5
Estonia	0,169	0,4	0,158	0,255	0,177	5
Finland	0,509	0,874	0,616	0,615	0,572	5
France	0,666	0,987	0,762	1	0,863	5
Germany	0,53	1	0,793	0,913	0,756	5
Greece	0,319	1	0,417	0,719	0,501	5
Hungary	0,278	0,353	0,375	0,448	0,41	5
Ireland	0,605	1	0,776	0,653	0,704	5
Italy	0,577	1	0,658	1	0,789	5
Latvia	0,33	0,658	0,299	0,219	0,257	5
Lithuania	0,356	0,59	0,217	0,194	0,175	5
Luxembourg	0,52	1	0,646	0,839	0,691	5
Macedonia	0,058	0,238	0,134	0,19	0,124	5
Netherlands	1	1	1	1	1	5
Poland	0,313	0,439	0,348	0,414	0,354	5
Portugal	1	1	1	1	1	5
Romania	0,515	0,695	0,392	0,409	0,284	5
Serbia-Montenegro	0,427		0,22		0,228	3
Slovakia	0,302	0,277	0,246	0,322	0,225	5
Slovenia	0,193	0,601	0,247	0,322	0,284	5
Spain	0,685	1	0,977	1	1	5
Sweden	0,614	0,882	0,828	1	1	5
Turkey	1	1	1	0,731	0,657	5
Ukraine	0,773	1	0,924	1		4
United Kingdom	1					1
avg	0,517	0,737	0,538	0,609	0,516	
n	31	28	30	29	29	

Returns to scale in passenger transportation (Table 7) show similarly large variation within countries and years, so clear trends of certain countries are difficult to point out. Though, it can be said that increasing returns to scale are dominating every year except 2002. This gives some room for merger speculation, as most of the companies are smaller than the efficient scale size.

Table 7. Returns to scale in passenger transportation (irs = increasing, drs = decreasing, - = constant)

Country	1994	1996	1998	2000	2002
Austria	irs	irs	irs	drs	drs
Belarus	drs				
Belgium	irs	irs	irs	-	irs
Bosnia-Herzegovina			irs	irs	irs
Bulgaria	irs	irs	irs	irs	drs
Croatia	irs	drs	irs	irs	irs
Czech Republic	irs	irs	irs	-	drs
Denmark	irs	irs	irs	-	-
Estonia	irs	irs	irs	irs	irs
Finland	irs	drs	irs	irs	drs
France	drs	drs	drs	-	drs
Germany	drs	-	drs	drs	drs
Greece	irs	-	irs	irs	drs
Hungary	irs	irs	irs	irs	drs
Ireland	irs	-	irs	irs	-
Italy	drs	-	drs	-	drs
Latvia	irs	drs	irs	irs	irs
Lithuania	irs	drs	irs	irs	irs
Luxembourg	irs	-	irs	irs	irs
Macedonia	irs	irs	irs	irs	irs
Netherlands	-	-	-	-	-
Poland	drs	irs	drs	irs	drs
Portugal	-	-	-	-	-
Romania	drs	irs	drs	irs	drs
Serbia-Montenegro	irs		irs		irs
Slovakia	irs	irs	irs	irs	irs
Slovenia	irs	drs	irs	irs	irs
Spain	drs	-	drs	-	-
Sweden	irs	irs	irs	-	-
Turkey	-	-	-	irs	drs
Ukraine	drs	-	drs	-	
United Kingdom	-				

In Table 8 relative efficiencies of freight transportation are presented. From the previous table it can be identified that some of the East European poor performers, especially the Baltic States, are drastically more efficient freight carriers than in running passenger operations. Alongside Estonia and Latvia, Luxembourg is also efficient in every year of the sample. Other very well performing countries are Sweden and Ukraine. The worst performing freight carrier is Greece, but Serbia-Montenegro, Macedonia and Croatia are also performing almost equally poorly. Overall, it can be said that the average efficiency of freight transportation on European railroads has a downward trend (1994: 0,563 à 2002: 0,418) which indicates that the efficiency gap between best performers and others has constantly expanded.

Table 8. DEA (CRS) of railways freight transportation 1994-2002

Country	1994	1996	1998	2000	2002	n
Austria	0,588	0,623	0,633	0,507	0,555	5
Belarus	0,9					1
Belgium	0,707	0,634	0,592	0,472	0,479	5
Bosnia-Herzegovina			0,638	0,224	0,488	3
Bulgaria	0,333	0,336	0,229	0,159	0,181	5
Croatia	0,209	0,212	0,217	0,148	0,193	5
Czech Republic	0,492	0,49	0,319	0,23	0,289	5
Denmark	0,55	0,535	0,603	0,637		4
Estonia	1	1	1	1	1	5
Finland	0,79	0,829	0,823	0,598	0,615	5
France	0,449	0,41	0,397	0,347	0,26	5
Germany	0,441	0,441	0,409	0,308	0,444	5
Greece	0,047	0,055	0,147	0,134	0,086	5
Hungary	0,262	0,304	0,344	0,277	0,288	5
Ireland	0,389	0,397	0,293	0,214	0,172	5
Italy	0,341	0,3	0,28	0,23	0,231	5
Latvia	1	1	1	1	1	5
Lithuania	0,935	0,826	0,692	0,582	0,678	5
Luxembourg	1	1	1	1	1	5
Macedonia	0,152	0,166	0,213	0,195	0,164	5
Netherlands	0,65	0,789	1		1	4
Poland	0,533	0,546	0,454	0,31	0,311	5
Portugal	0,497	0,499	0,463	0,381	0,333	5
Romania	0,303	0,405	0,247	0,179	0,136	5
Serbia-Montenegro	0,102		0,123		0,105	3
Slovakia	0,547	0,606	0,518	0,381	0,353	5
Slovenia	0,491	0,456	0,405	0,321	0,426	5
Spain	0,294	0,348	0,401	0,315	0,29	5
Sweden	1	1	0,909	1		4
Turkey	0,453	0,449	0,368	0,371	0,219	5
Ukraine	1	1	1	0,963		4
United Kingdom	1					1
avg	0,563	0,559	0,524	0,446	0,418	
n	31	28	30	28	27	

Returns to scale with freight transportation model are quite clearly divided in two groups (Table 9). Decreasing returns to scale in every year of the sample can be found from Austria, Belgium, Czech Republic, Finland, France, Germany, Hungary, Italy, Poland, Romania and Slovakia. The group with decreasing returns to scale could be argued as too big, as they are having scale inefficiencies. On the other hand increasing returns to scale in every year of the sample can be found from Croatia, Denmark, Greece, Ireland, Macedonia, Portugal, Slovenia and Turkey. These railways are having increasing returns to scale, and so in theory model suggests that if these countries would increase inputs, e.g. through merger and acquisitions, and they would get proportionally more outputs in return. In US mergers have been found to allow rail freight firms to utilise their track networks more efficiently, but having no effect on the overall technical efficiency (Chapin & Schmidt 1999).

