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Efficiency Measurement of Indian Railways - A DEA based Study

Sabyasachi S Roy[1], Mukul Kulshrestha[2]
[1] Senior Instructor, Indian Railway Institute of Civil Engineering, Pune, India, Email: sit10iricen@gmail.com
[2] Professor, Department of Civil Engineering, MANIT-Bhopal, India, Email: mukul_kuls@yahoo.com

ABSTRACT

Indian Railways (IR) rank amongst the World's largest Government owned Railway networks, and is governed by a separate government Ministry, unlike the other worldwide Railway systems that have been corporatized. Being a monopoly of government, Railway services in India remain essentially stretched and scope exists for making the services efficient, although there is a dearth of scientific studies that prove so. This paper uses a Data Envelopment Analysis (DEA) based methodology to estimate efficiencies of Indian Railways for Fifteen years period by deploying Two Input Oriented Models that account for indicators like Operating Expenditures, Staff Employed, Passengers originating, Freight Carried and Rail Network length. The Results of the various Models such as the Efficiencies, the Returns to Scale, and the notional loss due to the inefficiencies are discussed in this paper. Results indicate existence of efficiencies that on the lower side range below 50%, with mostly decreasing returns to scale implying that even increase in operating expenditures or staff are likely to yield lesser and lesser benefits. In this context, the paper identifies operating expenditure and staff reduction as measures that may be undertaken by the India Railways for bringing about increasing efficiencies.

Key words : Data Envelopment Analysis, Indian Railways, inefficiencies, Operating Expenditures, Staff reduction.

1. INTRODUCTION

Indian Railways are burdened with extraordinarily large operations. They have 4th largest rail network in the world after US, China and Russia, and are the eighth biggest employer in the world [1] employing 13.31 million employees who operate on ninety three Track kilometers laid across the country. Running as many as 11200 locos, 70000 coaches and 252000 wagons, the Indian Railways carry twenty three million passengers daily, plus three million tons of freight. This is achieved by running twenty-one thousand trains on a daily basis [2].

In terms of performances, the services remain stretched and passengers remain far from being fully satisfied, although the level of satisfaction seems to have increased in recent years. Improvement in terms of speed of trains, as well as the quality of services measured by seat availability, quality of coaches and platform maintenance remains highly sought after despite government trying its might. Efficiencies need to be inducted essentially if private sector participation is warranted. For this, the performances of the Indian Railways need to be analysed first to ensure further reforms.

This paper applies a non-parametric technique, Data envelopment analysis (DEA) used in operations research and economics for the estimation of efficiencies in a multiple outputs and multiple inputs situations often encountered in network industries such as the Indian Railways. The paper evaluates the efficiencies of the Indian Railways (yearly performances of Indian Railways over a period 2002-2017) with the objective of evaluating the time-variation of efficiencies of Indian Railways, and for assessing the potential of efficiency improvements in Staff management and Operational Efficiencies.

2. LITERATURE REVIEW

Data Envelopment Analysis (DEA) is a mathematical technique for determining the relative efficiencies of firms. Its applications spread widely across various infrastructure sectors such as the

- Irrigation networks [3]-[5]
- Municipal Solid waste [6]
- Transportation Networks [7]-[13]
- Water supplies [8]-[9]

However, there exists a deficiency of studies that employ DEA for the Indian Railways, despite some studies on evaluation of the railways in other parts of the world (example, [16]-[18]). Indian Railways being government controlled, have not bothered much about measuring efficiencies, thus effectively lacking a transparent publicly available database on performance parameters, which might be the cause for scarce measurements in this Indian sector.

3. METHODOLOGY EMPLOYED AND MODEL FORMULATION

The current study employed a non-parametric approach (DEA) to evaluate the efficiencies of the Indian Railways and suggest some policy perspectives. DEA has two advantages over other techniques. First, it does not require specification of any functional form for production, avoiding the bias produced by an incorrect functional form. Second, DEA is better than parametric techniques at assessing the productive efficiency of railway companies since it can handle the multi-product nature of some companies as has been pointed out by Cantos et al (2000) [19]. The methodology is applied to two different models with constant-returns-to-scale (CRS) model, and the variable-returns-to-scale (VRS) model.

