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Malmquist Index Based Productivity Analysis for Various Zones of Indian Railways

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ABSTRACT: Productivities of Indian Railways remain unmeasured to this day, though its services are often perceived as inadequate with considerable scope for improvement. The challenges to operate world's largest carrier in terms of passengers transported remain immense, as Indian Railways are strictly monopolized by the government. The present work analyses data of 16 zones of the Indian Railways and evaluates decadal productivities during the period 2006-07 and 2016-17. The methodology employed for the estimation of productivity, computes the Malmquist productivity index using a non-parametric technique called the Data Envelopment Analysis (DEA) based analysis. The paper compares the performances of Indian Railways Zones for the periods 2006-07 and 2016-17, and evaluates the quantum and direction of productivities. A total of six Models were employed, two of which were Input Oriented while 4 Output oriented. The results of the various Models in the form of Decadal Productivity change indicate significant declining productivities which may be a cause of worry for policy-makers. The paper discusses these results in the light of possible reforms and policy measures that can lead to increased productivities in the sector. The work will be found useful by various stakeholders including Indian railways, policy-makers, and transportation planning and management experts.

Keywords: Data Envelopment Analysis, Indian Railways Zones, Malmquist productivity Index, policy measures, Productivities, reforms

Abbreviations: DEA, Data Envelopment Analysis; IR, Indian Railways; MI, Malmquist Index; OPEX, Operational Expenditure

I. INTRODUCTION

The Indian Railways (IR) is amongst the largest railway systems in the world covering 30 States and 3 Union Territories [1]. Being a driver of economic growth the IR offer affordable and reliable transportation across almost 8500 stations – from Baramulla in the north to Kanyakumari in the south and from Naliya in the west to Lido in the east, the Indian Railways spans the country *a capite ad calcem*. Running 13000 passenger trains per day that carry more than 23 million passengers daily and 8000 freight trains that carry 3 million gross tons of freight per day [2], the IR revenues amount to approximately one percent of India's GDP [3].

At present, IR is divided into 18 zones, which is headed by General Managers who report to the Railway Board. These 18 zones are further subdivided into 69 divisions, headed by Divisional Railway Managers (DRMs). Besides Operating Zones and Divisions, IR has 10 production units, 297 training establishments (06 Centralized training Institute for Railways Officers, 56 Zonal Training Centers and 235 Other Training centers) [4], 16 public sector Enterprises [5] and other offices working under the control of the Railway Board.

Table 1 delineates the various Zonal Railways, its date of Establishment, its Headquarter (HQ) along with its Divisions. In 1951, the national carrier was unified as one unit and the entire Railway network was divided into nine Zones namely Northern Railway (NR), North Eastern Railway (NER), Northeast Frontier Railway (NFR), Western Railway (WR), Southern Railway (SR), South Central Railway (SCR), South Eastern Railway (SER), Eastern Railway (ER) and Central Railway (CR) [6]. For enhancing efficiency in administration, better customer care and reducing work load on the administrators, seven new zones were created in 2002 [7] taking the count to 16 Zones. The new zones were South Western Railway (SWR), North Western Railway (NWR), West Central Railway (WCR), North Central Railway (NCR), South East Central Railway (SECR), East Coast Railway (ECoR) and East Central Railway (ECR). In 2010, Kolkata Metro was given the status of seventeenth zone of IR thus making the total number of zones 17 while Konkan Railway has been deemed a zone for administrative purpose [8].

The scale of IR has drastically expanded since its nationalization in 1950-51 and further its bifurcation in 2002-03 in terms of number of trains and their carrying capacity as well as in terms of quantum of traffic carried and the area of coverage of its service. However, there is still a wide gap between the improvements in the supply side and the expectations in demand side, both in terms of speed of trains as well as quality and quantum of services. The performance evaluation and productivity estimation is theoretically the first step in any move to make the sector operate in a sustainable fashion. The performance productivity of these Railway zones is not evaluated scientifically till date, and no studies seem to be available on the subject in the literature.

Table 1: Various Zones of the Indian Railways.