Table 9. Returns to scale in freight transportation (irs = increasing, drs = decreasing, - = constant)

Country	1994	1996	1998	2000	2002
Austria	drs	drs	drs	drs	drs
Belarus	drs				
Belgium	drs	drs	drs	drs	drs
Bosnia-Herzegovina			irs	irs	irs
Bulgaria	irs	-	irs	irs	irs
Croatia	irs	irs	irs	irs	irs
Czech Republic	drs	drs	drs	drs	drs
Denmark	irs	irs	irs	irs	
Estonia	-	-	-	-	-
Finland	drs	drs	drs	drs	drs
France	drs	drs	drs	drs	drs
Germany	drs	drs	drs	drs	drs
Greece	irs	irs	irs	irs	irs
Hungary	drs	drs	drs	drs	drs
Ireland	irs	irs	irs	irs	irs
Italy	drs	drs	drs	drs	drs
Latvia	-	-	-	-	-
Lithuania	irs	-	irs	drs	irs
Luxembourg	-	-	-	-	-
Macedonia	irs	irs	irs	irs	irs
Netherlands	irs	drs	-		-
Poland	drs	drs	drs	drs	drs
Portugal	irs	irs	irs	irs	irs
Romania	drs	drs	drs	drs	drs
Serbia-Montenegro	irs		irs		irs
Slovakia	drs	drs	drs	drs	drs
Slovenia	irs	irs	irs	irs	irs
Spain	irs	irs	drs	drs	irs
Sweden	-	-	drs	-	
Turkey	irs	irs	irs	irs	irs
Ukraine	-	-	-	drs	
United Kingdom	-				

4.1.3 Overall Efficiency of Railways

Overall efficiency is measured with third model (previously presented in Figure 11) which tries to combine both passenger and freight transportation models into a one grand model. Results of railways DEA using grand model are gathered in the next table. From Table 10 we can see that there are four countries being efficient in every year. Those countries are Netherlands, Ukraine, Sweden and Latvia. Netherlands, Ukraine and Sweden are not exactly surprising results, as they were performing well using individual models, but Latvia certainly is. Latvia was one of the rather poorly performing East-European countries in passenger transportation with efficiency clearly below average. Bosnia-Herzegovina and Serbia-Montenegro are still, as one could add up from previous results, the most inefficient countries in rail transport. All in all, grand model levels a bit the differences between the performances of different countries.

Table 10. DEA (CRS) efficiency of railways passenger and freight transportation

Country	1994	1996	1998	2000	2002	n
Austria	0,561	0,855	0,607	0,721	0,563	5
Belarus	1					1
Belgium	0,589	0,7	0,576	0,799	0,609	5
Bosnia-Herzegovina			0,289	0,061	0,151	3
Bulgaria	0,466	0,495	0,419	0,358	0,337	5
Croatia	0,216	0,487	0,234	0,262	0,377	5
Czech Republic	0,428	0,502	0,383	0,381	0,291	5
Denmark	0,716	0,697	0,748	1		4
Estonia	0,959	0,869	1	1	1	5
Finland	0,844	1	0,921	0,807	0,784	5
France	0,754	1	0,85	1	0,913	5
Germany	0,584	1	0,865	1	0,867	5
Greece	0,319	1	0,432	0,758	0,524	5
Hungary	0,307	0,352	0,408	0,493	0,446	5
Ireland	0,634	1	0,724	0,781	0,732	5
Italy	0,68	1	0,758	1	0,814	5
Latvia	1	1	1	1	1	5
Lithuania	0,924	0,947	0,798	0,585	0,692	5
Luxembourg	0,436	1	0,444	0,493	0,398	5
Macedonia	0,086	0,264	0,202	0,242	0,172	5
Netherlands	1	1	1		1	4
Poland	0,51	0,785	0,536	0,495	0,449	5
Portugal	0,76	0,685	0,685	0,703	0,809	5
Romania	0,565	0,689	0,446	0,414	0,334	5
Serbia-Montenegro	0,427		0,233		0,284	3
Slovakia	0,475	0,557	0,488	0,46	0,41	5
Slovenia	0,421	0,71	0,458	0,421	0,393	5
Spain	0,72	1	0,996	1	1	5
Sweden	1	1	1	1		4
Turkey	1	1	1	0,755	0,791	5
Ukraine	1	1	1	1		4
United Kingdom	1					1
avg	0,657	0,807	0,650	0,678	0,598	
n	31	28	30	28	27	

4.2 DEA of Global Container Shippers

Global container shipping was chosen for analysed segment of shipping market. As the container shipping is very international business and only few of the big shippers are European, twenty biggest owners TEU slots in service were selected as data collection sample. After data collection twelve of these twenty could be taken into consideration for DEA. Data for the DEA model was collected from CI Yearbook 2006 and from the annual reports of shipping companies. Data collection was somewhat difficult due to the fact that for certain companies container shipping is only one part of their business and are not individually taken into consideration in e.g. staff announcements. With four companies in the sample e.g. we had approximate the number of staff in container shipping using percentage of container shipping turnover of total turnover.

4.2.1 DEA Global Container Shipping Model

DEA model (Figure 12) consists of three inputs and one output. All the inputs are technical by nature; the output is financial, due to difficulties in data collection. But in our opinion container shipping turnover represents accurately enough the amount of transported containers.

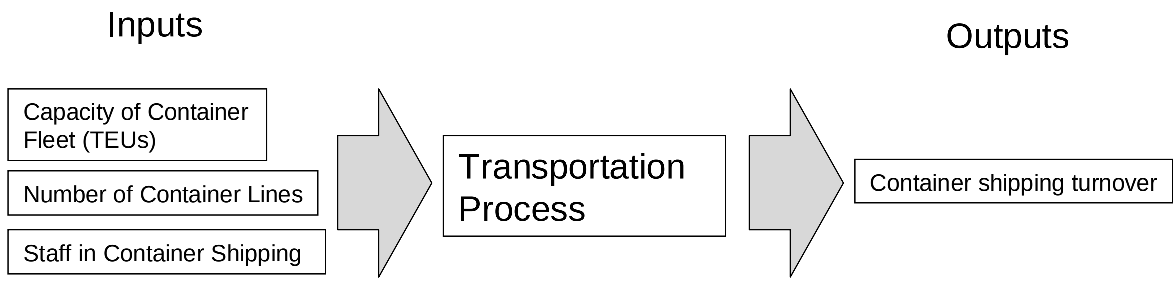


Figure 12. Global container shipping DEA model

Capacity of container shipping fleet, number of container lines and number of staff in container shipping were chosen as inputs; the before mentioned container shipping turnover was chosen as the output.

4.2.2 Results of Global Container Shipping DEA

Twelve companies is rather small, but adequate sample for DEA analysis. More importantly four of these companies (AP Moller Maersk Group, CMA CGM, Hapag-Lloyd (incl. CP Ships) and Hamburg Sud) are European. So we can compare these companies against their similarly sized competitors rather than their smaller European rivals. The results are presented in following Table 11.

Table 11. DEA efficiency of global container shipping (European companies in italic).

Shipper	crs	vrs	returns to scale
AP Moller Maersk Group	0,834	1	decreasing
APL	1	1	-
CMA CGM	1	1	-
CSAV Group	0,481	1	increasing
CSCL	1	1	-
Evergreen Group	0,627	0,628	decreasing
Hamburg Sud	0,986	1	increasing
Hanjin	1	1	-
Hapag-Lloyd (incl. CP Ships)	0,898	0,991	increasing
MOL	0,926	1	increasing
NYK	1	1	-
OOCL	0,872	0,967	increasing
avg	0,885	0,966	
n	12	12	

From Table 11 we can see that according to this model the biggest players in container shipping industry are performing rather well, with two exceptions. Those exceptions are Evergreen Group and CSAV Group. Between these two there seems to be one clear difference. As CSAV Group is having increasing and Evergreen is having decreasing returns to scale. In fact, Evergreen Group and the gigantic AP Moller Maersk Group are the only companies having decreasing returns to scale, and thus are having scale inefficiencies, because of their size. On the other hand CMA CGM is only efficient European company. Other efficient performers when using constant returns to scale assumption are NYK, Hanjin, CSCL and APL.