3.1 The CRS model

This model was suggested by Charnes, Cooper and Rhodes in [20] (hence also called the CCR model) which is concerned with the estimation of technical efficiency and efficient frontiers. This model uses a constant return to scale assumption.

Efficiency = Σ weighted outputs / Σ weighted inputs (1)

If the sample has z utilities, each having outputs and inputs m and n respectively, the efficiency of utility p can be attained as:

$$\max \quad \sum_{k=1}^{n} v_k y_{kp} / \sum_{j=1}^{m} u_j x_{jp}$$

$$s.t. \quad \sum_{k=1}^{n} v_k y_{ki} / \sum_{j=1}^{m} u_j x_{ji} \le 1 \quad \forall i$$

$$u_{j,} v_k \ge 0 \quad \forall j,k \qquad (2)$$

where i= 1 to z, j= 1 to m, k= 1 to n, yki= amount of output k produced by DMU i, xji= amount of input j utilized by DMU i, vk= weight given to output k and uj= weight given to input j.

Equation (2) can be converted to a linear programming format that is solved using a mathematical dual to determine efficiency score θ

$$\min_{\theta,\lambda} \theta$$

$$s.t. \quad \theta x_{jp} - \sum_{i=1}^{z} \lambda_i x_{ji} \ge 0 \quad \forall j$$

$$- y_{kp} + \sum_{i=1}^{z} \lambda_i y_{ki} \ge 0 \quad \forall k$$

$$\lambda_i \ge 0 \quad \forall i \qquad (3)$$

Where, λi = dual variables

3.2 The VRS model

Banker et al. [21] added a convexity constraint as shown in equation 4, to determine efficiency under variable-returns-to–scale condition.

$$\min_{\theta,\lambda} \theta$$

$$s.t. \quad \theta x_{jp} - \sum_{i=1}^{z} \lambda_i x_{ji} \ge 0 \quad \forall j$$

$$- y_{kp} + \sum_{i=1}^{z} \lambda_i y_{ki} \ge 0 \quad \forall k$$

$$\sum_{i=1}^{z} \lambda_i = 1$$

$$\lambda_i \ge 0 \quad \forall i \qquad (4)$$

3.3 Model Formulation

Two Input oriented DEA models (Table 1) were used for efficiency evaluation of Services of Indian Railways. The aim was to minimize the Inputs while obtaining a fixed Level of Services. Thus, 2 Inputs were sought to be minimized - the Operating Expenditure (OPEX) (Model 1), and the level of Manpower or the Staff deployed (Model 2). Four Outputs were thought to be adequately representing the model formulation. The quantum of Passengers and Freight carried formed the obvious two Outputs, while the extent of service coverage represented by the 2 indicators-The Route Length and the Numbers of stations, formed the other 2 Outputs.

Table 1: Summary of DEA Models Employed

Model	Inputs	Outputs
1	1.OPEX (Million Rs.)	1. Passengers (Nos.) 2. Freight ('000 tonnes) 3. Route (kms) 4. Stations
2	1.Staff (Nos.)	1. Passengers (Nos.) 2. Freight ('000 tonnes) 3. Route (kms) 4. Stations

4. RESULTS AND DISCUSSIONS

DEA was applied to various parameters affecting the services/ operations of Indian Railways for a Fifteen years period (2002-2017) that was collected from Indian Railways Annual Statistical Statements, 2002-03 to 2016-17, Railway Board, Ministry of Railways, Govt. of India. Table 2 presents the descriptive analysis of the data for the year range 2002-03 to 2016-17.

Table 2: Descriptive Statistics for Input and Output Variables for the Indian Railways

	Mean	Std Dev	Max	Min
OPEX(Million Rs.)	870889	430380.4	1595110	379970
Staff (Nos)	1373147	53859.23	1475884	1306210
Passengers('000)	7055853	1313545	8420659	4970803
Freight('000 tonnes)	875300	209240.3	1192806	542690
Route Kms	64575	1479.61	67677	63122
Stations(Nos)	6780	987	7783	5124

Descriptive Statistics for the 15 years data (2002-03 to 2016-17) as depicted in Table 2, indicates that the standard deviations were large and the variation between the maximum and minimum values was also large for all the parameters. This indicates the extent to which the Railway Services in India have undergone changes in just a period of one and half decades.