S.No.	Zone	Established	Headquarter
1.	Northern	14 April 1952	Delhi
2.	North Eastern	14 April 1952	Gorakhpur
3.	Northeast Frontier	15 January 1958	Guwahati
4.	Eastern	14 April 1952	Kolkata
5.	South Eastern	1955	Garden Reach, Kolkata
6.	South Central	2 October 1966	Secunderabad
7.	Southern	14 April 1951	Chennai
8.	Central	5 November 1951	Mumbai
9.	Western	5 November 1951	Mumbai
10.	South Western	1 April 2003	Hubli
11.	North Western	1 October 2002	Jaipur
12.	West Central	1 April 2003	Jabalpur
13.	North Central	1 April 2003	Allahabad
14.	South East Central	1 April 2003	Bilaspur
15.	East Coast	1 April 2003	Bhubaneswar
16.	East Central	1 October 2002	Hajipur
17.	Kolkata Metro	24 October 1984	Kolkata

II. MATERIALS AND METHODS

A. Work Objectives

The objective of this work was to evaluate the Performance productivities of Indian Railways over a decade, and learn the lessons on the development and evolution of the sector in terms of the various zones of the Indian Railways. The performances were evaluated in terms of operational parameters like annual expenditure, staff, Operating Service level, Revenues earned, freight carried and passenger volumes carried by various zones of Indian Railways.

B. Methodology Applied

The current work employs Malmquist Index (MI) to measures the Productivity change between periods "t" and "t+1".

The Malmquist Index (MI) is a bilateral index used for comparing production technologies of 2 economies or sector performances where time based panel-data is available. Named after Sten Malmquist, the originator of the idea, the Malmquist Productivity Index was formulated and introduced by Douglas W. Caves *et al.,* (1982) [9].

Based on the concept of the Production function, in the present paper construction of Malmquist index is based on DEA methodology, a non-parametric approach for performance evaluation of the efficiencies of Indian Railways Zones. The advantage of DEA being that it does not require specification of any functional form avoiding the possible bias of an assumed incorrect functional form. DEA based analysis to compare the performances of Indian Railways Zones for the periods of 2006-07 and 2016-17 was carried out with the objective of evaluating the time-variant inefficiencies of Indian Railways and for assessing the potential of efficiency improvements in Staff management, Operational Efficiencies, cost and service effectiveness. This analysis was employed to estimate the Malmquist Productivity that declines if Mo > 1, remains unchanged if Mo = 1 and improves if Mo < 1 [10].

The Periods 2006-07 and 2016-17 were chosen to find the Malmquist Index of Indian Railways Zones as these years delineate the implementation of Pay Commission in Indian Railways which represent the pay hike of the employees once in every ten years period.

C. Models Formulation

2 Input-oriented and 4 Output-oriented DEA models were used to assess time-variant efficiency of Indian Railways Zones. These models are presented in Table 2. For Input Oriented Models, the aim was to minimize the Inputs while obtaining a fixed output service while for the Output Oriented Models, aim was to maximize Output services keeping Inputs constant.

Data availability formed a factor in the choice of indicators. In the envelopment model, the number of degrees of freedom increase with the number of zones, and decrease with the number of inputs and outputs. To take care of this constraint, as pointed by Cooper, Seiford and Tone (1999) [11] the number of zones need to be at least thrice the total number of input and output variables. Since data was available for 16 zones the model inputs+outputs were restricted to a maximum of 5.

Thus, 2 Input oriented models were sought to be minimized the Operating Expenditure (OPEX) (Model A), and level of Manpower (Model B). In 4 Output oriented models, the Passengers and Freight carried formed two Outputs, while extent of service coverage represented by Route Length and the Numbers of stations formed the other 2 Outputs. Revenue in Models C and D, and the Passengers Originating and Freight Carried formed Outputs in Models E and F. The Inputs in the Output Oriented Models were Stations covered and the Route Length in combination with either OPEX or the manpower. The models are summarized in Table 2.

Table 2: Model Details.

