

# **Benchmark Analysis of Railway Networks and Undertakings**

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## **Abstract**

Benchmark analysis of railway networks and companies has been stimulated by the European policy of deregulation of transport markets, the opening of national railway networks and markets to new entrants and separation of infrastructure and train operation. Recent international railway benchmarking studies which are mostly based on statistical data compiled by UIC demonstrate a variety of performance measures, assessment methods and the results suggest no clear interdependence between the organisation model of the railway industry and its efficiency. Economic evidence suggests that vertical separation between infrastructure management and train operations increases costs at higher traffic densities, while at lower densities it reduces costs. At mean traffic densities a holding model reduces costs compared with vertical integration, while vertical separation does not change costs. In this paper a more comprehensive approach for benchmark analysis is proposed that includes relevant technical and economic key performance criteria and indicators for assessing the transport and traffic output, effectiveness, productivity, and efficiency performance of railway networks and undertakings. In first instance, data and preliminary results and conclusions from a regression analysis of empirical technical and commercial data and Data Envelopment Analysis of the network productivity and operating efficiency of 11 mid-size European railway networks and undertakings in the year 2009 are reported.

## **Keywords**

benchmarking, infrastructure, operations, productivity, efficiency

## **1 Introduction**

The transport and railway deregulation policy of the European Union has led to an increased interest of governments, advisors and researchers for appropriate methods to assess the effects of reorganization of the railway industry and the factors that govern the effectiveness and efficiency of railway networks and train operations. Available international benchmark studies are based on statistical data from different periods and sets of railway infrastructure managers and train operating companies (TOC) compiled since decades by the Union International of Railways (UIC).

The major problems that endanger the reliability of the existing performance assessment methods, their explanatory power and the robustness of (political) conclusions are threefold: weaknesses of the database, complexity of measurement and risk of biased evaluation. It is known that the definitions for the UIC Railisa database, in practice, are not always applied correctly and completely by UIC members, some essential data are missing (Smith, 2010) and private train operators are not obliged to report in sufficient detail. The measurement of railway infrastructure management, passenger and freight transport work, energy and costs is very difficult due to the multiplicity of outputs, inputs, joint costs and economies of scale, as well as differences in the environment including geographical factors and government intervention (Nash & Smith, 2007). Benchmark analyses may be stimulated ex-post by governments and researchers with the aim to support previously decided strategies to separate infrastructure and train operations, and introduce competition in order to demonstrate their benefits. This may have an influence on the selection of the consultant and lead to prejudicial choice of methods and interpretation of results.

The aim of this paper is to synthesize the relevant technical and economic criteria and indicators for performance analysis such that the variety and impact of some quantitative input variables on the output, in first instance, can be explained qualitatively on the basis of a small number of railway networks and railway undertakings and data. The data used is limited due to lack of available resources to only one year, while the smaller and the larger railway networks in Europe have been excluded, so far, from the empirical analysis. The contribution of the paper is better interdisciplinary insight into the main drivers and constraints of railway network performance.

The paper is organized as follows. First, the existing assessment methods for benchmarking are briefly reviewed, the applied criteria and key performance indicators are discussed. Second, the available infrastructure and transport network characteristics of the investigated 11 mid-size networks in Europe used in this study are described. Third, preliminary results of the benchmark analysis for the railway networks regarding the network productivity and operating efficiency in 2009 are reported. Finally, the main conclusions and need for further research are presented.

## **2 Benchmarking Approach**

### **2.1 Assessment method**

The main objective of benchmarking is to measure and compare the realized output of a product or service with the amount of inputs. Network infrastructure, track maintenance and renewal expenditures have been analysed periodically by a number of UIC members (UIC, 2006). The input parameters contain network characteristics, their utilization and economic characteristics, while the output uses key performance indicators with regard to network use and life cycle costs (LCC) per track kilometre and transport unit respectively. The LCC costs of infrastructure, defined as yearly costs per main track kilometre, have been harmonized with regard to purchasing power, labour cost levels, degree of electrification, percentage of single tracks, switch density and track utilization. In general, UIC considers seven key performance indicators (KPI) relevant for benchmarking: Mobility & Accessibility, Safety, Service Quality & Reliability, Innovation & Growth, Asset Utilisation, Financial Effectiveness, and Efficiency.

Yu (2008) assessed the efficiency and effectiveness of 40 railways through network data development analysis in year 2002 from UIC members in Asia, Europe and Africa.

He used (i) the length of railway lines, number of passenger cars, number of freight cars and number of employees as inputs, (ii) the passenger train-km, freight train-km as produced outputs, and (iii) passenger-km and tonne-km as consumed outputs. The gross national income per capita and population density were considered as environmental variables.

Lan & Lin (2006) examined panel data from 39 worldwide railway systems over the period 1995-2002 of UIC by a stochastic distance function with regard to technical efficiency and service effectiveness respectively. They used the same input and output variables as Yu and found the railways' technical inefficiency and service ineffectiveness to be negatively influenced by gross national income per capita, percentage of electrified lines, and line density. Significant changes of both efficiency and effectiveness frontiers during the 8 year period could not be observed. The elasticity of the input distance function with respect to the number of employees was greater than that with regard to the number of freight cars and passenger cars.

Nash & Smith (2007) presented an overview of railway performance models. They distinguish index number approaches (partial productivity measures, total factor productivity measures), econometric approaches and efficiency-based approaches (e.g. data envelopment analysis, corrected ordinary least squares, stochastic frontier analysis), and describe their principle features, benefits, limitations and typical applications. There is little consensus from the different studies regarding the relative efficiency and productivity performance of the railway periods prior to the mid-1990s.

Growitch & Wetzel (2009) tested the economies of scope in European railways by analysing the technical efficiency of in total 54 integrated and non-integrated railway undertakings from 27 countries by means of non-parametric data envelopment analysis (DEA) of the period 2000-2004. The input variables consist of number of employees, number of rolling stock, operating expenses and network length, while the output variables are train-km, passenger-km and tonne-km respectively.

Cantos et al. (2010) reported beneficial effects of organizational reforms on efficiency, productivity, and technical change in 16 national railway systems over the period 1985-2005. The number of employees, number of coaches, railcars and multiple-units for passenger transport, freight wagon strength and network length are considered as input variables, while the number of passenger-km and the number of tonne-km transported respectively are used as output variables. They use DEA to calculate the distance function.

Smith (2012) emphasizes the problems of lack of comparable data, capital cost measurement and controlling for cross-country network differences for international efficiency comparisons. He adopts a time varying inefficiency model using a panel dataset of 13 European rail infrastructure managers (1996-2006) of UIC in order to determine the efficiency of Network Rail against international best practice. The dataset comprises maintenance costs, renewal costs and total costs using Purchasing Power Parity exchange rate data from the OECD for conversion to a common currency and price level. The standard main output vector consists of passenger train-km and freight train-km respectively per route-km, while typical network variables as proportion of electrified track and the ratio of single track to route-km are taken into consideration.

