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Efficiency Evaluation of Pakistan Railways Using Data Envelopment Analysis

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Abstract
Rails are one of the safe, reliable and profitable transportation system for any country. The Pakistan Railways carried only 47 million passengers and 1.6 million tonne freight in 2013-14, compared to 113 million passengers and 11 million tonnes freight in 1985-86. There is greater need for efficiency evaluation of Pakistan Railways. In this report we are using Data Envelopment Analysis (DEA) method to evaluate and compare the efficiency of Pakistan Railways from the year 1950 to 2014. We have used super efficiency model to rank the efficient years and reference units were introduced for every inefficient year and determine the amount of input decrease and output increase to make them efficient. We found that the minimum and maximum efficiency is 0.518 and 1.151, respectively and only six years were identified as efficient years. The results show that the efficiency of railway in the year after 1980 are inefficient years, except 2006-07 and 2008-09 which represents the declining trend of railways. Taken together, these results suggest that the mismanagement and lack of professional expertise plague the railways as a fast shrinking public sector organization.
Keywords: Data Envelopment Analysis, Railways, Efficiency

1. INTRODUCTION

It is collectively acknowledged that transport is essential for sustained economic growth and modernization of country. Transport infrastructure is an important determinant for the success of nation expanding its production, trade and linking resources and markets into integrated economy. Therefore, transport is a key input in production process and adequate provision of transport infrastructure helps in increasing productivity and lowering production costs.

Transportation can be divided into air, railways, land and sea. In comparison to other modes of transport, rail transport is relatively reliable and safe. Thus high level of safety makes the rail transport more favourable and preferable. The appropriate employment of this mode to its full potential can help reduce the jamming and irregularities of road transport, safeguarding a further safer and smooth travelling. Railway traffic is an efficient and environment friendly transport system in many cases, whereas large volumes of goods can be transported over long distances quickly with minor impact upon the environment. The share of CO_2 emissions from transport has continuously increased since 2010 from 22.7% to 23.4% in 2013. In 2013, 3.5% of transport CO_2 emissions were due to the rail sector, while railways transported 8% of the world's passengers and goods [20]. Road transport occupies almost 74% of agricultural land while railway transport occupies 27% only, even though its traffic performance is almost twice as that of the road traffic [21].

The idea of a railway system in Indian Subcontinent was first initiated in 1850s. During the British ruler ship in the Indian Subcontinent which was initially named as "North Western State Railways", later renamed as "North Western Railways" and afterward extensions were carried out infrequently as per needs and requirements and eventually after independence this became Pakistan Railways in 1947. At the time of independence, North Western Railways was divided with 1,847 route miles lying in India and 5048 route miles in Pakistan [20]. Pakistan railways is a two-gauge system i.e., broad-gauge and meter-gauge. In 2015, the track kilometres of broad-gauge and meter-gauge was 11,492 and 389 respectively.

The Pakistan Ministry of Railway is responsible for the overall control of Railways as well as to guide and formulate its overall policy. Pakistan Railway comprises of four directorates: Administrative Directorate, Technical Directorate, Planning Directorate, and Finance Directorate [17]. Railway Board is the highest body for technical matters of the Railways; Secretary of Ministry of Railways is also ex-officio Chairman of the Railway Board. Currently Pakistan Railways is a vertically integrated organization with four business units and is headed by a General Manager, who is the Chief Executive Officer assisted by four Additional General Managers, namely, Infrastructure Business Unit, Passenger Business Unit, Freight Business Unit and Manufacturing and Services Unit that looks after: Concrete Sleeper Factories, (CSF), and Carriage Factory Islamabad, (CFI), Locomotive Factory Risalpur, Rehabilitation Project, Medical and Health Service; Railway Construction Company (RAILCOP), Pakistan Railway Advisory and Consultancy Services (PRACS) and Educational Facilities.