The results of both the models are presented in Figure 1 and Figure 2, illustrating the CRS and VRS Efficiencies. Table 3 presents the returns to scale (RTS) and Scale Efficiencies.

Nearly 80% of the Years showed efficiencies below 90% for CRS Models and more than 50% of the years saw efficiencies scoring below 90% for VRS Models, while nearly 25% or 1/4th of the years saw efficiencies below 70% for all the CRS Models taken together. Thus, the Indian Railways have been significantly inefficient, and it is only recently that better practices are emerging in the sector, probably because of the style of governance of the new government after 2014.

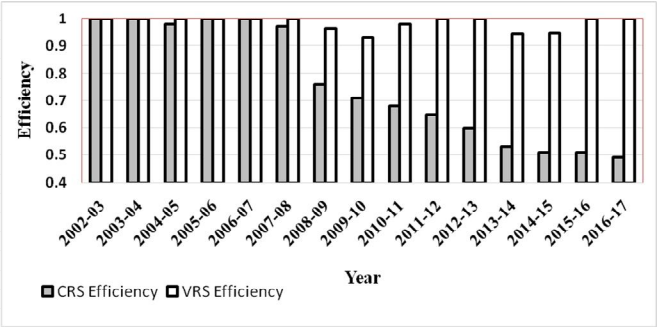

Figure 1: Time-variation of DEA Efficiencies for the Indian Railways for Model 1

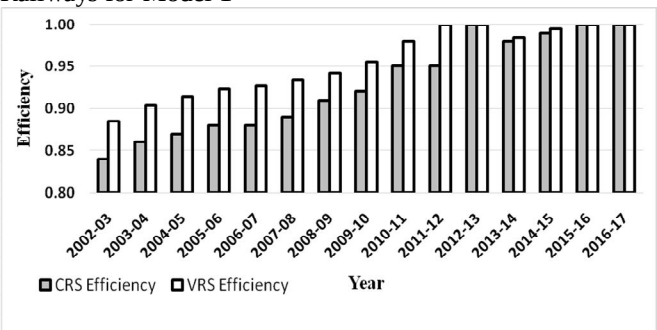

Figure 2: Time-variation of DEA Efficiencies for the Indian Railways for Model 2

Figure 1 depicts that both the CRS and VRS efficiencies of OPEX (Model 1) of the Indian Railways show a decreasing trend while Staff employed show an increasing trend over the period of 15 years. This can also be cross verified from Table 3 which depicts that 80% of the Years for Model 1 show Decreasing Return to Scale while nearly 70% of the Years for Model 2 Show Increasing Return to Scale. This is due to the fact that OPEX of Indian Railways have tremendously increased over the years while earnings from Passengers and Freight have not increased to that extent or might have not kept the pace in line of increase in OPEX. Moreover, IR over the years have not been able to increase its service area in terms of construction of New Railway Lines, Doubling work of the existing Single line sections and construction of new Stations. This is also factually correct that there is a hike in Operating Expenditure due to price rise in fuel cost, increasing cost of maintenance and implementation of seventh pay commission in 2016-17 for its employees which showed 2.57 times rise in salary of the Indian Railway employees [22]. It is evident that the efficiencies for Model 2 in CRS as well as in VRS efficiencies have been steadily on the rise as with the progress of time. The improvements may also have been possible due to reductions in the staff employed over time since 2002-03 and earlier, which must have hugely benefitted the organization. This is due to the fact that government data showcases that there has been a level of reduction in staff from 16.51 lakhs in 1990-91 to 13.31 lakhs in the year 2015-16 [23]. It is noteworthy that railways had become staff heavy due to socialist inclination of the Indian State in the first few decades after independence, and since 1990s when the era of liberalization started in India, employee retirements with new recruitments not keeping the pace along with the retirements saw the employee size pruned to better sizing with passing time, leading to increase in efficiencies over the years. However, the debatable question arises here is that why the OPEX has not decreased while the Staff count has declined over the years as the Staff Salary accounts for about 65% of the OPEX in the year 2016-17 [24]. The reason is that there is a drastic decrease in staff observed only in Group D category of the Railway Employees, while staff Count in Group A, B and C have steadily increased over a period from 1990-91 to 2016-17 as shown in Table 4 [25]. Moreover, the decrease in Group D Staff will only bring down the overall number of staff count and will not boost the economy in a gigantic manner because their annual average salary is 0.425 Million Rupees which is almost 21.5% (1/5th) of Annual Average salary of 1.97 Million Rupees of Group A and B staff and 59% of Annual Average salary of 0.721 Million Rupees of Group C staff for the year 2016-17 [25].