Karlaftis & Tsamboulas (2012) discussed definitions, measurement and different methods as stochastic frontier production functions, Data Envelopment Analysis (DEA) and Neural Networks to assess transit efficiency and effectiveness. They used data from 15 European transit systems for the period 1990-2000, applied a range of performance assessment models, evaluated and compared the results. They found considerable efficiencies in European transit systems, but markedly lower effectiveness. Peer group

comparisons and performance assessments based only on averages may yield erroneous findings and lead to skewed policy recommendations.

Van de Velde et al. (2012) carried out an economic assessment of rail system cost and modal shares on 26 OECD countries over 1994-2010, as well as of state spending in railway for 5 European countries. They controlled for output size, input and factor prices, tested for the effects of various structural reforms and found that vertical separation increases costs at higher traffic densities, does not change costs significantly at mean densities and reduces costs at lower densities. A high dependence on freight traffic, too, increases the costs of vertical separation. There is no evidence that the modal share of rail in both passenger and freight is higher in countries with vertical separation compared to countries with a holding company model. Neither the modal share of rail, nor the value-for-money for state budgets in a country depends significantly on the vertical separation, holding company or integration model.

From the review of literature the following can be concluded. The performance and costs of railway systems vary a lot. The railway network characteristics and organisation models of the railway sector both are rather different from country to country. The rolling stock cannot be easily used for other kinds of transport service and train operation is mostly limited regionally: There are only few or even no alternative uses once the infrastructure is built, while the train design, equipment and operations are closely related to the infrastructure. Transport service is a non-storable commodity. The surplus capacity at low demands cannot be used at high demands and is wasted. The input of railway transport (vehicles, labour, energy) and the output in larger networks (passenger and freight services) both are multiple.

In general, the impact of network characteristics, as density, share of single tracks, share of electrified tracks, and distribution of personnel between passenger and freight traffic on effectiveness and efficiency is not considered explicitly in most of the models except in the very recent EVES-Rail study (Van de Velde et al. 2012). The overall infrastructure management, maintenance and train operation costs of railway networks inter alia depend on the traffic density and the organisation model of the railway sector. The Railisa database of UIC unfortunately does not contain sufficient information about the kind and number of passenger stations and freight terminals in a network. The transport capacity offered, measured by the number and density of seats and standees per type of trains operated in a network, are not reported, which means that one of the most important performance indicators, the loading factor of the trains still cannot be estimated.

The scope and focus of existing studies is often limited to a number of European railways and simple efficiency indicators like costs per track-km, per train-km, per passenger-km and per freight tonne-km. The transport capacity of trains can vary very much from line to line and area due to different vehicle design (single or double deck, length, amount and density of passenger spaces), number and length of train units or cars, which means the units train and train-km are no uniform measurement units and can represent very different weights. Index and panel data from different periods used for DEA may restrict, too, the dependability and comparability of the results.

The performance of networks is evaluated on the basis of standard (economic) criteria and indicators for efficiency and effectiveness of the infrastructure and train operations respectively. The following paper is an extension of a previous benchmark analysis of five mid-size European railway networks and undertakings in 2009 in comparison to East Japan Railways for the special investigation committee of the Dutch Parliament (Hansen et al., 2012).

## **2.2 Performance criteria**

The (economic) performance of railway networks and undertakings is expressed in general by criteria as effectiveness, efficiency and productivity. Effectiveness is defined as capability of producing a desired result (e.g. number of passengers or train-km respectively per period). Efficiency is determined by the ratio of output (e.g. passenger-km) to input (e.g. train-km). Productivity is a specific measure of the efficiency of production related to the input needed to produce a desired output (e.g. train-km per network-km). The importance of the performance criteria may differ per stakeholder.

## **2.3 Key performance indicators**

As the economy of railway systems and networks clearly depends on scale, international and interregional benchmarking analysis needs to be done for networks and transport volumes of about similar scope. The most important characteristics of railway infrastructure networks are the route length, track length, mean distance between stations, percentage single tracks, and percentage electrified tracks. The percentage of dedicated high-speed and freight route respectively is generally small, but the transport performance of the corresponding trains can be rather high because of the considerably higher operating speed.

The fleet size and composition of rolling stock is given by the number of trains, locomotives, rail cars and multiple unit train sets. However, the distribution of locomotives between passenger and freight trains of integrated companies is not fixed and depends on the scope of the freight transport business compared to the passenger transport market, as well as on the distribution of locomotive hauled rail cars and (electrical) multiple units. As the transport capacity of TOCs depends on the power of locomotives, maximum axle load, weight and length of trains, while the number and density of seats and standees varies a lot in large networks with mixed operation of passenger and freight trains, a comparison of yearly outputs (passenger-train-km, freight-train-km, passenger-km, tonne-km, ticket revenues, freight revenues) per train, locomotive, rail car and multiple unit train set respectively makes sense only for dedicated lines with similar transport services.

The principle Key Performance Indicators (KPI) that express best the effectiveness of railway networks and undertakings with regard to transport supply are: number of train trips, volume of freight load transported, number of passenger-km, train-km, and tonne-km per year.

The most relevant KPI regarding the efficiency of infrastructure management (IM) are the expenditure per network-km, per track-km, per train-km, and per gross tonne-km respectively. The activities and costs of IM can principally be further broken down into main areas of general administration, maintenance and repair, traffic control and (investment) projects. The accountancy of the staff and material costs, however, may be ambiguous due to the allocation of shared services especially if the railway undertaking is organized still as an integrated enterprise or a holding of the divisions IM, passenger train operation, cargo train operation, and power generation and distribution.

Some IM have subcontracted the (scheduled) track maintenance and/or other technical equipment to private companies, while the own staff manages only the planning, tendering, contracting and supervision of works like the procurement of major repair, renovation, construction and delivery of new technical equipment, while integrated undertakings may still employ own workshops and personnel for routine maintenance and repair. The most important revenues of IM are generated by government subsidies for maintenance, public funds for planning and construction of new lines and stations, and

track charges. If the IM owns the ground and (station) buildings, significant costs and revenues may be accounted for maintenance and development of commercial properties.

The important KPI regarding the efficiency of train operations are the operating costs and revenues per train-km, per passenger and tonne or container transported, per passenger-km and tonne-km respectively, as well as the operating ratio of revenues and costs per line and per time period. The occupancy rate of the trains is an indicator of passenger transport comfort and transport efficiency. It is defined by the ratio of passengers and tonnes per train, passenger-km and tonne-km per train-km. However, the transport capacity (number and density of seats and standees, maximum weight) per train varies a lot depending on e.g. the width, length (number of wagons or train sets), height (single or double deck), maximum axle load, power and traction (locomotive hauled or diesel and electric multiple units). The output per train and train-km, therefore, may vary a lot, which can bias benchmarking results significantly. A more accurate efficiency indicator for the transport capacity consumption of passenger trains would be the number of passenger-km per seat-km and per passenger space-km provided that no standees are counted for long-distance trains and the same space and density per seat and standee is applied.