Pakistan Railway is labour intensive industry having workforce of about more than 78 thousand employees. Apart from the formal employment, Pakistan Railway is generating informal employment to majority of individuals. Once Pakistan Railways was life line of the country, with budget deficit of billions of dollars, decreasing market share and corruption scandals, the future of Pakistan Railways is grim. At the time of independence both India and Pakistan inherited the Railway Network laid down by British. While India Railways has emerged as a highly profitable organization, contrary is the situation for Pakistan Railways that is struggling for its survival. According to rail transport network size, Pakistan stood 27th in world ranking with 7791 railway length km [18] and India stood 4th with 66,687 railway length km [9]. Pakistan's performance on the quality of transportation infrastructure is worse than that of other Asian countries. Railway transport in Pakistan is functional, it suffers from low quality, long travelling times and poor reliability. Pakistan railways used to be major mode of transportation in the country, which, at its peak in the 1960s and 70s, handled more than 70 percent of freight traffic, compared to less than four percent in 2014. Total number of locomotives, freight and passenger wagons decreased to 47, 36 and 33 percent from 1950 to 2014 respectively.

Efficiency evaluation is important for staying competitive and prospering in a business environment facing global competition. Efficiency can be used as a criterion for analysing the performance of organisations in different times. Efficiency has been analysed under many points of view, using different techniques and investigating its main determinants.

There are very few studies about analysing and estimating productivity and efficiency in transportation especially in railways. Oum and Yu [20] attempted to compare and reconcile the results of efficiency obtained by using concept of output. Also Oum et al. [14] measured alternative methodologies for measuring and comparing the efficiency of railways and published a complete overview of productivity and efficiency in rail transport in which it is clear that results of these estimates are very sensitive to output specifications. Cantos at al. [3] analyses the efficiency of European railway companies to different alternatives in output specification. In this study the number of passenger-kilometres, ton-kilometres, passenger train-kilometres and freight train-kilometres are used as outputs and number of workers, consumption of energy and materials, number of locomotives, number of passenger carriages, number of freight cars and number of track-kilometres as inputs. Cowie and Riddington [6] used different methodologies and concluded that accurate measurement of efficiency is not possible, although the research is able to indicate good and bad performers and efficiency of the railways is of good management.

One of the factors showing efficiency of railways is the ratio of outputs to inputs. There are two ways of analysing the efficiency, which are parametric methods and non-parametric methods. One of these non-parametric method called Data Envelopment Analysis (DEA). It has been extensively used to compare the efficiencies of non-profit and profit organizations in which there are homogenous units.

DEA has been applied in the field of transport like ports, railways, airlines and urban transit. It is used for calculating efficiency of transport companies, cross-country and cross-year comparisons. Sanchez [7] undertakes a comparative efficiency analysis of public bus transport in Spain using Data Envelopment Analysis. A procedure for efficiency evaluation was established with a view to estimating its technical and scale efficiency. Savolainen [19] uses Data Envelopment Analysis as a method to evaluate individually the current relative technical efficiencies of three European transportation systems: rail, maritime and air. Railways show huge variations between different countries and also between different years within same company in relative technical efficiency. Movahedi et al [11] evaluated the Iranian railway efficiency from 1971 to 2004 and efficiency of each year is compared to other years by using Data Envelopment analysis.

In our study we focus on calculating and comparing the Pakistan Railway efficiency in different years. Other purposes are; which and how many of inputs should be decreased and which outputs should be increased for increasing the efficiency. The efficiency and performance of railway in different years will be compared by using DEA method. The main benefit of the DEA method is reflected that have multiple inputs and outputs. After identifying the efficient years, the Andersen-Petersen method is used for ranking.

2. METHODOLOGY

Data Envelopment Analysis (DEA) is a linear programming technique that evaluates the relative efficiency of homogenous units called Decision making units (DMUs) by considering multiple inputs and inputs. DEA calculates the efficiency as a ratio of the weighted sum of outputs to the weighted sum of inputs. DEA produces a single comprehensive measure of performance for each DMU for a given set of input and output variables.

2.1 CRS and VRS DEA models

There are two types of DEA models – CRS and VRS model, depending on the type of envelopment surface. Charnes, Cooper and Rhodes proposed the CRS model and alternatively called as CCR model by the authors [4]. The basic idea of this model is to assume constant return to scale and CRS model is appropriate when all DMUs are operating at optimal scale. Banker, Charnes and Cooper suggested the VRS model and alternatively called as BCC model by authors [2]. BCC model is an extension of the CRS DEA model to account for variable returns to scale situations.