Model	Inputs	Outputs	Orientation
A	OPEX	Passenger Carried, Freight Carried, Route length, Number of Stations	Input Oriented Models
B	Manpower	Passengers Carried, Freight Carried, Route length, Number of Stations	
C	Number of Stations, Route length, OPEX	Revenue	Output Oriented Models
D	Number of Stations, Route length, Manpower	Revenue	
E	Number of Stations, Route length, OPEX	Passenger Carried, Freight Carried	
F	Number of Stations, Route length, Manpower	Passenger Carried, Freight Carried	

III. RESULTS AND DISCUSSIONS

A. Data Analysis, Results, Discussions and Policy Implications

For determining the Time variant Performance analysis of Zonal Railways, Malmquist Index was evaluated by applying DEA to various parameters affecting the services and operations of Indian Railways Zones for the years 2006-07 and 2016-17 which was collected from Indian Railways Annual Reports and Accounts, Railway Board, Ministry of Railways, Govt. of India [12,13]. Table 3 presents the descriptive analysis of the data for the years 2006-07 and 2016-17 respectively.

Table 3: Indian Railways Zonal Data Description and the Descriptive Statistics for various Model Variables.

Parameter	Year	OPEX (Million ₹)	Route length (km)	Passengers Carried ('000)	Freight carried ('000 ton)	Manpower (Numbers)	Revenue (Million ₹)	Number of Stations
Mean	2006-07	28387.91	3036.39	34383	76639.50	82694	33970.00	379
Standard Deviation	2006-07	10871.82	1249.80	43842	34707.09	34344	14425.67	159
Maximum	2006-07	53212.2	6561.38	133318	119571	156618	63186.94	790
Minimum	2006-07	13956.23	1548.15	2436	19165	33332	11414.88	176
Mean	2016-17	98340.69	3836.25	49126	138091.19	76402	100854.95	639
Standard Deviation	2016-17	35315.93	1382.41	55079	72839.69	29455	41745.37	257
Maximum	2016-17	191380.30	6968.00	175790	249115.00	144057	160993.87	1142
Minimum	2016-17	54975.78	2414.00	9571	30222.00	37320	31375.07	342

Descriptive Statistics data for the year 2006-07 and 2016-17 indicate that the standard deviations were large and the variation between the maximum and minimum values was also quite high, indicative of the fact that Railway Zones in India have undergone significant changes in just a period of 10 years as illustrated in Table 4.

Table 5 gives the Malmquist Index for various Models for the periods 2006-07 and 2016-17. Malmquist Index measures the Productivity change between periods "t" and "t+1". Productivity declines if Mo > 1, Remains unchanged if Mo = 1 and Improves if Mo < 1 [10] . Periods 2006-07 and 2016-17 are chosen to find the Malmquist Index of Indian Railways Zones as these years delineate the implementation of Pay Commission in Indian Railways which represent the pay hike of the employees once in every ten years. Model B shows100 % improvement in Productivity while, Models D and F show declination in Productivity by 100 % over the period 2006-07 to 2016-17. Model E shows 81.25% increment in productivity while Model A and Model C show major inclination towards declination in productivity. Thus, Indian Railways Zones seem to be relatively less efficient with respect to the Operating Expenditures that have increased multi-folds from Rs 454207 Million in 2006-07 to Rs 1573451 Millions in Year 2016-17, the latter being nearly 3.5 times the former representing 246.4% increase of OPEX in 10 years. OPEX increase as input variable over time has actually outstripped the increase in Model Outputs such as the Passenger Originating, Freight Carried, Route Length, and Number of Stations. This has led to a declining trend in Efficiencies with respect to OPEX over the study time period as depicted in Model A and Model C as shown in Table 5.

Table 4: The Decadal change in Performance Indicators (2006-07 to 2016-17).