### **3 Infrastructure and Transport Network Characteristics**

#### **3.1 Database**

In order to perform analysis on the KPI data have been examined from various Railway Undertakings, Infrastructure Managers and Train Operating Companies. The data in this publication are for the largest part taken from the Railisa Database (<http://railisa.tsf.it/railisa/>) as composed and provided by UIC. Data in Railisa are provided by individual members of UIC, typically large Train Operating Companies or Infrastructure Managers. The data examined comprises only the year 2009 due to the restricted time and resources.

Next to the aggregated datasets that are publicly available from Railisa, additional datasets are at disposal of members of UIC or consultants. These additional datasets contain less aggregate and more detailed information on economic indicators and have been used, too, for plausibility checks. The expenses and revenues of railway undertakings in countries with a different currency than Euro have been converted to Euro based on the official currency rates of December 31, 2009.

Since in some cases data of UIC seem not to be appropriate (especially in the case of integrated Railway Undertakings) additional sources of information are used in order to refine the original Railisa Dataset. These additional sources include Annual Reports of Railway Undertakings, Infrastructure Managers or Train Operating Companies and additional statistics provided by national statistical agencies and our foreign research partners. Passenger transport data are quite consistently available in most countries under investigation. However, concerning freight transport, the Railisa Database unfortunately contains lots of gaps, since private freight operators are typically no member of UIC and do not report commercial data of specific railway networks. If it has been impossible to obtain and validate required data, the graphs show N/A as to data that are Not Available.

#### **3.2 Railway networks**

The networks length of the 11 selected mid-size railway networks in Europe ranges from about 2200 km in Denmark to 20,000 km in Poland. The networks can be split into two sub-groups: seven smaller networks with a length of up to 5,300 km and four

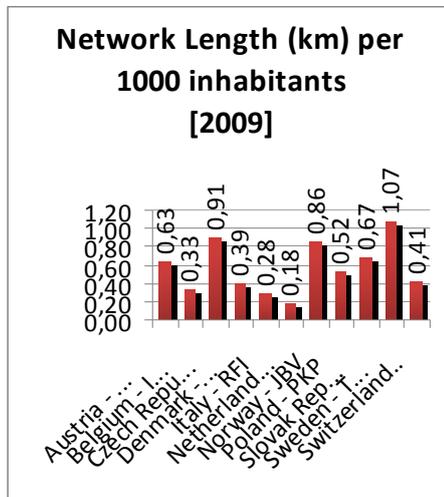


Figure 1: Network length per 1000 inhabitants of mid-size European railway networks 2009

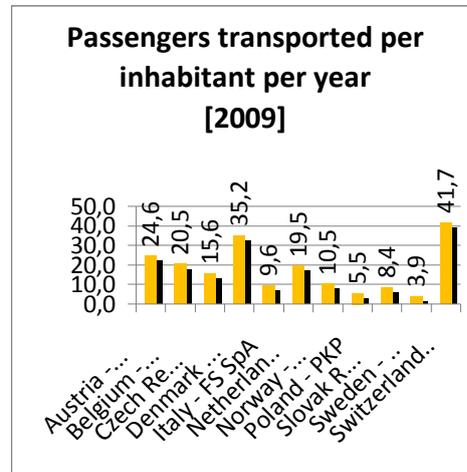


Figure 2: Passenger transport volume per inhabitant of mid-size European railway networks 2009

considerably bigger networks of 9,500 km up to 20,000 km. The network length per 1000 inhabitants is used for comparing the density of the infrastructure network supply (Fig. 1). The least railway route metres per inhabitant exist 2009 in the Netherlands (180 m), while the route length in Sweden of 1070 m per inhabitant is the largest of this sample in Europe. Unfortunately, the number of stations is generally not reported, although the number of stations per network length is a also good indicator of the network density and a second best indicator of the mean network speed.

The total track length per network ranges from 3276 km in Denmark to 37967 km in Poland with mean track-km per network-km of 1.5 km in Denmark to 2.4 km in the Netherlands and in Switzerland SBB. The ratio between track length and network length ranges between 1.1 in Norway with mostly single track routes and 2.4 in the Netherlands and Switzerland with the majority of two and more tracks per route. The percentage of electrified network is used as an indicator for technological development: It varies a lot between 40% in Denmark up to 100% in Switzerland. If the amount of (traction) energy consumed and the degree of use of non-fossil energy resources were available, these inputs could be used as indicators for energy efficiency and sustainability. The percentage of network infrastructure operated by ERTMS will be also an interesting measure of technological change and safety.

### 3.3 Passenger train operations

The passenger volume in 2009 varies between a maximum of 42 trips per inhabitant and year in Switzerland and a minimum of 4 trips in Sweden (Fig. 2). The yearly transport production measured in passenger-km per inhabitant in 2009 ranges from a maximum of 2100 km in Switzerland to a minimum of 410 km in Slovakia, while Austria, Belgium, Denmark and the Netherlands generate around 1000 km per inhabitant and year (Fig.3).

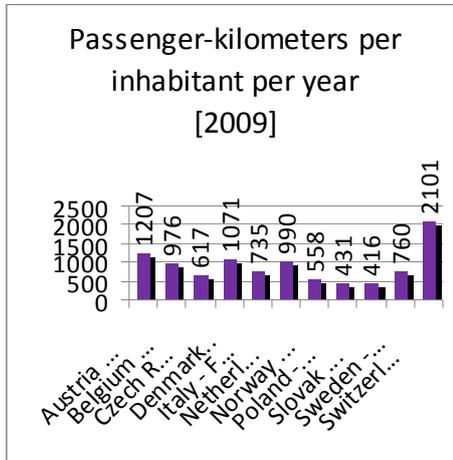


Figure 3: Passenger-km per inhabitant in mid-size European railway networks 2009

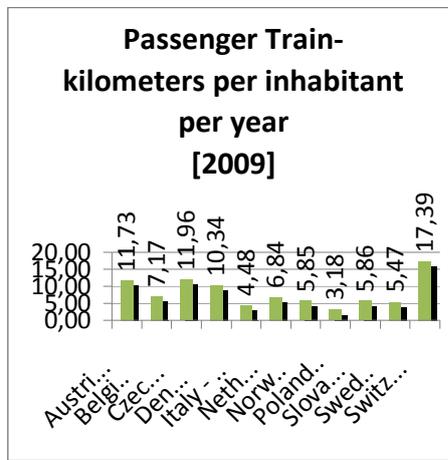


Figure 4: Passenger train-km per inhabitant of mid-size European railway networks 2009

The number of passenger train-km per inhabitant in 2009 ranges from a maximum of 17 in Switzerland to a minimum of 3 km in Poland (Fig. 4). Unfortunately the number of seat-km offered by the train operators is not reported because the train length and number of seats per train changes significantly per season, type of day and hour of the day. Hence, the prime indicator of transport efficiency being the occupancy rate (passenger-km/seat-km) cannot be calculated, while it is most important for benchmarking of train operators.