4.3 DEA of Airline Companies

In this subchapter efficiency of airlines for both passenger and freight transportation is measured with DEA models. Data was collected from database (AEA 2006) by the Association of European Airlines (AEA). In other words data was only available of AEA member airlines which fortunately are the most important ones, excluding Ryanair and the other no-frills airlines.

4.3.1 DEA Airline Models

Both passenger and freight transportation (Figure 13 and Figure 14) DEA models consist of three inputs and two outputs. Again, all the inputs and outputs are technical and non-financial by nature, to avoid the effects of currency fluctuations.

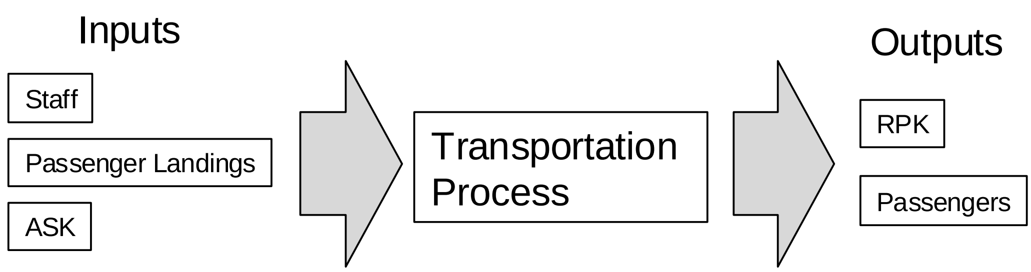


Figure 13. Airlines passenger DEA model

For the DEA model of passenger transportation three inputs chosen were staff, number of landings in passenger services and available seat kilometres (ASK) on all services. On the other hand, outputs were revenue passenger-kilometres (RPK) which is the number of carried paying passengers multiplied by the kilometres they fly, and number of carried paying passengers.

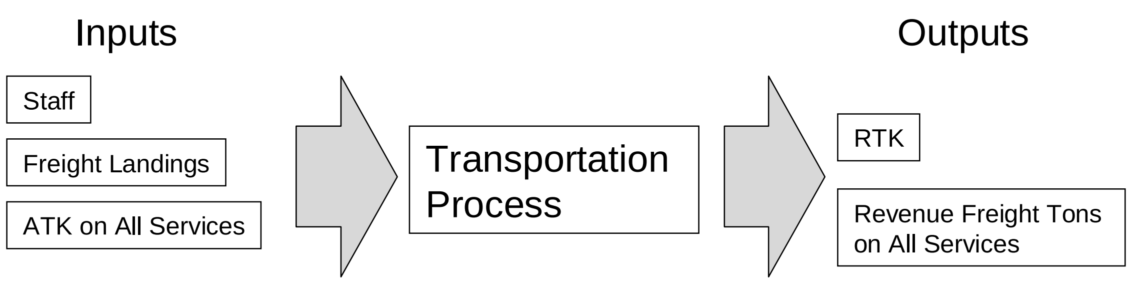


Figure 14. Airlines freight DEA Model

Freight DEA model has same kind of structure as the passenger model above. Inputs are again staff, number of landings on all-freight services and available tonne-kilometres (ATK) on all services. The two outputs were revenue tonne-kilometres (RTK) which is the amount of carried revenue earning freight tonnes multiplied by the kilometres they are carried, and number of carried revenue earning freight tons.

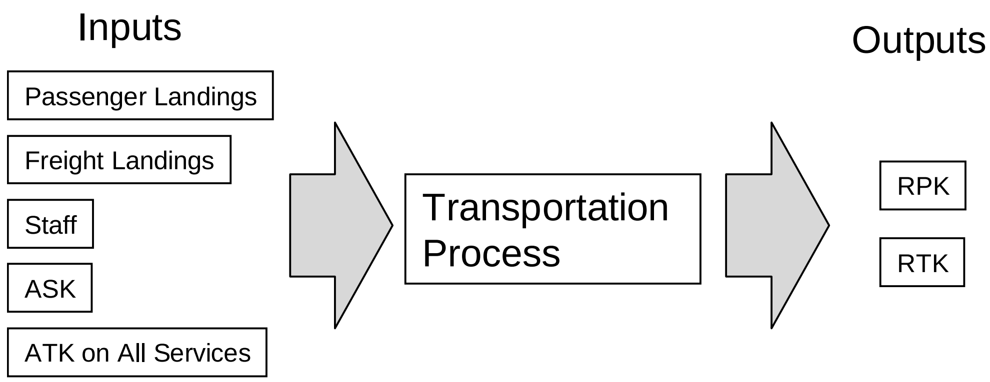


Figure 15. Airlines grand DEA model

In developing grand DEA model (Figure 15) we have tried conclude efficiency of both passenger and freight transportation. The model is based on outputs which are measured in quantity-kilometres (passenger-kilometres or tonne-kilometres).

4.3.2 Results of Airlines DEA

Table 12 shows DEA of passenger transportation from year 1996 to 2004. From the table it can be said that efficiency performance of the European airline companies has been very solid throughout the time period, e.g. compared to railway transportation. The best of all-round good performers clearly are KLM and bmi who are considered as part of the efficiency frontier in every year of the sample. Other clearly solid and above average performers are Iberia, Cyprus Airways, Turkish Airlines, Lufthansa, Air France and Alitalia.

Table 12. DEA (CRS) of airlines passenger transportation 1996-2004

Carrier	1996	1998	2000	2002	2004	n
Adria Airways	0,722	0,915	0,985	0,832	0,909	5
Aer Lingus	1	1	1			3
Air France	1	1	0,993	0,965	0,94	5
Air Malta	0,948	0,93	0,883	0,96	1	5
Alitalia	1	1	0,947	0,969	0,942	5
Austrian Airlines	0,814	1	0,864	0,926	0,946	5
Balkan Bulgarian Airlines	0,772	0,803				2
bmi	1	1	1	1	1	5
British Airways	1	1	0,941	0,915	0,937	5
Croatia Airlines		0,931	0,878	0,857	0,983	4
CSA Czech Airlines	0,866	0,862	0,904	0,96	0,93	5
Cyprus Airways	1	1	0,997	1	0,959	5
Finnair	0,895	0,932	0,831	0,899	0,873	5
Iberia	0,981	1	1	0,992	0,99	5
Icelandair	0,982	1	1	1	1	5
JAT Airways	0,788	0,701	0,796	0,84	0,768	5
KLM	1	1	1	1	1	5
LOT Polish Airlines				0,9	0,962	2
Lufthansa	0,969	1	0,994	0,993	0,978	5
Luxair	0,829	0,857	0,822	0,884	0,856	5
Malev Hungarian Airlines	0,796	0,854	0,831	0,853	0,889	5
Meridiana				1		1
Olympic Airlines	0,882	0,864	0,847	0,884	1	5
Sabena	0,793	0,914	0,959			3
SAS	0,898	0,916	0,911	1	0,975	5
SN Brussels Airlines				0,681	0,887	2
Spanair			1	0,972	1	3
SWISS				0,896	0,996	2
Swissair	0,879	1	1			3
TAP Portugal	0,889	0,931	0,945	0,91	0,923	5
TAROM Romanian Airlines			0,745	0,819	0,857	3
Turkish Airlines	1	1	0,984	0,952	1	5
Virgin Atlantic				1	1	2
avg	0,908	0,939	0,928	0,926	0,946	
n	25	26	27	29	28	