Table 3 indicates that Scale Efficiencies which showed decreasing trend for Model 1 after 2006-07 and gradually reduced further in the years to come. This was due the implementation of the 6th Pay Commission in the Year 2006-07 in Indian Railways which indicates the pay hike of all the serving and retired employees once in a ten years

period. For Model 2, the Scale Efficiency showed a higher high since 2012-13.

Table 3: RTS and Scale efficiencies for the two Models

Year	RTS		Scale Efficiency	
	Model 1	Model 2	Model 1	Model 2
2002-03	C	I	1	0.94
2003-04	C	I	1	0.96
2004-05	D	I	0.98	0.96
2005-06	D	I	1	0.96
2006-07	C	I	1	0.95
2007-08	D	I	0.97	0.96
2008-09	D	I	0.79	0.97
2009-10	D	I	0.76	0.96
2010-11	D	I	0.69	0.97
2011-12	D	I	0.65	0.95
2012-13	D	C	0.6	1
2013-14	D	C	0.56	1
2014-15	D	C	0.54	1
2015-16	D	C	0.51	1
2016-17	D	C	0.49	1
Trend of RTS (Percent of Total)	D=12 (80%)	D=0 (0%)		
	I=0 (0.%)	I=10 (66.7%)		
	C=3 (20%)	C=5 (33.3%)		

Table 4: Service Group wise Staff Strength in Indian Railways

Year	Group A & B	Group C	Group D
1990-91	14300	891400	746100
2016-17	17308	1230244	83881
Variation (%)	+ 3008 (21.03%)	+ 338844 (38.01%)	- 662219 (88.76%)

The trend of inefficiencies indicates that that there exists significant scope for improvement and rectification of the system. This obviously becomes relevant only if efficiency score is less, as is the case of both the Models, indicating that lessons from the Efficient Years exhibiting the best efficiencies could have been deployed by conducting Micro-level studies to understand the reasons behind efficiencies and the lessons could have been applied to the subsequent Input and Output parameters in future to arrest the decline of efficiencies. This missed opportunity can also be interpreted as wastages in terms of extra cost incurred due to increasing inefficiencies in terms of internal savings that might have been possible by arresting the efficiency decline that took place due to refusal to learn from the current trend of inefficiency prevailing in the system.

The scope of possible potential annual savings was estimated using the CRS models. In theory a lot of possibility of OPEX was squandered away during 2004-05 and after the year 2006-07. This might be due to increased wages of the Railway employees after implementation of the sixth pay commission in the Year 2006-07. Results indicate that by appropriate replication of policies, possibly may have resulted in potential internal savings of Rs. 43,74,955 Millions ($ 58332.73 Millions) for the period of 15 years from 2002-03 to 2016-17. On the other hand if Model 2 was taken into consideration, then also the quantum of savings in terms of Staff comes out to be 1.45 Million for the 15 years period. This implies that even the better efficient model has drastic inefficiencies which if identified and rectified on time, might have generated huge internal savings for the organization.

5. CONCLUSION

Although amongst the world's largest Railway networks, the historic evaluation of performance efficiencies for the Indian Railways has never been systematically attempted so far. The present work has been an attempt to evolve a framework for evaluating these efficiencies of Indian Railways.

The results of the assessment of the efficiencies of the Indian Railways indicate that there are noteworthy inefficiencies in terms of OPEX taken as input variable for the 15 years that were investigated. However, to the credit of the government, the Indian Railways have over the years, consistently improved their performances. It is suggested that to further improve the OPEX, diesel engines may either be phased out, or new technological innovations be made that would not only reduce cost, but also reduce emissions, particularly the greenhouse gases [26], making the Railways environment friendly too.