DEA models can be applied in input and output orientation. Input-oriented measures keep output fixed and explore the proportion of the possible reduction in inputs, while output-oriented measures keep inputs fixed and explore the possible proportional expansion in output. DEA results are same under CRS whether an input orientation or an output orientation. However, the input and output orientation are not same under VRS.
The DEA method expresses the following pattern to measure the efficiency:

$$Max\ W = \sum_{r=1}^{s} u_r y_{rj} \quad (1)$$

$$s.t: \sum_{i=1}^{m} v_i x_{ij} = 1 \quad (2)$$

$$\sum_{r=1}^{s} u_r y_{rj} - \sum_{i=1}^{m} v_i x_{ij} \leq 0, \quad j = 1, 2, \ldots\ldots n, \quad (3)$$

$$u_r \geq 0 \ \ r = 1, 2, \ldots\ldots\ldots s \quad (4)$$

$$v_i \geq 0 \ i = 1, 2, \ldots\ldots\ldots m \quad (5)$$

where
y_{rj} is the amount of output r from unit j
x_{ij} is the amount of input i to unit j
W is the relative efficiency
n is number of DMUs
m is number of inputs
s is number of outputs
u_r is weight coefficient of output r
v_i is weight coefficient of input i

The above model is used in our study to identify the best performing years. DEA is a powerful tool when used wisely. As DEA can handle multiple input and multiple output, inputs and outputs can have different units. It doesn't require an assumption of a functional form relating inputs and outputs and DMUs are directly compared against a peer or combination peers.

2.2 Super-Efficiency Model

The maximum efficiency value obtained by DEA model is 1, and the efficiency values of efficient DMUs are same. Therefore, it is possible to rank the inefficient unit based on their inefficiency, while the efficient units fail to be ranked. For ranking the efficient units, a model proposed by Anderson and Peterson which is also known as super-efficiency model [1]. This model is as follows:

$$\min \theta$$

$$s.t. \sum_{\substack{j=1 \\ j \neq k}}^{n} \lambda_j x_{ij} \leq \theta x_{ik}$$

$$\sum_{\substack{j=1 \\ j \neq k}}^{n} \lambda_j y_{rj} \geq y_{rk}$$

$$\lambda \geq 0$$

$$i = 1,2 \ldots, m; r = 1,2 \ldots, q; j = 1,2 \ldots, n \ (j \neq k)$$

Super-efficiency model described above was used in our study to rank the efficient years and identify the best performing one. DEAP program is used for DEA calculations and MaxDEA software is used for super efficiency calculations. Research sample of our study is described in the following section.

2.3 Data Sample:

The aim of this study is the analysis and calculation of annual performance and efficiency in years 1950-2013. So, the railway efficiency in each year was calculated and the annual performance of railways was considered as an independent DMU.

By using DEA model, Movahedi et all [13] compared the Iranian railway performance with 70 countries. This research has considered the main tracks, number of locomotives, passenger cars, freight wagons and staff, as inputs and the passenger-kilometre and freight ton-kilometre as output variables. Our selection of input and outputs is in line with the study done by Movahedi et all [12]. We used five inputs and two outputs for DEA efficiency calculations. Each factor which has a cost nature is considered as an input and each factor with a benefit nature is considered as an output. The used inputs and outputs were selected based on the research limitations and availability of information which are as under:

(a) Input variables

I1: Number of Locomotives owned
I2: Number of freight wagons owned
I3: Number of coaching vehicles
I4: Total track-kilometres
I5: Total number of employed persons

(b) output variables

O1: Total number of passengers carried in thousands
O2: Total freight carried tonnes in thousands

The input and output data in each year for the railway were obtained from Pakistan railway year book 2014-2015 and Pakistan Economic Survey 2014-15 and 2006-2007. According to availability, data is taken as an average of every five years from 1950 to 1995 and from 1996 to 2013 each year data is used.