It can be seen from the efficiency comparison results above (Table 12) that there are some airlines in the market that are developing into more efficient direction, but some others show just opposite development. The passenger carriers with emerging technical efficiency are Adria Airways (steady growth until 2000), TAROM Romanian Airlines (had steady growth from 2000 to 2004) and CSA Czech Airlines (steady, but relatively slow growth in efficiency until 2002). It can be also noted that Belgian airline Sabena also improved its technical efficiency from 1996 to 2000 (0.793 à 0.959) until its bankruptcy in November 2001. Its successor – and former regional subsidiary – SN Brussels Airlines (known before as Delta Air Transport) first full year (2002) was not success in terms technical efficiency, but year 2004 showed that the direction however is right. Some of the bigger airlines, such as Alitalia, Air France and British Airways, had slightly decreasing efficiency towards the end of the examined time period. Although as noted before, overall their efficiency in passenger transportation was still on a very good level.

Passenger model additionally suggests that most of the bigger airline companies (e.g. British Airways, Air France and Lufthansa) have decreasing returns to scale (Table 13); unless they are having efficiency of 1. Then they are having constant returns to scale. From the decreasing returns to scale one could argue that these companies are too big and therefore scale efficiencies are diminishing. Of year 2004 it can be noticed that the percentile of companies with increasing scale efficiency has dropped 27 percent points (48% à 21%) from year 2002. Percentiles of companies with decreasing and especially constant scale efficiencies have grown substantially. This could indicate market getting more saturated, because more companies are using their resources more effectively, and those who are not, are considered too big (having decreasing returns to scale). But only with this one observation, not very certain conclusions can be made.

Table 13. Returns to scale in passenger transportation (irs = increasing, drs = decreasing, - = constant)

Carrier	1996	1998	2000	2002	2004
Adria Airways	irs	irs	irs	irs	irs
Aer Lingus	-	-	-		
Air France	-	-	drs	drs	drs
Air Malta	irs	irs	irs	irs	-
Alitalia	-	-	drs	drs	drs
Austrian Airlines	irs	-	irs	irs	drs
Balkan Bulgarian Airlines	irs	irs			
bmi	-	-	-	-	-
British Airways	-	-	drs	drs	drs
Croatia Airlines		irs	irs	irs	irs
CSA Czech Airlines	irs	irs	irs	irs	-
Cyprus Airways	-	-	irs	-	-
Finnair	irs	-	irs	irs	-
Iberia	drs	-	-	drs	drs
Icelandair	irs	-	-	-	-
JAT Airways	irs	irs	irs	irs	irs
KLM	-	-	-	-	-
LOT Polish Airlines				irs	drs
Lufthansa	drs	-	drs	drs	drs
Luxair	irs	irs	irs	irs	irs
Malev Hungarian Airlines	irs	irs	irs	irs	-
Meridiana				-	
Olympic Airlines	-	irs	irs	irs	-
Sabena	-	-	drs		
SAS	drs	drs	drs	-	drs
SN Brussels Airlines				irs	irs
Spanair			-	drs	-
SWISS				irs	drs
Swissair	-	-	-		
TAP Portugal	irs	irs	-	drs	drs
TAROM Romanian Airlines			irs	irs	irs
Turkish Airlines	-	-	drs	drs	-
Virgin Atlantic				-	-

The sample in DEA of freight transportation is much smaller than in passenger side, because some of the companies do not have any sole freight landings which are used as an input in this DEA model. Clearly the most efficient freight carriers are Cargolux, TAP Portugal and KLM (Table 14). Also Swissair and its successor SWISS were efficient where data was available. Former British Midland, bmi, was on the efficiency frontier in every year of the sample in the passenger transportation, but tables are turned in freight transportation efficiency; bmi is clearly the most inefficient freight carrier throughout the sample. Turkish Airlines had similar inefficiency problems in the early years of the sample, but the last two years were already somewhat efficient, possibly due to investments in infrastructure by government of Turkey (new international airport and new international terminal opened in the existing airport) and abandoning of several non-profitable routes (AEA 2002).

Table 14. DEA (CRS) of airlines freight transportation 1996-2004

Carrier	1996	1998	2000	2002	2004	n
Aer Lingus	1	1				2
Air France	1	0,883	0,896	0,909	0,89	5
Air Malta					0,772	1
Alitalia	0,973	0,9	0,886	0,889	0,881	5
Austrian Airlines	1					1
bmi	0,734	0,627	0,665	0,646	0,684	5
British Airways	0,995	0,915	0,898	0,903	0,878	5
Cargolux	1	1	1	1	1	5
Finnair	0,802	0,766	0,725	0,773	0,79	5
Iberia	0,862	0,775	0,777	0,786	0,821	5
Icelandair	0,928	0,825	0,74	0,818		4
KLM	0,993	1	1	1	1	5
Lufthansa	0,913	0,863	0,866	0,951	0,925	5
Sabena	1					1
SAS		0,792	0,985	1	1	4
SWISS					1	1
Swissair	1	1	1			3
TAP Portugal	1	1	1	1	1	5
Turkish Airlines	0,752	0,632	0,795	1	0,959	5
avg	0,935	0,865	0,874	0,898	0,900	
n	16	15	14	13	14	

If we examine efficiency development of freight carriers, few examples, in good and poor, can be pointed out. The ones categorised as good, would be the before mentioned Turkish Airlines and SAS which has had strong improvements in CRS efficiency since 1998. The poor performers in most of the years in the sample are Air France, Icelandair and especially bmi.

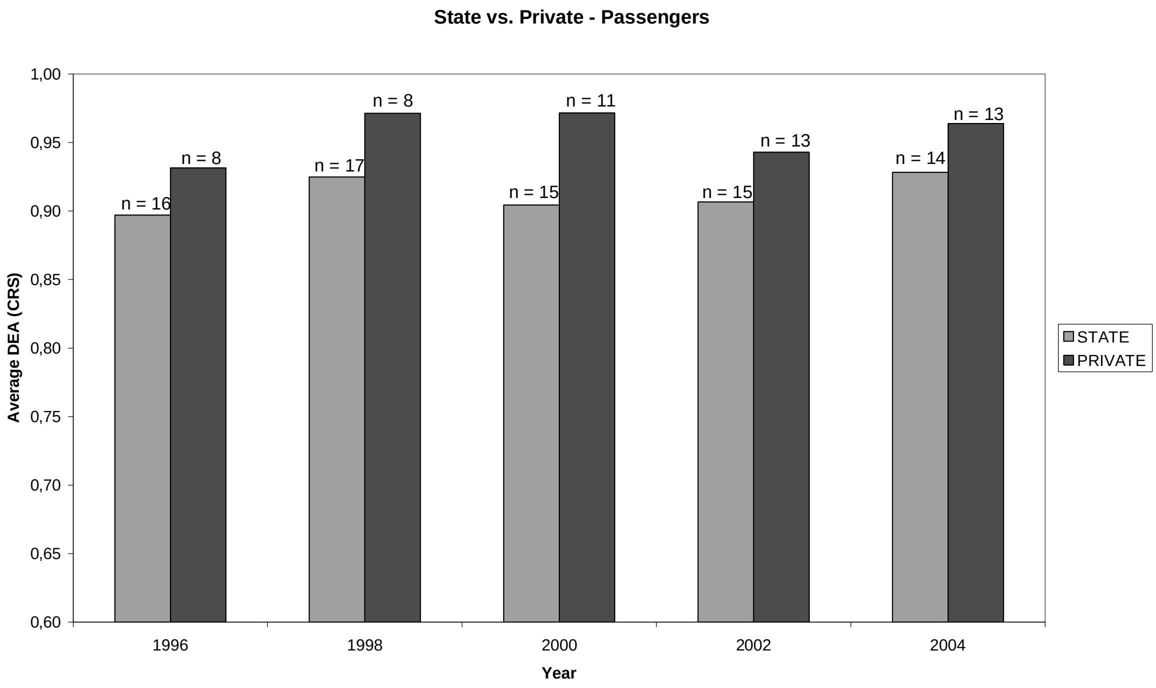
Also freight DEA model suggests that British Airways, Air France and Lufthansa have decreasing returns to scale. As Alitalia, bmi, Finnair, Icelandair and Turkish Airlines have increasing returns to scale on every year of the sample, there is clear evidence that their freight operations efficiency would benefit from new investments.