Zones	OPEX	Manpower	Route Length	Numbers of Stations	Passengers Carried	Freight Carried	Revenue
Northern Railway	3.60	0.92	1.06	1.45	1.22	1.63	2.55
North Eastern Railway	3.73	0.88	2.37	3.05	2.37	1.91	2.75
Northeast Frontier Railway	3.38	0.89	1.95	3.11	4.15	1.58	2.31
Eastern Railway	3.39	0.89	1.07	1.37	1.42	1.74	2.98
South Eastern Railway	3.69	0.93	1.02	1.23	1.54	2.04	3.40
South Central Railway	3.26	0.91	0.65	1.77	1.91	1.57	3.02
Southern Railway	3.35	0.90	1.55	2.05	1.69	1.10	2.58
Central Railway	3.24	0.88	1.20	1.47	1.34	1.33	2.63
Western Railway	3.07	0.93	1.57	2.00	1.20	1.71	2.55
South Western Railway	3.94	1.12	1.19	1.80	2.87	1.73	2.67
North Western Railway	4.04	0.86	1.85	2.45	1.74	2.80	3.66
West Central Railway	2.98	0.96	1.00	1.34	1.57	1.61	3.33
North Central Railway	3.47	0.85	1.15	1.19	1.34	1.38	3.01
South East Central Railway	3.65	1.10	1.46	1.86	1.72	2.18	3.27
East Coast Railway	3.73	1.10	1.03	0.63	2.14	2.57	3.78
East Central Railway	3.79	0.99	1.34	2.16	1.46	2.07	3.07
***Av Increase/ Decrease**	**3.52**	**0.94**	**1.34**	**1.81**	**1.85**	**1.81**	**2.97**

*Average Increase/Decrease = the Number of times (2016-17 value/2006-07 value).

As also evident from Table 4 that compares decadal data, Output parameter Revenue has merely increased by 2.97 times while, input parameters like Number of Stations, Route Kilometer and Operating Expenditure has increased drastically by 1.81, 1.34 and 3.52 times respectively causing low Efficiencies for the Models C. In the same context for Model A, Input parameter OPEX has severely increased by 3.52 times while output parameters like Passengers originating, Freight Carried Route and Number of Stations have increased merely by 1.85, 1.81, 1.34 and 1.81 respectively generating declining Productivity of the Indian Zonal Railways.

However, under Model B wherein the staff employed (Model Input) in the services has actually decreased from 1323099 in 2006-07 to 1222436 in 2016-17, a decrease of 100663 numbers of staff, representation nearly 8% of the staff reduction over a decade, even as number of passengers went up from 5.50120 billion to 7.86010 billion (1.43 times) while the freight carried increased from 1226.23 Million tons to 2209.46 Million tons (1.80 times). Thus, over time as the manpower has reduced, the productivities have witnessed an uptrend.

Table 5: Malmquist Index (Mo) for different Models.

Railway Zones	Model A	Model B	Model C	Model D	Model E	Model F
Northern Railway	2.81	0.73	1.20	2.42	0.64	1.40
North Eastern Railway	1.47	0.33	0.92	1.59	0.65	1.34
Northeast Frontier Railway	1.17	0.33	0.88	1.46	0.76	1.51
Eastern Railway	2.31	0.59	1.98	2.80	0.88	1.39
South Eastern Railway	2.10	0.57	1.82	3.00	1.07	1.65
South Central Railway	19.67	0.68	0.50	3.51	0.23	1.77
Southern Railway	1.95	0.50	1.11	1.93	0.61	1.34
Central Railway	0.62	0.30	1.40	2.15	1.92	2.99
Western Railway	2.56	0.69	1.13	2.11	0.53	1.23
South Western Railway	2.32	0.75	0.99	2.34	0.68	1.80
North Western Railway	2.00	0.45	1.09	3.31	0.69	2.37
West Central Railway	2.13	0.75	1.71	2.92	0.82	1.45
North Central Railway	2.64	0.67	1.46	2.86	0.68	1.35
South East Central Railway	1.83	0.55	1.41	2.36	0.93	1.54
East Coast Railway	2.30	0.73	1.79	3.51	1.31	2.35
East Central Railway	1.89	0.51	1.36	2.43	0.84	1.55
Productivity*	D_P=15 (93.75) C_P= 0 (0.00) I_P= 1 (6.25)	D_P = 0 (0.00) C_P = 0 (0.00) I_P = 16 (100.00)	D_P =12 (75.00) C_P = 0 (0.00) I_P = 4 (25.00)	D_P =16 (100.00) C_P = 0 (0.00) I_P = 0 (0.00)	D_P = 3 (18.75) C_P = 0 (0.00) I_P = 13 (81.25)	D_P =16 (100.00) C_P = 0 (0.00) I_P = 0 (0.00)

*D_P= Declining Productivity, C_P= Constant, I_P= Improving Productivity.
Figures in the bracket denote the percentage of total productivity.