### 3.4 Freight train operations

The total yearly freight transport volume in 2009 per network is not known for all the countries. The share of freight train-km in 2009 ranges from 9% in the Netherlands to a maximum of 34% in Austria. The latter is higher than in Switzerland due to the heavy freight transit traffic between Germany and Italy via the Brenner route.

## 4 Performance Analysis

The performance analysis is first based on productivity indicators regarding the generated output of transport and traffic volume per network length, train and staff in 2009. Then, the operating efficiency is measured by the expenditure of the incumbent passenger operator per network-km, train-km and passenger-km respectively. The performance of freight transport operators cannot be assessed due to the lack of sufficient commercial data from private entrants. The interdependence between a number of input and output variables is further analysed by means of regression analysis. Finally, a Data Envelopment Analysis (DEA) is performed for certain productivity and efficiency indicators.

### 4.1 Network and staff productivity

The passenger transport productivity of the Dutch (NS only) and SBB network is more than twice compared to Austria, Belgium, Denmark and Italy, while the passenger transport density in the Czech Republic, Norway, Poland, Slovakia and Sweden is much lower (Fig. 5). The passenger train traffic productivity in 2009 differs a lot between a minimum of 9,000 train-km in Slovakia to a maximum of nearly 43,000 train-km per

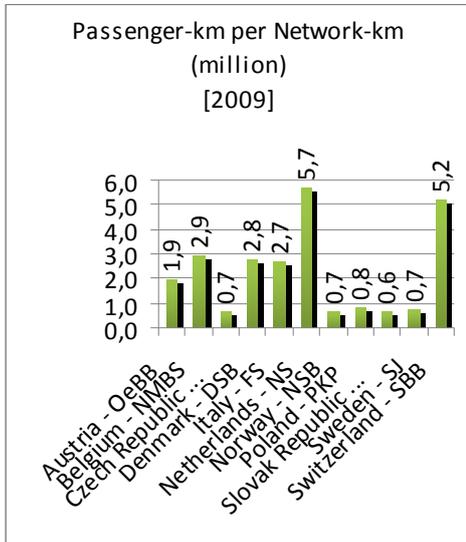


Figure 5: Passenger-km per network-km of mid-European railway networks 2009

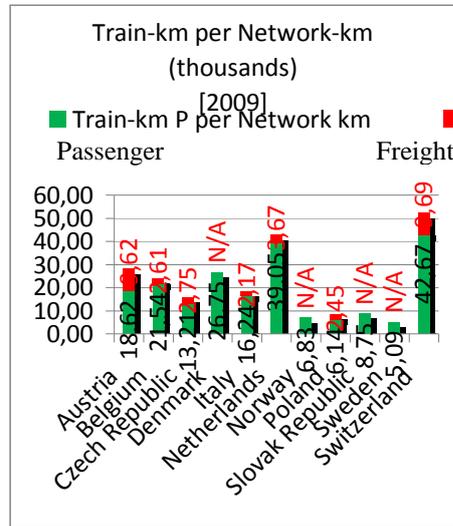


Figure 6: Passenger and freight train-km per km of mid-size European railway networks 2009

network-km in Switzerland (SBB only) (Fig. 6). While the network in Belgium, Slovakia and Switzerland (SBB) has about the same length of around 3,000 km, the passenger traffic volume generated of SBB is roughly two times higher than of SNCB, and four times higher than in Slovakia. The share of freight train-km in most networks, except Switzerland and Austria due to the heavy transit traffic crossing the Alps, is rather limited.

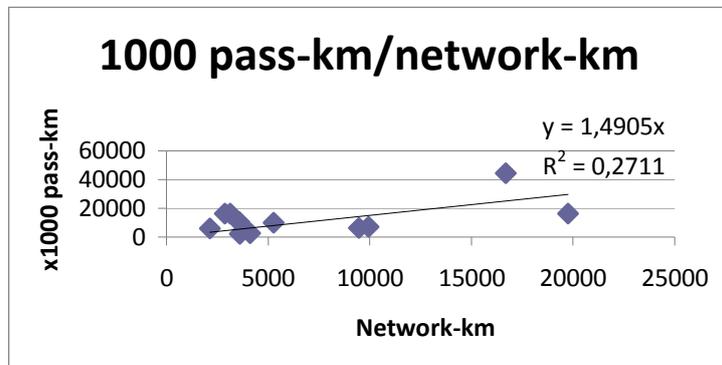


Figure 7: Scatter diagram of incumbent passenger-km per network-km in mid-size European railway networks 2009

An indicative regression analysis between the output-input values shows only a weak relation between the number of passenger-km of the incumbent train operator and the network size (Fig. 7). The regression function is not reliable as the total number of networks observed is rather small and the correlation coefficient of 0,271 is very low.

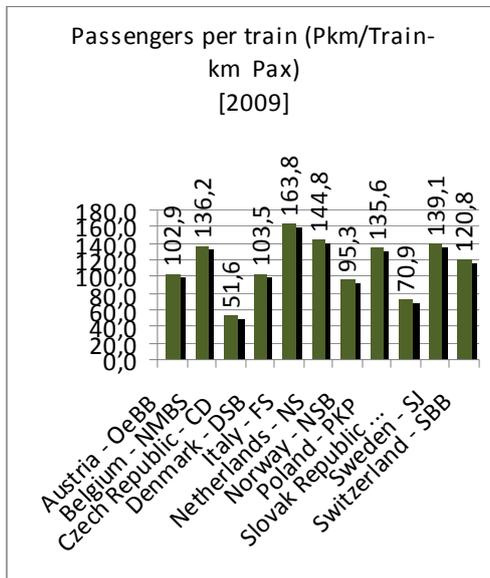


Figure 8: Mean number of passengers per train of mid-size European railway networks 2009

The average passenger transport productivity ranges between 52 passengers/train in the Czech Republic to a maximum of 164 passengers/train in Italy (FS only), while the mean train load in Belgium, the Netherlands (NS only), Poland, Sweden (SJ only) and Switzerland (SBB only) varies a little between 120 and 145 passengers/train (Fig. 8).

The passenger transport-kilometres per train-km of the incumbent train operator in 2009 per network shows a remarkably high correlation coefficient of 0.86 (Fig. 9). The number of passenger-km increases rarely by 0.136% per 1000 passenger train-km of the incumbent train operator.