Table 15. Returns to scale in freight transportation (irs = increasing, drs = decreasing, - = constant)

Carrier	1996	1998	2000	2002	2004
Aer Lingus	-	-			
Air France	-	drs	drs	drs	drs
Air Malta					irs
Alitalia	irs	irs	irs	irs	irs
Austrian Airlines	-				
bmi	irs	irs	irs	irs	irs
British Airways	drs	drs	drs	drs	drs
Cargolux	-	-	-	-	-
Finnair	irs	irs	irs	irs	irs
Iberia	drs	irs	irs	irs	irs
Icelandair	irs	irs	irs	irs	irs
KLM	drs	-	-	-	-
Lufthansa	drs	drs	drs	drs	drs
Sabena	-				
SAS		irs	drs	-	-
SWISS					-
Swissair	-	-	-		
TAP Portugal	-	-	-	-	-
Turkish Airlines	irs	irs	irs	-	irs

4.3.3 Ownership Considerations

Due to airlines deregulation, it is interesting to examine if ownership of airlines would have difference on their efficiency performance. Airlines were divided into two groups, depending on their ownership; companies with over 50% private ownership are considered privately owned and the rest, of course, were considered state owned. SAS was left outside of this consideration, because its ownership is basically evenly distributed between private companies (50%) and Swedish (21,4%), Danish (14,3%) and Norwegian (14,3%) states.



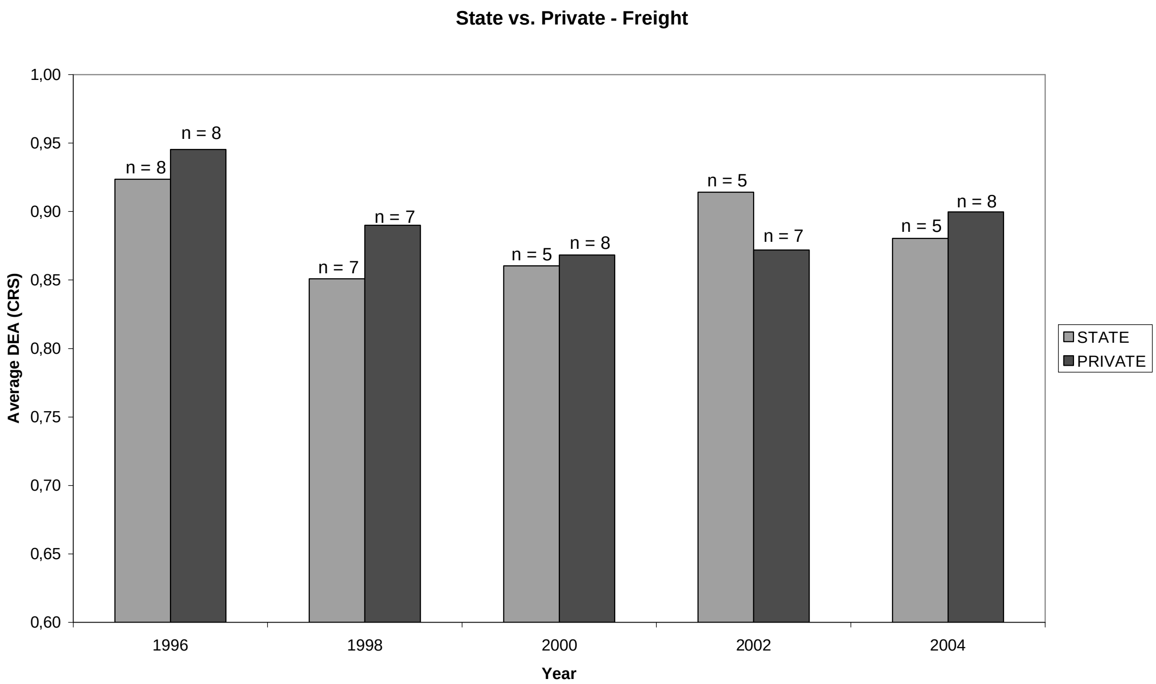


Figure 16. **Comparison of average technical efficiencies of passenger and freight transport between state and privately owned companies.**

From the previous Figure 16 it seems that the average passenger transportation efficiencies of the private companies are consistently higher than the ones of state owned companies. The same can not be said of the freight transportation, because state owned companies are more efficient in year 2002; although private companies are more efficient when looking only at the average of the all observations.

Statistical consideration whether private companies really have better efficiency was conducted by comparing average efficiencies of state and privately owned companies during the examined time period. Independent samples t-test is used, where sample is divided into two, assumedly independent, groups by their ownership structure. In Group 1 are the state owned companies and in Group 2 are the privately owned companies. Then t-test for equality of means of these groups is conducted with SPSS software and results of year 2000 are presented in Table 16 as an example. All the results from the tests can be found from Appendix 1. Before conducting the actual test, SPSS examined the equality of variances using Levine's test. Variances of groups could be assumed to be equal, as *Sig.* is bigger than 0,1. Difference between sample means divided by the standard error of the difference is *t* statistic represented in the table. Column *df* represents degrees of freedom which equals total size of sample minus two. *Sig. (2-tailed)* is a probability from the t distribution with 24 (and 11) degrees of freedom. The *Sig. (2-tailed)* value is the probability of obtaining an absolute value greater than or equal to the observed *t* statistic, if the difference between the sample means is purely random. Mean difference is the sample mean of Group 2 subtracted from the sample mean of Group 1 (SPSS 2005). Test was conducted at confidence level of 95 percent.

Table 16. Output table from SPSS. The independent samples t-test, year 2000.