3. RESULTS

The railway efficiency was analysed during 27 years for the period of 1950-2013 and results obtained by DEA models are presented in table 1. The table contains DMUs, efficiency scores and reference sets. The results show that, within the 27 years, only 6 years (1955-60, 1960-65, 1965-70, 1975-80, 2006-07 and 2008-09) were found to be efficient years. Although within the 06 years the railway efficiency has been equal to "1", of course it doesn't mean that it is perfect "100%", and only shows that the railway efficiency in these years is higher than the other ones. For example, the year 2008-09 is an efficient year which means that the railway has used its resources better than the other years. Contrary, the year 2012-13 is an inefficient year in which its efficiency value equals 0.56. It means that the railway just uses 56% of its inputs to maximize the output and 44% of them were wasted.

Table 1: Efficiency Scores and Reference sets of Inefficient Years

DMUs	Efficiency	Benchmark (λ)
1950-55 Average	0.847	1960-65 = 0.277 1955-60 = 0.455
1970-75 Average	0.965	1975-80 = 0.780 1960-65 = 0.162
1980-85 Average	0.855	1975-80 = 0.517 1960-65 = 0.302
1985-90 Average	0.920	1960-65 = 0.774
1990-95 Average	0.740	1975-80 = 0.019 1960-65 = 0.525
1996-97	0.744	1960-65 = 0.027 1975-80 = 0.449
1997-98	0.754	1960-65 = 0.010 1975-80 = 0.436
1998-99	0.724	2006-07 = 0.403 1975-80 = 0.214
1999-00	0.750	2008-09 = 0.311 1975-80 = 0.106 2006-07 = 0.315
2000-01	0.762	2008-09 = 0.381 1975-80 = 0.257
2001-02	0.805	2008-09 = 0.369 1975-80 = 0.242 2006-07 = 0.039
2002-03	0.838	2008-09 = 0.283 1975-80 = 0.209 2006-07 = 0.221
2003-04	0.858	1975-80 = 0.126 2008-09 = 0.694
2004-05	0.932	1975-80 = 0.037 2008-09 = 0.645 2006-07 = 0.232
2005-06	0.973	1975-80 = 0.023 2006-07 = 0.931
2007-08	0.986	1960-65 = 0.080 1975-80 = 0.204 2008-09 = 0.487
2009-10	0.949	2008-09 = 0.907
2010-11	0.809	1975-80 = 0.022 2008-09 = 0.325 2006-07 = 0.415
2011-12	0.518	2008-09 = 0.243 2006-07 = 0.251
2012-13	0.560	2008-09 = 0.247 2006-07 = 0.257
2013-14	0.735	2006-07 = 0.568

In table 1, the reference benchmarking is denoted by Benchmark (Lamda), where Lamda is the referenced coefficient of DMU. The values of benchmark column showed that each inefficient year have been compared to which one of the efficient years. For example, the reference benchmarks of 2012-13 are 2008-09 (0.247) and 2006-07 (0.257), which means that the projection point of 2012-13 on the frontier is made up of a linear combination of the input-output of 2008-09 and 2006-07, and weight coefficients are 0.247 and 0.257 respectively. Also for the other inefficient years we can get similar results. The year 2008-09 has got better efficiency than 2009-10, because its efficient value is equal to 1.

DEA divides the analysed units into two groups of efficient and non-efficient. Efficient units are those that their rank of efficiency equals 1. The non-efficient units will be ranked but the units whose ranks are 1 are not able to be ranked using the classic DEA methods. For this reason, Anderson-Peterson ranking model is used which is also called as super efficiency model.

Table 2: Rank of Efficient Years

Year	1975-80	2008-09	1960-65	2006-07	1965-70	1955-60
Rank	1	2	3	4	5	6
Efficiency	1.151783	1.090099	1.074654	1.029495	1.023792	1.01179

Table 2 shows the efficient years, which were ranked according to their efficiency. Based on the results, the efficiency value of 1975-80 is 1.151 as first rank and the years 2008-09, 1960-65, 2006-07, 1965-70 and 1955-60 are ranked respectively.

Table 3 shows the necessary changes in inputs and outputs to make the non-efficient years as an efficient one. For example, in 2013-14 the railway could have to decrease the input usage for 26.55% for number of locomotives, 31% for freight wagons, 35.78% for coaching vehicles, 43.84% for total track kilometres and 38.53% for number of employed persons. Also, the railway has to increase the number of passengers carried by 36.15% and freight carried in tonnes by 208.60% to achieve the efficiency level. Also, the similar results can be achieved for the other non-efficient years.