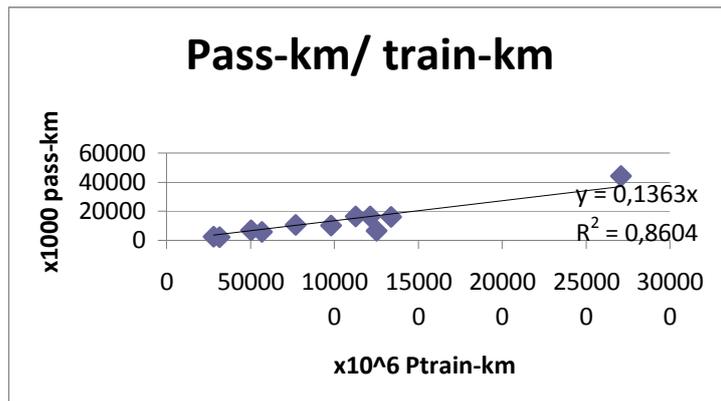


Figure 9: Scatter diagram of passenger-km per train-km of incumbent train operator in mid-size European railway networks 2009

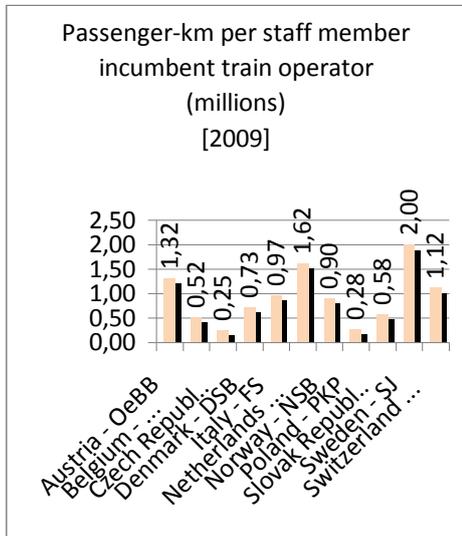


Figure 10: Volume of passenger-km per staff member of incumbent train operating company of mid-size European railway networks 2009

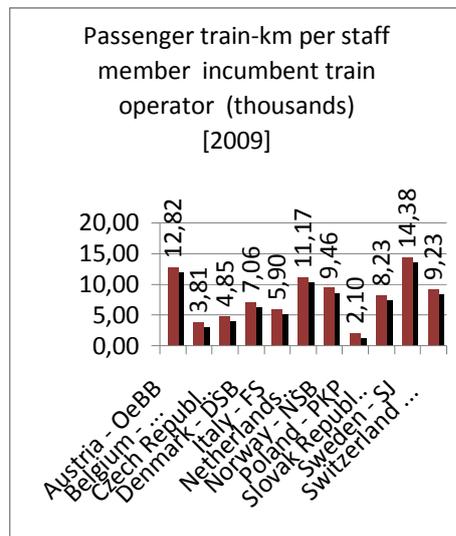


Figure 11: Number of train-km per staff member of incumbent train operating company of mid-size European railway networks 2009

The passenger transport productivity per staff member of the incumbent operator varies a lot between 250,000 per year in the Czech Republic and 2 million passenger-km in Sweden (SJ only) (Fig. 10). The top performance of SJ is due to the very high operating speed of its long-distance high-speed line network, while the regional passenger networks in Sweden are operated by other (private) operators. The traffic productivity of the staff of the incumbent train operator varies between a minimum of 2,100 passenger train-km in 2009 in Poland and a maximum of 14,380 train-km of SJ in Sweden (Fig. 11).

The transport productivity is only weakly correlated with the number of staff. The number of 1000 passenger-km per year grows slightly with the size of staff (Fig. 12).

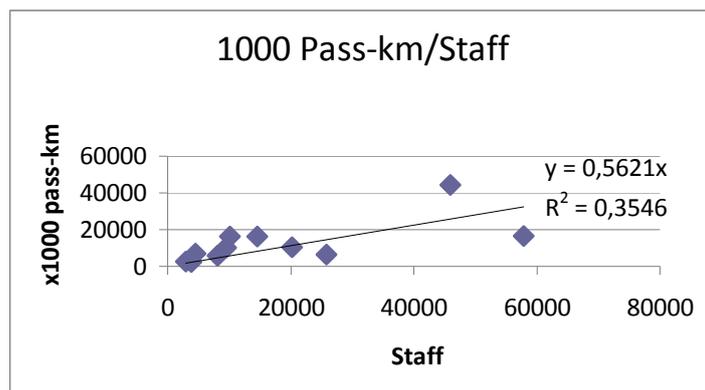


Figure 12: Scatter diagram of 1000 passenger-km per staff of incumbent train operator in mid-size European railway networks 2009

#### 4.2 Operating efficiency of the incumbent passenger train operating companies

The operating expenditure of the incumbent passenger train operator per network-km in 2009 shows a wide range of €390,000 (ÖBB) to €910,000 (NS) for the West and South European networks, while the East and North European networks are clearly at the bottom (Fig. 13). Dutch Railways NS spends in 2009 most per network-km, followed by SBB, as both companies exploit their trains and networks most intensively. FS (Italy) and NMBS (Belgium) spend in 2009 almost the same amount of €34 per train-km (Fig. 14). The incumbent passenger train operators in the Czech Republic and Slovakia spend the least, while the Polish Railway has not reported any expenditure costs in 2009.

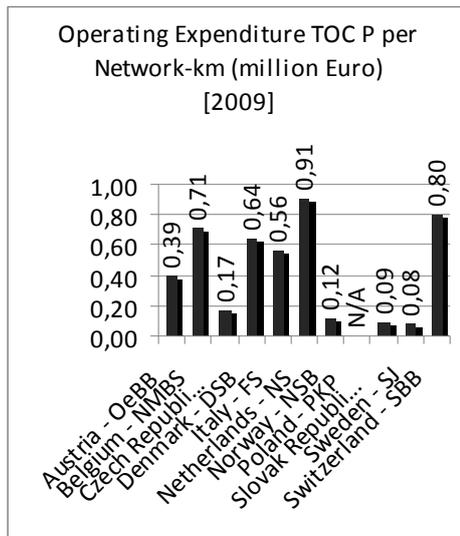


Figure 13: Operating expenditure per network-km of incumbent train operator in mid-size European networks 2009

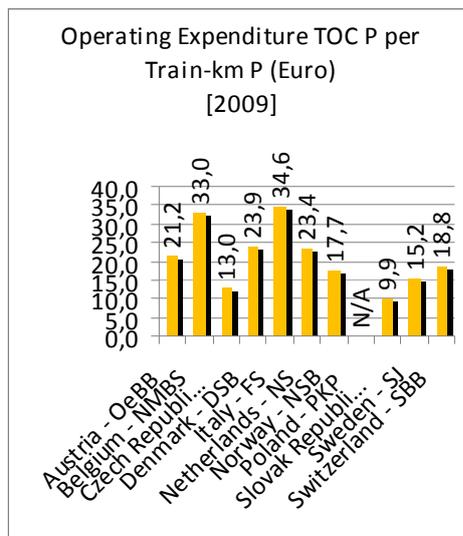


Figure 14: Operating expenditure per train-km of incumbent train operator in mid-size European networks 2009

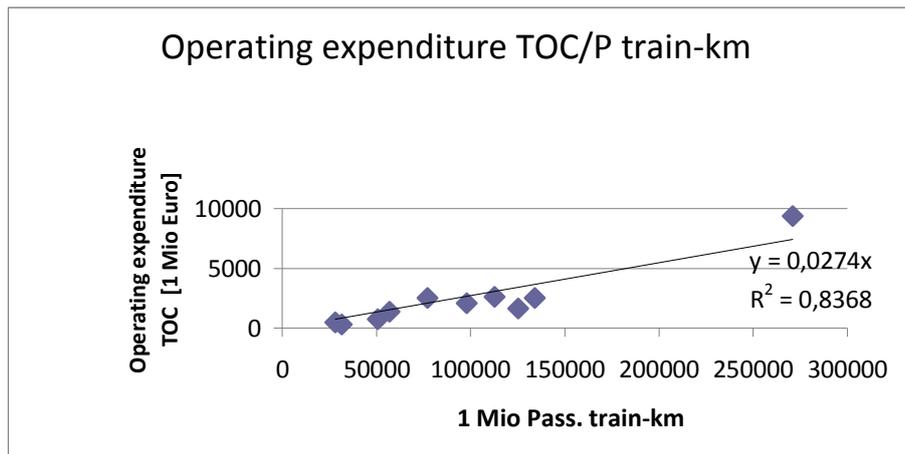


Figure 15: Scatter plot of operating expenditure of incumbent passenger train operator per train-km in mid-size European railway networks 2009

The operating costs of the incumbent passenger train operators are correlated strongly (coefficient 0.84) and increase slightly with the number of train-km performed (Fig. 15).