It is evident from the current study that the Staff employed in Indian Railways plays a vital role in deciding the efficiency of this Government owned Railway. This conforms to the observations that government earlier had lack of proper staff management in operations of services of Indian Railways which has been rectified in the past few years. It is noteworthy that amongst the developing countries like India, it is common that a gigantic organization like the Indian Railways deploys huge manpower, avoiding the use of advanced machineries and automation for carrying out the tasks like cleaning of toilets, track maintenance work, patrolling of track, etc., even though it is possible to have automation in most of the above work, and even in the construction of Metro Tracks as is being done in Nagpur, India [27]. Yet, labour-intensive policies are likely to be prudent in reducing the level of unemployment, although this excess staff leads to inefficiencies.

The study also indicates the importance of learning from the current trend of inefficiencies pertaining in the organisation, as it can result in significant savings in OPEX and manpower.

In other words, if the railways remain inefficient, the government is likely to suffer increasing OPEX and Manpower requirement. Thus, purely from the economic and commercial point of view, the Indian railways need to push reforms faster for bringing about improvements - a decision that would indeed additionally bring about significant social and political benefits too.

REFERENCES

1. Forbes. ***The World's biggest Employers***. Available online https://www.forbes.com/sites/niallmccarthy/2015/06/23/the-worlds-biggest-employers-infographic/#537ce2f686b5 (Last Accessed 18 July, 2020), 2019
2. Ministry of Railways. ***Report of the Committee for Mobilization of Resources for Major Railway Projects and Restructuring of Railway Ministry and Railway Board*** , June 2015, Ministry of Railways, GoI, New Delhi. Available Online http://www.indianrailways.gov.in/railwayboard/uploads/directorate/HLSRC/FINAL_FILE_Final.pdf. Last Accessed 30/03/2020, 2015
3. Sanjay S. Phadnis, Mukul Kulshrestha. **Evaluation of irrigation efficiencies for water users' associations in a major irrigation project in India by DEA**, *Benchmarking: An International Journal*, Vol 19, No 2, pp 193-218, Emerald, USA, 2012 https://doi.org/10.1108/14635771211224536
4. Sanjay S. Phadnis, Mukul Kulshrestha, **Benchmarking for water users associations to enhance performance of the Samrat Ashok Sagar major irrigation Scheme,** *Journal Irrigation and Drainage*, Published on behalf of International Commission for Irrigation and Drainage, Vol 61, pp 449-463, Wiley Publications, 2012 https://doi.org/10.1002/ird.662
5. Sanjay S. Phadnis, Mukul Kulshrestha, **Evaluation for measuring the irrigation service Performance using a scorecard framework**, *Journal Irrigation and Drainage*, Published on behalf of International Commission for Irrigation and Drainage, Vol 62 , pp. 181-192, Wiley Publications http://onlinelibrary.wiley.com/doi/10.1002/ird.1725/abstract, 2013
6. Amit Vishwakarma, Mukul Kulshrestha and Mudit Kulshreshtha. **Performance Assessment of Urban Municipal Solid Waste Management Services in an Indian State**, *The Journal of Solid Waste Technology and Management*, Vol 41, No 3, School of Engineering, Widener University, USA, p 275-284, 2015
7. Kocak, H., **Efficiency examination of Turkish airports with DEA approach**. *International Business Research*, 4(2), 204-212, 2011.
8. Pels, E.and Njegovan, N. **Low-cost airlines and airport competition**. *Transportation Research Part E Logistics and Transportation Review* 45(2), 335-344, 2009
9. Prakash, N.and Dhingra, T. **Efficiency Assessment at major Ports of India for the period 2007-08 to 2013-14 using Data Envelopment Analysis (DEA).** *Energy Infrastructure and Transportation* "Challenges and Way Forward", 46-61, 2016
10. Sameni, M., Priston, J.and Sameni, M. **Evaluating efficiency of Passenger railway stations: A DEA approach**. *Research in Transportation Business and Management*, Vol. 20, 33-38, 2016. https://doi.org/10.1016/j.rtbm.2016.06.001
11. Smith, A.and Nash, C. Discussion Paper- **Rail Efficiency: Cost Research and Its Implications for Policy**. *International Transport Forum*, International Energy Agency, Paris, France, 2014
12. Vishnu, C. R.and Regi, V. **Performance Evaluation of Road Transport Corporations: A Data Envelopment Analysis Approach.** *International Journal of Innovative Research in Science, Engineering and Technology*. Volume 3, Special Issue 5, 468-476, 2014.
13. Wolff, M. **A Model for the Evaluation of Brazilian Road Transport: A Sustainable Perspective**. *Journal of Advanced Transportation*. Volume 2018, 52-61, 2018
14. Sai Amulya Nyathikala and Mukul Kulshrestha, **Performance and productivity measurement of urban water supply services in India**, *Water Science and Technology: Water Supply*, 17(2) International Water Association, IWA, UK , p 407-421 https://doi.org/10.2166/ws.2016.106, 2017
15. Mukul Kulshrestha and Amit Vishwakarma. **Efficiency Evaluation of Urban Water Supply Services in an Indian State**. *International Journal Water Policy*, 15, 134-152, Official Journal of the World Water Council, International Water Association, IWA, UK, 2013
16. Coelli, T.and Perelman, S. **Efficiency measurement, multiple-output technologies and distance functions: with application to European Railways**. *Applied Economics* 32, 1967-1976, 2020
17. Khadem, M.and Preston, J. **Evaluating efficiency of passenger railway stations: A DEA approach**. *Research in Transportation Business and Management*. Volume 20, September, 33-38., 2016
18. Yu, M. M. and Lin, E. T. J. **Efficiency and effectiveness in railway performance using multi-activity network DEA model**. *Omega* 36(6), 1005–1017., 2008
19. Cantos, P. Pastor, J.M, and Serrano, L . **Efficiency measures and output specification: The case of European railways,** *Journal of Transportation and Statistics*, vol. 3 (3), 61-68, 2000.
20. Charnes, A., Cooper, W. W.and Rhodes, E. **Measuring the efficiency of decision-making units**. *European Journal of Operational Research*, 2, 429-444, 1978 https://doi.org/10.1016/0377-2217(78)90138-8
21. Banker, R. D., Charnes, A., & Cooper, W. W. **Some models for estimating technical and scale inefficiencies in data envelopment analysis.** *Management Science*, 30 (9), 1078-1092, 1984