Table 3: Percentage change in input and output

Year	I1	I2	I3	I4	I5	O1	O2
1950-55 Average	24.80	15.26	18.14	26.39	15.26	22.09	18.01
1970-75 Average	9.44	10.13	11.90	5.72	3.53	3.66	3.66
1980-85 Average	15.64	20.79	19.17	19.55	14.55	17.02	17.02
1985-90 Average	8.04	31.38	24.29	25.54	26.28	29.14	8.74
1990-95 Average	25.96	43.16	38.82	47.63	43.29	35.06	35.06
1996-97	25.58	25.72	36.67	48.37	32.54	34.37	34.37
1997-98	24.59	33.03	38.21	51.49	36.05	32.61	32.61
1998-99	27.60	35.69	32.98	36.07	32.33	38.12	38.12
1999-00	25.02	35.52	25.02	25.02	26.37	33.37	56.39
2000-01	23.83	33.24	23.83	33.31	25.84	31.29	35.32
2001-02	19.46	31.90	19.46	32.21	19.46	24.17	27.99
2002-03	16.15	28.90	16.15	26.10	16.34	19.26	19.26
2003-04	14.23	23.93	14.23	15.65	15.86	16.59	23.49
2004-05	6.85	20.86	6.85	6.85	7.68	7.35	8.28
2005-06	2.75	8.14	2.76	3.45	2.75	2.83	7.17
2007-08	1.39	1.39	8.49	20.86	8.20	1.41	1.41
2009-10	5.30	5.07	9.92	9.25	7.95	5.35	13.63
2010-11	19.12	21.08	19.12	24.15	19.12	23.65	146.61
2011-12	48.22	48.22	50.14	50.97	48.43	93.12	381.02
2012-13	44.03	44.03	48.01	49.94	47.16	78.65	491.53
2013-14	26.55	31.00	35.78	43.84	38.53	36.15	208.60

4. CONCLUSION:

In this study we have performed an extensive analysis of efficiency and performance of Pakistan Railways from 1950 to 2014. We found that year 2011-12 has the minimum efficiency of 0.518 and 1975-80 has the maximum efficiency of 1.151. The efficiency score shows that railway was at its peak in the 1960s to 80s. Railways used to be the predominant mode of transportation in Pakistan, handled 73 percent of the freight traffic in 1960s, compared to less than four percent by 2011 and total freight and passengers carried decreased by 31 percent [10]. From 1980-85 to 2005-06 we find no efficient years whose reason is decrease in freight and passengers carried. The scarcity of locomotives forced the railways to focus on passenger traffic more than the transportation of goods, though it is more profitable.

It is important to understand that Pakistan railways is dying a slow death. The main reason is decrease in assets like locomotives, wagons and track kilometres. Corruption, mismanagement, nepotism and lack of professional expertise plague the railways as a fast shrinking public sector organization in Pakistan. The input and output data shows that, Pakistan railways carried only 47 million passengers in 2013-14, compared to 113 million in 1985-86. From 11 million tonnes of freight in 1985-86, the volume was down to 1.6 million tonnes. Despite the drastic decline in services, railways still carried a workforce of 80,000 employees.

In order to improve the efficiency one solution to prepare better plans for using railway inputs efficiently and economically. The other solution is to increase the outputs which can be obtained through more freight and passengers carried. The third solution for increasing efficiency is to replace the old and out of service locomotives and wagons with new ones. The other solutions are to increase the revenues and decrease in expenditures with upgradation of technology and decrease in employed persons.

It should be mentioned that there are some other factors that can affect the efficiency of railways. These factors are quality of service, installation of modern infrastructure and longer rail routes in comparison to the roads. For example, if rail route is longer than roads the ton-milometer and passenger-kilometre would be longer than the road in which it seems that the railway efficiency is higher while the railway customers waste a lot of time. There are several potential capabilities in the railway which must be studied. In regard to the research limitations, the above mentioned items can be used for future research.

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