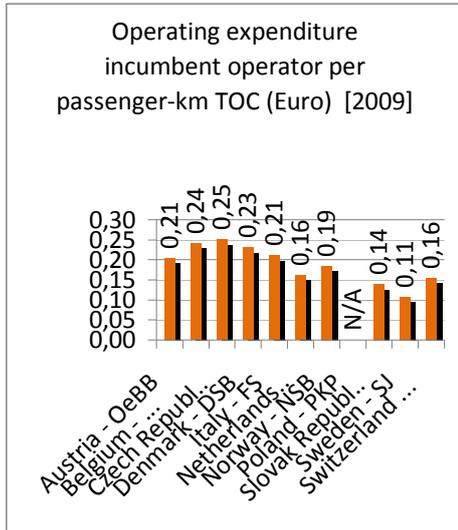


Figure 16: Operating expenditure per pass-km of incumbent passenger train operator of mid-size European railway networks 2009

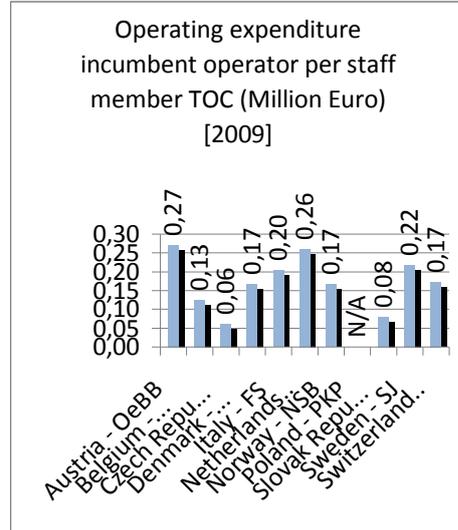


Figure 17: Operating expenditure per staff of incumbent passenger train operator of mid-size European railway networks 2009

The operating expenditure in 2009 per passenger-km of the incumbent passenger train operator is shown in Fig. 16. About one half of the passenger train operators spend €0.20 up to €0.25 operating costs per passenger-km, while the minimum of only €0.11 per passenger-km is achieved by SJ in Sweden. The operating costs of the incumbent train operator per staff member are highest for ÖBB and NS with about €0.20 per staff member in 2009, whereas the least costs are generated by the Czech Railways with only €0.06 per staff member (Fig. 17).

The yearly expenditure [1 million Euro] for train operations of the incumbent passenger transport operator is strongly correlated (coefficient 0.80) with the number of staff employed (Fig. 17) as personnel costs are dominant. The rate of increase of should be treated very cautiously as the conversion rates for expenditure of countries which have another currency than Euro has been based on the exchange rate of a single day in June 2009 and has neglected the impact of Purchasing Power Parities.

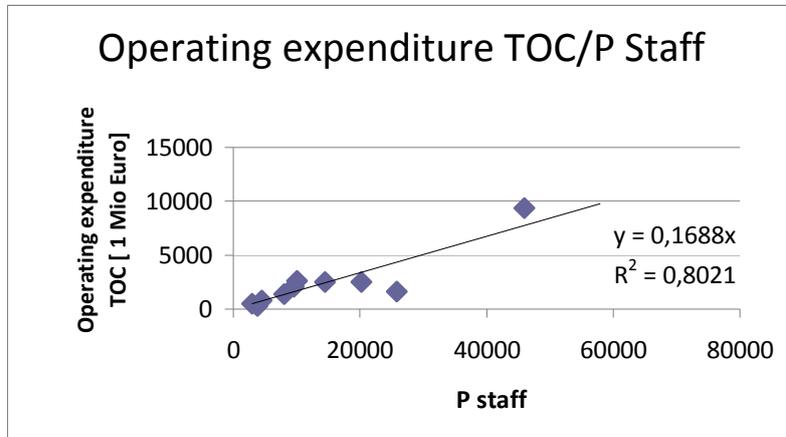


Figure 17: Scatter plot of operating expenditure of incumbent passenger train operator per staff in mid-size European railway networks 2009

### 4.3 Operating efficiency of the infrastructure managers

The operating expenditure for infrastructure management in 2009, unfortunately, is not reported by RFF (Italy), PKP (Poland) and Trafikverket (Sweden), so that the total network expenditure can only be given for the remaining seven networks (Fig. 18 and 19). The West European infrastructure managers spend €0.35 to €0.70 per network-km and corresponding €0.20 to €0.30 per track-km in 2009, while the expenditure of the Scandinavian and East European infrastructure managers is much less.

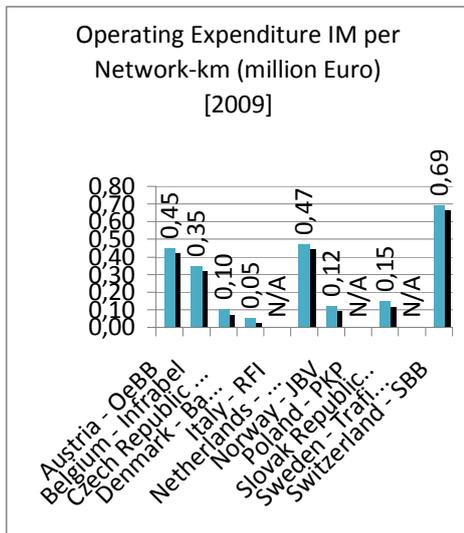


Figure 18: Operating expenditure per network-km for infrastructure management in mid-size European railway networks 2009

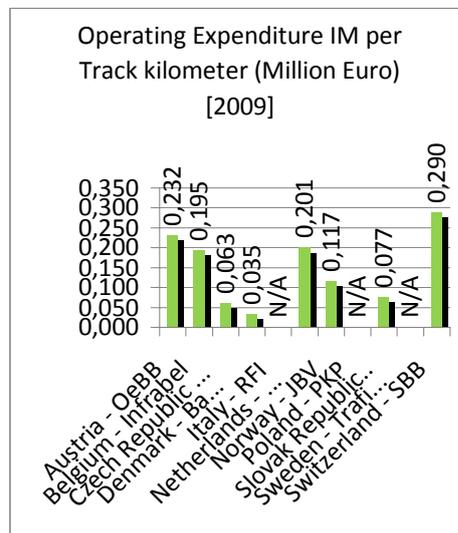


Figure 19: Operating expenditure per track-km for infrastructure management in mid-size European railway networks 2009