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
PASS00	Equal variances assumed	1,988	,171	-1,939	24	,064	-,05742	,02962	-,1185	,00371
FREIGHT00	Equal variances assumed	,562	,469	-,113	11	,912	-,00785	,06941	-,1606	,14492

Since the significance values, *Sig. (2-tailed)*, in both passenger and freight transportation are bigger than 0.05 (1 – 0,95), it can be concluded that differences in means of two groups can be considered to be mostly due to chance, and thus not significant. The very same conclusions at confidence level of 95 percent are made concerning all the other observed years (1996, 1998, 2002 and 2004), and both freight and passenger side. When looking at the output from SPSS more thoroughly, we can see that the *Sig. (2-tailed)* for passenger transportation is 0,064. In other words, differences between means for passenger transportation in 2000 would be significant already at confidence level of 93,5 percent. So, we could conclude, that in year 2000 private airlines were performing better than state-owned airlines at confidence level of 93,5 percent. As we can see from results of other years (Appendix 1; also complete outputs from all the t-tests presented in this chapter can be found from there), confidence levels of passenger models from years 1998, 2002 and 2004 are also somewhat high (respectively 82,4 percent, 79,0 percent and 87,7 percent). So, some evidence of better performance in passenger operations by privately owned airlines in comparison with state owned airlines is provided.

In search of further support to the positive effect of the ownership of airlines regarding the technical efficiency, the same test was conducted for the whole sample. The results from the test are presented in the following Table 17.

Table 17. Output tables from SPSS. Independent samples t-test, all observations.

Group Statistics

	OWN	N	Mean	Std. Deviation	Std. Error Mean
PASS	state	77	,9122	,07831	,00892
	private	53	,9546	,06879	,00945
FREIGHT	state	30	,8873	,10662	,01947
	private	38	,8958	,11687	,01896

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
PASS	Equal variances assumed	2,596	,110	-3,185	128	,002	-,04240	,01331	-,06874	-,01606
FREIGHT	Equal variances assumed	,219	,641	-,309	66	,758	-,00848	,02747	-,06333	,04637

When examining the whole sample of passenger transportation, we found that *Sig. (2-tailed)* is 0,002 which indicates that the difference of means between these two groups is significant at confidence level of 95 percent; actually with that low figure of *Sig. (2-tailed)* difference would significant also at the confidence level of 99%. On the freight side of air transportation the efficiency differences are not significant, or even close to significant, on any of the previous tests.

4.3.4 Overall Efficiency of Airlines

When considering overall efficiency of carriers with these two separate DEA models of freight and passenger transportation, the best performer is KLM. KLM was part of efficiency frontier in every sample year on both freight and passenger side with one exception of freight efficiency in 1996, when it was still very good 0,993. Other well-performing companies in overall efficiency (number of years out of five when both freight and passenger transportation efficiency is over 0,9) are TAP Portugal (4), SAS

(3), Lufthansa (3) and British Airways (3).

To have more specific measure on the overall efficiency of the carriers a third model was created. The model (Figure) has two outputs and five inputs. So the model measures relative efficiency on quantity-kilometres basis. With this model we examined the efficiency in freight and passenger transportation in year 2004. Results are displayed in Table 18.

Table 18. DEA (CRS) efficiency of passenger and freight transportation in 2004

Carrier	crs	vrs	scale	irs/drs
Air France	0,946	1	0,946	drs
Finnair	0,927	0,927	1	-
Alitalia	0,94	0,994	0,946	drs
British Airways	1	1	1	-
bmi	0,886	0,917	0,966	drs
Iberia	1	1	1	-
KLM	1	1	1	-
Air Malta	1	1	1	-
Lufthansa	0,97	1	0,97	drs
SWISS	1	1	1	-
SAS	1	1	1	-
Turkish Airlines	1	1	1	-
TAP Portugal	1	1	1	-
avg	0,975	0,988	0,987	

As we can see from Table 18, this model seems to even up the differences, which already were relatively small, between airlines. The even smaller differences between the efficiencies are most likely a result of too many inputs and outputs for too small sample size. Most of the companies are on the efficiency frontier, regardless of returns of scale assumption (CRS or VRS). Results show that some companies are more inefficient than others, but it is very difficult to make any differences between the companies on efficiency frontier. As we can see, the ones that can be named as inefficient according to CCR DEA are bmi, Finnair, Ailitalia, Air France and Lufthansa.

5 DISCUSSION

5.1 Previous Research and Results of this Study

Technical efficiency of rail transportation has been evaluated rather sparsely using DEA and stochastic frontiers during last decade (e.g. Cantos et al. 1999, de Jorge & Suarez 2003, and Hilmola 2007). Cantos et al. examined the operations of 17 European railway companies during 1970-1995 and found the efficiency differences to be quite low between different companies; oppositely to our efficiency analysis in this study. Their other conclusions were that the most of the growth of productivity has been achieved during 1985-1995 and it was mostly due to technical progress. Hilmola (2007) examined the efficiency of rail freight transportation in Europe during 1980-2003. His conclusions were that the efficiency of some of the strong railways of 1980s (e.g. Hungary and Romania) declined drastically during the 1990s and new railway powers emerged, most notably Estonia and Latvia. Hilmola's findings are similar to this study for most of the parts; the most noteworthy exception is Sweden which performed much better in this study.

Measuring technical efficiency of airlines has been even more uncommon; only few articles could be found from journals, and most of them were rather old concerning the technical efficiency of US airlines (e.g. Alam & Sickles 2000). Schefczyk (1993) examined the operational efficiency of airlines from different parts of the world. The study had both passenger and freight operations covered, and even Federal Express as a pure freight carrier was included in the sample of total 15 companies. Schefczyk concluded that there is a correlation, but not very significant one, between the operational efficiency and profitability. He reminded that the result was expected, because it is possible to be operationally efficient and yet unprofitable. Good et al. (1995) have a bit different approach as they used both DEA and stochastic frontier analysis to make a very interesting comparison between technical efficiencies of the eight biggest airlines of both Europe and US. They found that during time period of 1976-1986 US airlines were much more efficient in passenger operations than the European companies. The fact that makes their findings interesting is that at the time US industry had already undergone deregulation, while Europe was still somewhat trailing behind in opening up the market for competition.

Also ownership and its effect on efficiency have been researched, but in rather small manner. On railways ownership considerations of efficiency have been restrained to comparison of two companies in a country, e.g. in railway operations Switzerland (Cowie 1999) and in Canada (Tretheway et al. 1997). Conclusions of these papers are somewhat mixed: Cowie (1999) concludes that in the Swiss case the private company has higher technical efficiency than the public one, while Tretheway et al. (1997) did not find any significant difference in total factor productivity of the two Canadian companies. Oum et al. (2006) examined the ownership considerations of transportation industry from the point of view of world's airports using variable factor productivity measure. They concluded, opposite to common belief, that purely privately owned or operated airports are not more efficient than airports in public or governmental control. In other words, literature review shows no or weak evidence in favour of private ownership. The findings of this study are very interesting as they provide clearly some evidence on superiority of passenger operations efficiency of private airlines compared to state owned airlines.

5.2 Correlations between Different Models

In this section it is examined whether there is a link between different air and rail transportation models. Container shipping was left out of the considerations because of the very small number of observations. In order to establish the link, correlations between models were calculated. In Figure 17 correlations between different models are presented. Here significant positive correlation is defined as confidence level of 95 percent. Observations of airlines were renamed corresponding to their native countries, so that they could be used for these calculations together with already country coded railways scores. Correlations were calculated from efficiency scores of all possible years, of course requiring that country had score from both models in question. Table of the airlines representing their respective countries and specific results of correlation calculations can be found from Appendix 2.