https://doi.org/10.1287/mnsc.30.9.1078

22. ***Report of the Seventh Pay Commission*** (Annex), https://www.finmin.nic.in/sites/default/files/7thCPC_revisedpayrules25072016.pdf?download=1 (Last Accessed 28 May,2020), 2016
23. Ministry of Railways. ***Indian Railways Annual Report and Accounts*** 2016-17, Ministry of Railways, Government of India, New Delhi, 2018.
24. PRS Legislative Research. ***Demand for Grant Analysis: Railways***, Available on https://www.prsindia.org/parliamenttrack/budgets/demand-grants-analysis-railways (Last Accessed 18 July, 2020), 2020
25. IRFC. ***Annual Report 2017-18***, Indian Railway Finance Corporation. Available Online http://irfc.nic.in/wp-content/uploads/2018/12/IRFC-AR-2017-18-Final.pdf, 2018
26. Andrey Y. Dunin , Nguyen Thin Quynh , Mikhail G. Shatrov , Leonid N. Golubkov. **Analysis of the Nozzle Hole Diameter Effect to Common Rail Diesel Engine Characteristics using a Calculated Model of an Internal Combustion Engine,** *International Journal of Emerging Trends in Engineering Research*, *IJETER*, Volume 8, No. 6, 2301-2308, June 2020. https://doi.org/10.30534/ijeter/2020/17862020
27. Adrika Bhattacharya, Shubhangi Neware. **Nagpur Metro Tracks Construction Monitoring System.** *International Journal of Emerging Trends in Engineering Research, IJETER*, Volume 8, No. 5, 2209-2213, May 2020. https://doi.org/10.30534/ijeter/2020/119852020