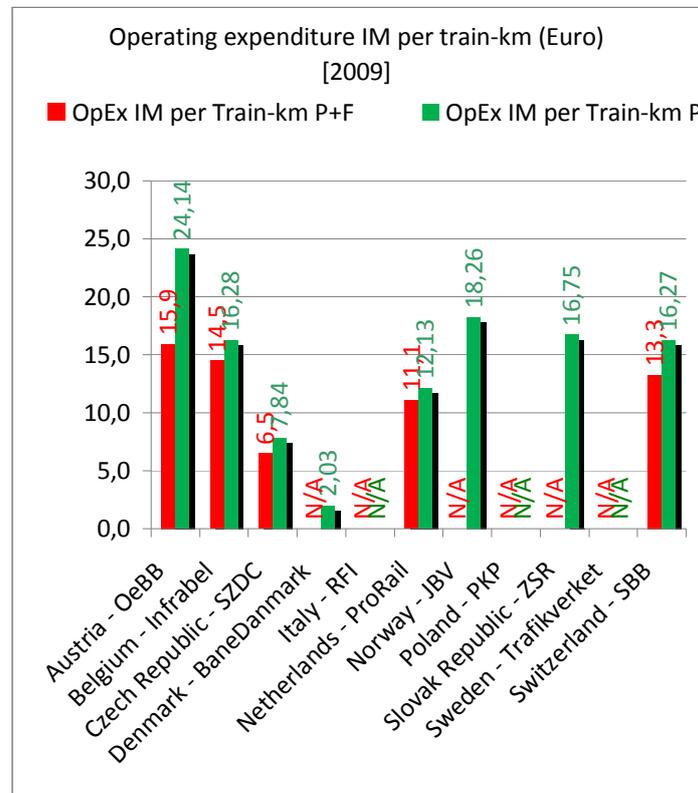


Figure 20: Operating expenditure of infrastructure manager per train-km in mid-size European railway networks 2009

The operating expenditure for infrastructure management per train-km including passenger and freight trains (red columns) is an indicator of the efficiency of network management (Fig. 20). The values belonging to the green columns are estimated by splitting the total operating costs according to the market share of passenger trains in each network. The specific operating expenditure of the infrastructure manager per freight train-km for example in networks with a high share of freight traffic like Austria is much higher than the costs per train-km of all trains.

The operating expenses for infrastructure management in 2009 increase with the number of train-km realized. A better indicator for the distribution of the operating costs for infrastructure management between passenger and cargo trains would be to calculate the costs per gross-tonne hauled. Unfortunately, this important data is not reported by most of the infrastructure managers.

As ProRail has subcontracted all infrastructure maintenance works, its operating costs are accounted for its own administration and engineering staff only and lead to relatively high costs per staff. In this case, the efficiency indicator of operating cost per staff member cannot be used for benchmarking with other railway undertakings and infrastructure managers. Furthermore, the cost allocation for property (station buildings and ground) that does not directly belong to the railway infrastructure may differ a lot.

#### 4.4 Data Envelopment Analysis

Data Envelopment Analysis (DEA) is a non-parametric estimation technique that uses linear programming to construct a piecewise linear envelopment frontier over the data points such that all observed points lie on or below the production frontier. In other words: DEA constructs a non-parametric surface or frontier over the data. Compared to others, railway systems located on the frontier are considered more efficient, systems located outside the frontier are considered less efficient. The relative distance to the frontier specifies the degree of inefficiency.

DEA is a preferred methodology in regulated industries (e.g. rail transport) where objectives as cost minimization or profit maximization might not be the prime objective. DEA can handle the multiple input-output relationships quite well. The shared nature of a railway system, in which both passenger and cargo services are offered on the same rail network, sometimes with shared rolling stock equipment and staff, is handled quite well by this multiple input-output assessment method. Together with the fact that DEA does not require data to be specified in monetary terms, it remains a popular way to estimate efficiency of railway systems due to the large difficulty of gathering price and cost data in the railway industry.

Efficiency and effectiveness levels of the different ‘Decision Making Units’ are then calculated by estimating the relative distance to the frontier. The type of DEA, inputs, outputs and evaluation methods chosen are listed in Tab. 1. The inputs consists of length of tracks, operating expenditure and staff strength of the incumbent passenger train operating company (TOC) and the infrastructure manager (IM) respectively. We assess the efficiency and effectiveness of the TOC and IM. The performance of freight train operating companies could not be analysed due to insufficient empirical data. However, the train-km and gross hauled tonne-km of freight trains on the infrastructure network have been considered in the analysis of the overall network load and assessment of the efficiency and effectiveness of the IM if they are reported.

Table 1 – DEA inputs, outputs and methods chosen of mid-size European railway operators and networks

| DEA Type                   | Inputs                        | Outputs                         | Model Type                             | Orientation    | Return to Scale                 |
|----------------------------|-------------------------------|---------------------------------|----------------------------------------|----------------|---------------------------------|
| Efficiency Analysis TOC    | Length of tracks (km)         | Train-km<br>Passenger<br>Trains | Basic Radial Model (Envelopment forms) | Input Oriented | Constant Returns to Scale (CRS) |
|                            | Operating Expenditure TOC (€) |                                 |                                        |                |                                 |
|                            | Staff strength TOC (fte)      |                                 |                                        |                |                                 |
| Effectiveness Analysis TOC | Length of tracks (km)         | Passenger-km (Pkm)              |                                        |                |                                 |
|                            | Operating Expenditure TOC (€) | # of transported Passengers     |                                        |                |                                 |
|                            | Staff strength TOC (fte)      |                                 |                                        |                |                                 |
| Efficiency Analysis IM     | Length of tracks (km)         | Train-km<br>Passenger<br>Trains |                                        |                |                                 |
|                            | Operating                     | Train-km                        |                                        |                |                                 |

|                           |                              |                           |  |  |  |
|---------------------------|------------------------------|---------------------------|--|--|--|
|                           | Expenditure IM (€)           | Freight Trains            |  |  |  |
|                           | Staff strength IM (fte)      |                           |  |  |  |
| Effectiveness Analysis IM | Length of tracks (km)        | Passenger-km (Pkm)        |  |  |  |
|                           | Operating Expenditure IM (€) | Gross hauled Ton-km (Tkm) |  |  |  |
|                           | Staff strength IM (fte)      |                           |  |  |  |

Results from DEA yield that a number of TOC operate 2009 on the efficient frontier if train-km is used as output variable: ÖBB, CD, NS, ZSSK, SJ and SBB (Fig. 21). FS, NMBS, DSB and NSB do not operate on the efficient frontier. The DEA efficiency score, thus, does not at all express the existing significantly different levels of train operating efficiency revealed in chapter 4.2. In respect to effectiveness scores, only NS, SJ and SBB perform on the effective frontier if passenger-km is used as output variable (Fig. 22).