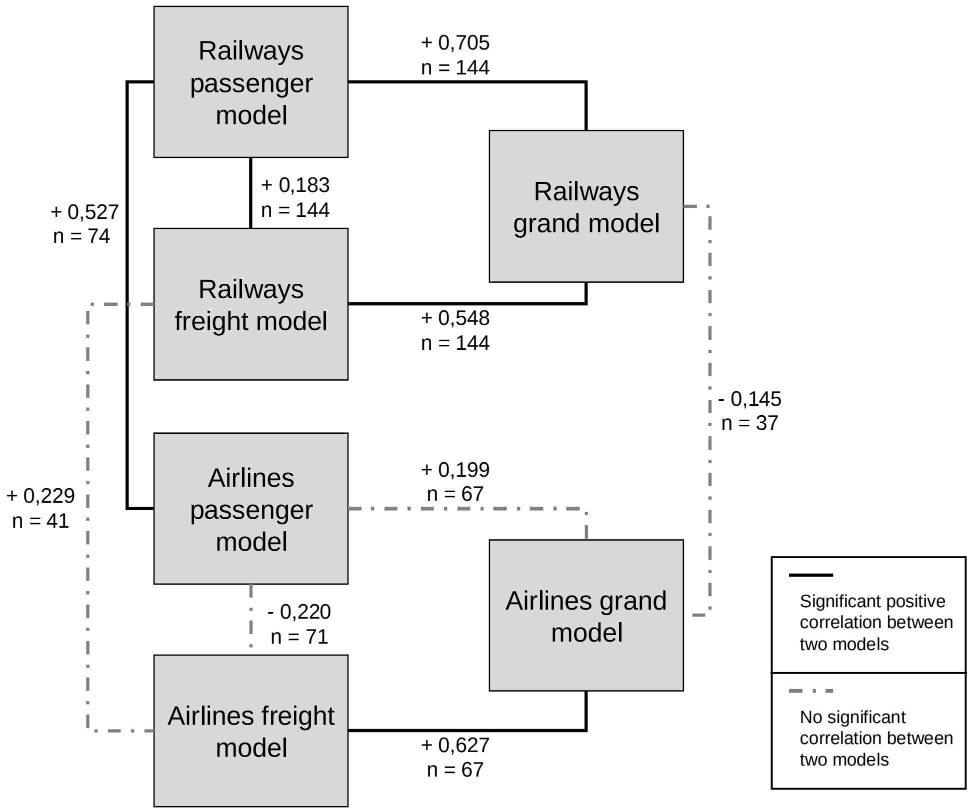


Figure 17. **Pearson correlations between different DEA models.**

As we can see from Figure 17, there is a significant positive correlation between all the railways models. Among the airline models the same situation does not apply; in fact, only freight and grand model have significant correlation. The fact that passenger model and grand model do not have significant correlation between them implies to freight transportation being the constraining component in the grand model.

This in turn is caused by the lack of airlines having flights cargo-only flights which was an input in both freight and grand models. These are also the reasons why very clear conclusions can not be made from the correlation between air freight and grand models, if only it suggests that investments in air freight transportation would benefit also the air transportation as a whole. More interestingly there is also significant and positive correlation between railways passenger model and airlines passenger model. In other words, correlation between the models indicates that if a country has efficient rail transport system for passengers, you are likely to do so with air transportation and vice versa. This could be a result of the fact that East European airlines are rather new and at same time people are still having rather low income level. At the same time these countries often have railways whose operations have collapsed from their glory days in the 1980s.

Also some implications, or confirmations, to decision making in transport policy level could be made from Figure 17; railways passenger model shows strong positive correlation between air passenger model and all the other railways models. The correlations between rail models are rather predictable, as the inputs of the models are to a great extent the same. From these correlations, one could argue that the investments in passenger transportation on rail would also benefit the efficiency all railway operations. In addition to these possibly multiplicative effects on railway operations, it seems that investments would also benefit air passenger transportation. One example of what these investments on passenger rail could represent are high speed (HS) trains which first emerged from Japan in 1964. In Europe France has been a pioneer with its TGV technology since early 1980s (Takagi 2005). HS traffic has enabled railways to challenge even airlines medium distances (Rodrigue 2006). More importantly railways and airlines working together with strengths of each other could represent an effective transportation system; in this scenario HS rail would concentrate on serving customers in medium and short distances and feeding airports with passengers, while airlines could serve customers on longer, more profitable, journeys (Knutton 2001).

6 CONCLUSIONS

As it has been demonstrated in this study, there are significant differences between the consistency of efficiency performances of transportation modes, when comparing railway companies and airlines. Airlines are performing much more solidly and there are no big differences between the efficient and the inefficient ones. Railways show huge variations between different countries in relative technical efficiency.

So, what are the factors behind the huge difference between railway and airline performance. The most obvious answers would be the different competition regulations between these two industries. Competition is opening in up, but it will take time until real competition takes place on European railroads. This is because of the several different standards on the railroads of Europe. Another important factor in explaining the performance difference is the toughness of airline industry; the fierce price competition and continuous increase of fuel prices. These factors probably eliminate rather fast the companies whose operations are poorly designed and executed; even the companies with adequate management might be struggling with their profitability. So, only the fittest have survived and will survive in the extremely competitive environment of the airline industry. Railroads and their passenger operations, however, have been considered most of the 19th century as public service and been funded from public sources. This has led to situation where state owned railway companies have not had virtually any competition as they have subsidised heavily by the state and this development undoubtedly still shows in the efficiency scores of European railways. Railways in Europe are at the moment proceeding towards open railway markets, but the ghosts of yesterday are still haunting. It seems that there is still in Europe much glorification of old days and necessity of change has not been realised. This development involves the risk of railways staying as marginal freight carrier and concentrating on its job as public servant in passenger transportation. As mentioned before, EU has laid the proper guidelines for the deregulation but the implementation still lags behind in EU (IBM 2006). Taking into account the ever increasing congestion on the roads of Europe, and its economic and environmental aspects, it would be the perfect time to invest in the sustainable future of transportation. It is possible to develop sustainable business on rail, at least in freight transportation. The solution might be to create an inter-European rail freight transportation network to serve material flows of Europe. This would allow new concepts on rail, such as inter-European block trains or rail transportation as vital part of express freight services (e.g. as presented in Ohnell & Woxenius 2001). Challenges are huge at the moment, but the current actions are mostly fragmental, marginal and on policy level; concrete actions to overcome the obstacles are needed. In addition to the actions taken to deregulate the rail industry in Europe, the importance of investments on rail, and especially on passenger, operations benefit the efficiency of whole industry.

Ownership considerations of airlines strongly suggested that privately owned companies were significantly more efficient in operating their passenger services. This is very interesting result, as it is still known a known fact that airlines yield the majority of their revenues from their passenger operations, even though the importance of freight operations is growing. In future it would be very interesting compare also the effect of ownership on efficiency performance similarly to completed analysis in this study which concerned airlines. At the moment it would not be very fruitful consideration, as so few countries have actually completed the deregulation of their railway operations, and opened the industry for competition. Also most EU countries are in the intermediate phase moving towards deregulation. Another interesting path for research would be a global comparison of airline efficiency.

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APPENDICES

Appendix 1. The independent samples t-test. Outputs from years 1996, 1998, 2000, 2002, 2004 and the whole sample.