IV. CONCLUSION

The present work has been an attempt to compare the productivity performances of the Indian Zonal Railway. Six models that were employed to assess DEA based performance efficiencies of 16 Zonal Railways which lay down an essential framework that may constitute a first step in the direction of bringing reforms in a sector that is otherwise undergoing decline in productivity. Appropriate interventions at reforms and policy level can possibly lead to improved levels of services with minimal incremental spending, a fact that may be of significance to policymakers and administrators who are invariably faced with a resource crunch in the context of developing country like India. This would, however, need micro-studies of the various zones and evolution of management models for enhancing services.

Based on field experiences and model formulations, a number of policy reforms are suggested. These may include steps such as

(a) No new recruitment of staff shall be done until the MCMTN (Manpower and Cost Norms for Track Maintenance) Formula is revised which was drafted way back in May 2000. As the scenario has changed in last 2 decades with respect to the requirement of Man Power in Train Operations and other allied facilities like machines have started to replace manual cleaning of toilet, thereby rendering some labor staff infructuous. Similarly, in Track maintenance work, huge on-track machines have replaced the manual labor in various works. Task of manual patrolling of Railway Tracks by Patrolmen has been replaced by Track circuiting network. Ticket vending staff is now fast being partly replaced by Online Ticketing system and Automatic Ticket Vending Machines (ATVMs) in Station areas. Thus, in the current scenario the requirement of staff is quiet less as compared to 20 years ago when the MCNTM Formula was derived.

(b) Operating expenditure may be curtailed by electrification of complete Railway network and running Electric Locomotives. Converting Narrow Gauge (0.610 m, 0.762 m), Meter Gauge (1.00 m) to an uniform Broad Gauge (1.676 m) across the country to minimize technical hassles and resultant delays, track renewals to reduce frequent maintenance of old tracks and reforms such as no new quarters to be constructed for staff as these newly constructed quarters will require routine water supply, sanitation work and frequent maintenance of structure in near future thereby creating an extra burden on the Operating Expenditure.

(c) Privileges to the Railway staff such as Free Passes for travel by Train within the country for self and for family of the Railway employee should be curtailed.

Procurement of Spare parts and materials from private players to be relinquished and the capacity to inbuilt the same should be sustained rather than the current trend of assembling the procured spare parts to form a complete structure as per the "Make in India" initiative and "Atmanirbhar Bharat" schemes of Government of India.

(d) For enhancing the Revenue, the rationalization of fare should also be done on the basis of route encompassed by the traveler in the train and not only on the basis of class of journey. For difficult terrains or routes which require massive maintenance activities in terms of Track work, higher Fuel consumption and frequent maintenance of Locomotives and carriages, the ticket price should be fixed higher as compared to other easy terrains.

(e) IR has around 43000 Hectares of vacant land [14] which can be commercially exploited and could be used for construction of Hotels, Restaurant and Recreational hub for Railway Passengers and outsiders near the station areas. The vacant land located away from urban areas and station premises could also be leased out to farmers and industries for cultivation of crops or for setting out of micro, small and medium scale industries. This would generate huge revenues for the Railways from the gigantic unutilized assets, and would help railways sustain financially.

Besides these aspects, modernization of stations, better governance, establishing of an independent Railway Regulator, introduction of private partners who bring capital, professional knowhow and managerial skills are all measures that may significantly contribute to efficiency enhancement of the Services. No private player would like to make an investment in a sector that fares poorly in terms of efficiencies. Therefore improvement of productivities should be the top agenda of the Indian Railways Zones, and studies like the present one truly needed to evolve a path to efficiency and sustainability.

V. FUTURE SCOPE

There exists a scope for analyzing the performances of the Indian Railways at the micro-level i.e, either at the level of Divisions or districts covered. Best practices need to be identified, and these management practices need to be replicated for increasing the overall productivities of the Railway services. There also exists scope to evolve methodologies other than the Malmquist Index for verifying the productivies by more than one methodology, and to eliminate any biases in the models employed.

Conflict of Interest. No.

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