When the number of passengers transported is taken as output, surprisingly DSB, NS and ZSSK operate at the effective frontier (Fig. 23). The resulting DEA effectiveness scores regarding the transport volume of incumbent TOC are not in line with the outcome of the productivity analysis, which rank FS, NS and SJ on top concerning e.g. the mean passenger volume per train (chapter 4.1).

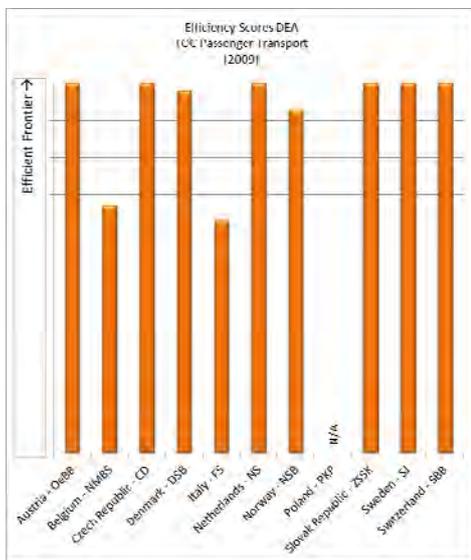


Figure 21: DEA Efficiency scores for train-km as output of incumbent passenger train operating companies in Europe 2009

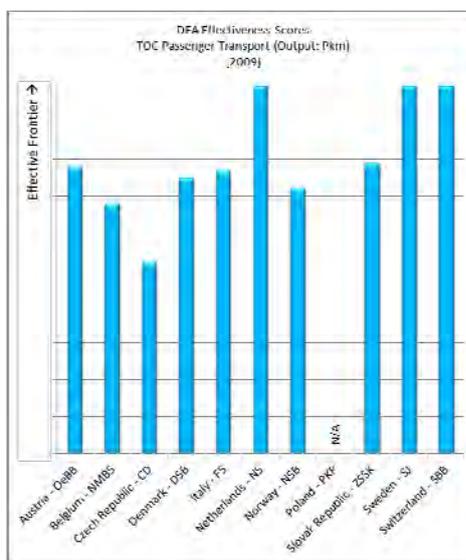


Figure 22: DEA Effectiveness scores for pass-km as output of incumbent passenger train operating companies in Europe 2009

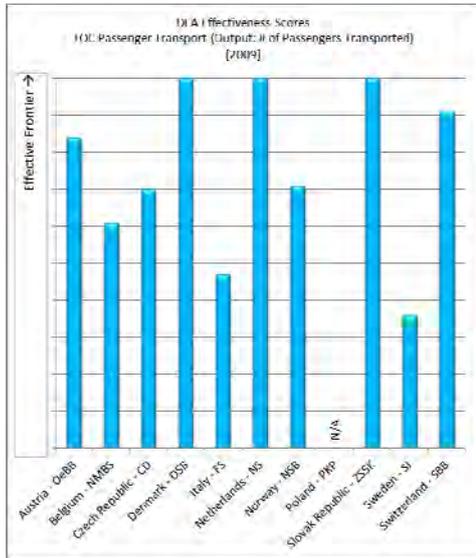


Figure 23: DEA Effectiveness scores for passenger volume as output of incumbent TOC 2009

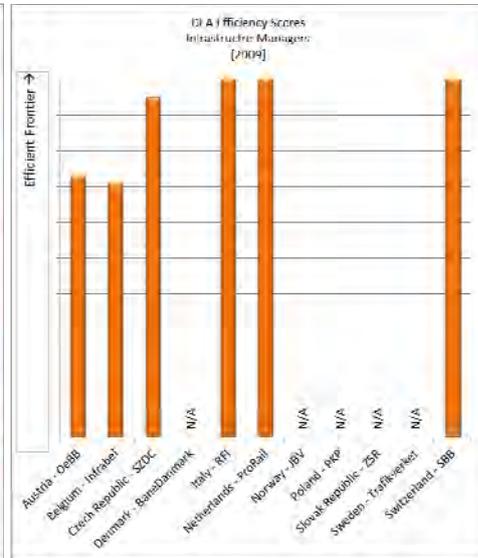


Figure 24: DEA Efficiency scores for output of infrastructure managers 2009

Regarding the efficiency of infrastructure managers only the IM's of Austria, Belgium, Czech Republic, Italy, the Netherlands and Switzerland provide sufficient data and can be included in the efficiency and effectiveness analysis by DEA. The Italian, Dutch and Swiss IM represent the efficiency frontier of production measured by the length of tracks, operating expenditure and staff strength 2009 (Fig. 24). The DEA effectiveness score of the infrastructure managers for the important output indicator tonne-km, unfortunately, cannot be calculated due to lack of data from a lot of countries.

Overall, the resulting DEA efficiency and effectiveness scores of TOC and IM of a single year suffer from incomplete data, are rather inconclusive and cannot explain satisfactorily existing performance differences. More disaggregated input and output data from more countries covering observation periods of about 10 years is needed to enable a better estimate for the relative distance of individual railway networks and train operating companies from the performance frontier.

## 5 Conclusions

The performance analysis of 11 mid-size European railway networks and undertakings by means of parametric system and regression analysis, as well as non-parametric DEA of key performance indicators for effectiveness and efficiency of the single year 2009 reveals structural shortcomings in the current database of UIC especially regarding freight transport, gross tonne-km production and regional passenger transport especially by private operating companies. The transparency of the operating cost and staff allocation for infrastructure management, passenger transport and freight transport is still insufficient. System and regression analysis of the passenger train operations and infrastructure management performance can generate new insights into the interdependence between the relevant inputs and outputs.

The transport performance of the main (incumbent) passenger train operating

companies, measured as number of passenger-km in 2009, depends strongly on the number of passenger train-km realised and increases by approximately 0.16% per train-km. The mean passenger volume per train trip varies between 52 and 164. Unfortunately, the corresponding load factor of the trains operated, which is one of the most important efficiency indicators of passenger transport companies, cannot be calculated because reliable data concerning the number and density of passenger spaces is either not reported or does not reflect the real variation of train types, lengths and transport capacity during the different service periods. The operating expenditure of the main passenger train operating companies

The performance analysis of train operating companies and infrastructure managers respectively by means of DEA for the single year 2009 did not generate satisfactory results as the data sample and the observation period are much too small. The output scores of a single year cannot well explain considerable differences regarding the network, train and staff productivity, as well as the efficiency and effectiveness of train operations and infrastructure management.

More comprehensive benchmark analysis research based on further extended empirical data is strongly recommended especially regarding the density of stations and transport volume per line, transport capacity, load factor and punctuality of the trains including private passenger and freight train operators, larger networks and longer observations periods (preferably 10 years). This will enable to identify the most important drivers for productivity, efficiency and reliability of railway networks and undertakings.

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