Group Statistics

	OWN96	N	Mean	Std. Deviation	Std. Error Mean
PASS96	state	16	,8971	,09632	,02408
	private	8	,9315	,08492	,03002
FREIGHT96	state	8	,9236	,10269	,03631
	private	8	,9454	,09236	,03265

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
PASS96	Equal variances assumed	,175	,680	-,857	22	,401	-,03444	,04020	-,11782	,04894
FREIGHT96	Equal variances assumed	,844	,374	-,445	14	,663	-,02175	,04883	-,12648	,08298

Group Statistics

	OWN98	N	Mean	Std. Deviation	Std. Error Mean
PASS98	state	17	,9249	,08566	,02078
	private	8	,9714	,05515	,01950
FREIGHT98	state	7	,8509	,13465	,05089
	private	7	,8900	,13604	,05142

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
PASS98	Equal variances assumed	1,129	,299	-1,396	23	,176	-,04649	,03329	-,11537	,02238
FREIGHT98	Equal variances assumed	,032	,862	-,541	12	,598	-,03914	,07235	-,19678	,11849

Group Statistics

	OWN00	N	Mean	Std. Deviation	Std. Error Mean
PASS00	state	15	,9044	,08205	,02118
	private	11	,9618	,06272	,01891
FREIGHT00	state	5	,8604	,10491	,04692
	private	8	,8683	,13041	,04611

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
PASS00	Equal variances assumed	1,988	,171	-1,939	24	,064	-,05742	,02962	-,1185	,00371
FREIGHT00	Equal variances assumed	,562	,469	-,113	11	,912	-,00785	,06941	-,1606	,14492

Group Statistics

	OWN02	N	Mean	Std. Deviation	Std. Error Mean
PASS02	state	15	,9067	,05820	,01503
	private	13	,9430	,09009	,02499
FREIGHT02	state	5	,9142	,09397	,04203
	private	7	,8720	,12997	,04913

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
PASS02	Equal variances assumed	,661	,424	-1,285	26	,210	-,03633	,02828	-,09446	,02180
FREIGHT02	Equal variances assumed	1,029	,334	,616	10	,551	,04220	,06846	-,11033	,19473

Group Statistics

	OWN04	N	Mean	Std. Deviation	Std. Error Mean
PASS04	state	14	,9282	,06591	,01761
	private	13	,9638	,04796	,01330
FREIGHT04	state	5	,8804	,10051	,04495
	private	8	,8998	,10961	,03875

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
PASS04	Equal variances assumed	,707	,408	-1,595	25	,123	-,03563	,02233	-,08163	,01037
FREIGHT04	Equal variances assumed	,003	,955	-,319	11	,756	-,01935	,06065	-,15285	,11415

Group Statistics

	OWN	N	Mean	Std. Deviation	Std. Error Mean
PASS	state	77	,9122	,07831	,00892
	private	53	,9546	,06879	,00945
FREIGHT	state	30	,8873	,10662	,01947
	private	38	,8958	,11687	,01896

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
PASS	Equal variances assumed	2,596	,110	-3,185	128	,002	-,04240	,01331	-,06874	-,01606
FREIGHT	Equal variances assumed	,219	,641	-,309	66	,758	-,00848	,02747	-,06333	,04637

Appendix 2. Table of airlines and their respective countries used in correlations considerations between different DEA models.

Airline(s)	Respective country
Air France	France
Finnair	Finland
Alitalia	Italy
British Airways	United Kingdom
Cyprus Airways	Cyprus
Icelandair	Iceland
Iberia	Spain
Adria Airways	Slovenia
JAT Airways	Serbia Montenegro
KLM	Netherlands
Air Malta	Malta
Luxair; Cargolux	Luxembourg
Lufthansa	Germany
LOT Polish Airlines	Poland
Swissair, SWISS	Switzerland
Malev Hungarian Airlines	Hungary
Olympic Airlines	Greece
CSA Czech Airlines	Czech Republic
Austrian Airlines	Austria
Croatia Airlines	Croatia
TAROM Romanian Airlines	Romania
SAS	Sweden
Sabena; SN Brussels Airlines	Belgium
Turkish Airlines	Turkey
TAP Portugal	Portugal

Appendix 3. Correlation tables between different DEA models.

Correlations

		RAIL_FR	AIR_FR
RAIL_FR	Pearson Correlation	1	,229
	Sig. (2-tailed)		,150
	N	41	41
AIR_FR	Pearson Correlation	,229	1
	Sig. (2-tailed)	,150	
	N	41	41

Correlations

		AIR_GRA	RAIL_GRA
AIR_GRA	Pearson Correlation	1	-,145
	Sig. (2-tailed)		,393
	N	37	37
RAIL_GRA	Pearson Correlation	-,145	1
	Sig. (2-tailed)	,393	
	N	37	37

Correlations

		RAIL_PA	AIR_PA
RAIL_PA	Pearson Correlation	1	,527(**)
	Sig. (2-tailed)		,000
	N	74	74
AIR_PA	Pearson Correlation	,527(**)	1
	Sig. (2-tailed)	,000	
	N	74	74

** Correlation is significant at the 0.01 level (2-tailed).

Correlations

		AIR_FR	AIR_PA
AIR_FR	Pearson Correlation	1	-,220
	Sig. (2-tailed)		,065
	N	71	71
AIR_PA	Pearson Correlation	-,220	1
	Sig. (2-tailed)	,065	
	N	71	71

Correlations

		AIR_GRA	AIR_FR
AIR_GRA	Pearson Correlation	1	,627(**)
	Sig. (2-tailed)		,000
	N	67	67
AIR_FR	Pearson Correlation	,627(**)	1
	Sig. (2-tailed)	,000	
	N	67	67

** Correlation is significant at the 0.01 level (2-tailed).

Correlations

			AIR_GRA	AIR_FR
Spearman's rho	AIR_GRA	Correlation Coefficient	1,000	,650(**)
		Sig. (2-tailed)	.	,000
		N	67	67
	AIR_FR	Correlation Coefficient	,650(**)	1,000
		Sig. (2-tailed)	,000	.
		N	67	67

** Correlation is significant at the 0.01 level (2-tailed).

Correlations

		AIR_GRA	AIR_PA
AIR_GRA	Pearson Correlation	1	,199
	Sig. (2-tailed)		,107
	N	67	67
AIR_PA	Pearson Correlation	,199	1
	Sig. (2-tailed)	,107	
	N	67	67

Correlations

		RAIL_FR	RAIL_GRA
RAIL_FR	Pearson Correlation	1	,548(**)
	Sig. (2-tailed)		,000
	N	144	144
RAIL_GRA	Pearson Correlation	,548(**)	1
	Sig. (2-tailed)	,000	
	N	144	144

** Correlation is significant at the 0.01 level (2-tailed).

Correlations

		RAIL_PA	RAIL_GRA
RAIL_PA	Pearson Correlation	1	,705(**)
	Sig. (2-tailed)		,000
	N	144	144
RAIL_GRA	Pearson Correlation	,705(**)	1
	Sig. (2-tailed)	,000	
	N	144	144

** Correlation is significant at the 0.01 level (2-tailed).

Correlations

		RAIL_PA	RAIL_FR
RAIL_PA	Pearson Correlation	1	,183(*)
	Sig. (2-tailed)		,028
	N	144	144
RAIL_FR	Pearson Correlation	,183(*)	1
	Sig. (2-tailed)	,028	
	N	144	144

* Correlation is significant at the 0.05 level (2-tailed).