COMPARING BRAZILIAN AND AMERICAN RAILWAYS WITH DEA

Brunno Santos Gonçalves

Federal University of Rio de Janeiro - brunno@pet.coppe.ufrj.br

Márcio de Almeida D'Agosto

Federal University of Rio de Janeiro - dagosto@pet.coppe.ufrj.br

Marcos Pereira Estellita Lins (Federal Universtity of Rio de Janeiro)

Federal University of Rio de Janeiro - estellita@pep.coppe.ufrj.br

Silvio dos Santos

Federal Universtity of Santa Catarina – silvio@labtrans.ufsc.br

ABSTRACT

To evaluate the performance of Brazilian railways and establish productivity goals, the National Land Transport Agency (ANTT) monitors a set of pre-selected indicators.
In this article we propose the use of data envelopment analysis (DEA) as an alternative for Brazilian railway performance evaluation, to enable systematic and comparative analysis of the efficiency of concessionaires.
To exemplify the method, we present an applied study comparing the efficiency of six Brazilian railroad companies and five American railroad companies, in terms of operational and financial results obtained along this decade.
The results show that the DEA method is effective to measure the relative efficiency of these railroads and indicate the areas for improvement for the underperformers.

Keywords: Data Envelopment Analysis (DEA), railways performance, Brazilian railways, American railways

INTRODUCTION

Most of Brazil's railroad system, originally owned by the federal government, was privatized in the second half of the 1990s, after being divided into regional operating units. These regional railroads were then auctioned off to private operators under long-term concession contracts (with nominal ownership remaining with the government). A regulatory agency was also created, the National Land Transport Agency (ANTT) to evaluate the performance of these concessionaires in line with the investment, productivity and operational efficiency targets set in the concession contracts.

It is generally agreed that the current method for evaluating Brazilian railway performance, although relying on an extensive number indicators, is inadequate since it does not entail a systemic and comparative analysis, but rather an individual one based on pre-established indicators.

The objective here is to propose the use of the data envelopment analysis (DEA) as a possible complementary method for the performance evaluation of Brazilian railways. It was done through an applied study of the relative efficiency of six Brazilian railroad companies and five American railroad companies between 2002 and 2008.

The study starts with the hypothesis that the use of DEA can be useful to evaluate the performance of railways and to realize comparative analysis of operational performance of this railway.

First, it was presented the current practice used by the ANTT to evaluate the performance of Brazilian railways. Then we describe the DEA model used in here. After that we present the stages of the method's application and the results, before presenting the final considerations.

PERFORMANCE EVALUATION OF BRAZILIAN RAILWAYS – CURRENT PRACTICE

By law and contractual stipulation, railway concessionaires in Brazil must report monthly operational and financial data to the ANTT. The Agency then analyzes these data to monitor compliance. The results are published in the "Relatório Anual de Acompanhamento das Concessões Ferroviárias" ("Annual Railway Concession Oversight Report"). This report presents the railroads' operational and financial performance evolution and the levels of compliance with the contractual goals for production and accident reduction.

Table I summarizes the information related to the performance indicators used by the ANTT. Although a series of operational and financial indicators are monitored, productivity goals are established for only two indicators, accident rate and volume transported. According to the present monitoring system, the concessionaires' performance has generally been considered satisfactory in light of their pre-established targets. However, the current evaluation system does not allow a systematic comparative analysis among the railways.

Table I – Indicators used by ANTT

INDICATOR CLASS	INDICATOR	DESCRIPTION	MEASUREMENT UNIT	GOAL
Financial	Profit	Operating profit	R$	No
	Operating Expenses	Operating expenses	R$	No
	Investments	Total amount of capital expenditures	R$	No
Operational	Total freight transported	Total paid freight carried in metric tons (tonnes)	Net tonne (NT)	No
	Freight transportation production	Measurement unit equivalent to the transportation of one net tonne over a distance of one	net tonne kilometer (NTK)	Yes
	Serious accident percentage	Ratio between the number of serious train accidents causing demage to the train, a fixed facility, persons, animals and/or other vehicles etc. and the total number of accidents involving the train	Number of grave accidents/ Number of accidentes	No
	Accidente rate	Ratio between the number of accidents and kilometers traveled (10^3)	Number of acidentes/ Million train.km	Yes
	Average production	Ratio between the net operting profit and NTKs	R$/NTK	No
	Commercial speed	Speed corresponding to the average of time spent to travel between two spots, including time stopped at intermediate stations	km/h	No
	Average speed	Speed corresponding to the average of time spent to travel the distance between two spots without stops	km/h	No
	Number of trains	Number of trains formed in the origin-destination pair for freight and/or passenger service	traim.km	No
	Number of locomotives	Number of locomotives or set of them that provide the necessary energy to move a train	Number of locomotives	No
	Number of rail cars	Number of rail cars for passengers or freight, including animals	Number of freight cars	No
	Fuel consumption	Quantity of fuel consumed by locomotives	Liters/NTK	No
			Liters/tku	No
			thousand liters	No
	Average course - locomotives	Ratio between the sum of the courses completed by locomotives and the fleet of locomotives in operation	km	No
	Average course - freight cars	Ratio between the sum of the courses completed by freight cars and the fleet of freight cars in operation	km	No
	Productivity	Ratio between the total freight transported and the number of freight cars	NTK/freight car	No
		Ratio between freight transportation production and the number of freight cars	NK/freight car	No

Source: ANTT (2009), adapted by the author

DEA METHODOLOGY

According to Novaes (2004), the Data Envelopment Analysis (DEA) has been developed in the 1970's decade by Charnes, Cooper and Rhodes, and has today large application on the productivity and efficiency of public organs, as well as providing support for benchmarking studies. DEA's objective consists on comparing a certain amount of Decision Making Units (DMU's), that perform similar tasks and are differentiated by the amount of resources consumed (inputs) and resources they produce (outputs). Through use of such technique, it is believed to be possible the systemic and comparative analysis of performance in Brazilian railways.

There are two classical DEA models: the CRS model, also known as CCR (Charnes, Cooper and Rhodes, 1978), which considers constant returns to scale, and the VRS model or BCC (Banker, Charnes and Cooper 1984), which considers variable returns to scale and does not assume proportionality between inputs and outputs.

Given the operational characteristics of the analyzed Brazilian railway companies, which show heterogenic operational capacity, it was understood that the use of the VRS model would be the most adequate for this case study. The output-oriented model was adopted, since the interest is to verify how the operational results of Brazilian railways can be enhanced.

In its mathematical formulation, it is considered that each DMUk, k = 1..n, is a production unit that uses r inputs xik, i =1..r, in order to produce s outputs yjk, j = 1..s. The VRS model of multipliers, shown in equations (1) and (2), maximizes the quotient between the linear combination of outputs and the linear combination of inputs, with the restriction that, for each DMUk this quotient may not be greater than 1. Thus, for a DMUo, ho is efficiency; xio e yjo are the inputs and outputs of DMUo; vi and uj are the weights calculated by the model for inputs and outputs, respectively, and u* a non-restricted variable included in the model in order to guarantee the characteristic convex linear combination mathematical condition of the models with variable scale return.

$$\max\ h_o = \frac{\sum_{j=1}^{s} u_j y_{jo} + u^*}{\sum_{i=1}^{r} v_i x_{io}} \qquad (1)$$

$$\text{sujeito a :}$$

$$\frac{\sum_{j=1}^{s} u_j y_{jk} + u^*}{\sum_{i=1}^{r} v_i x_{ik}} \le 1, \quad k = 1,\dots,n$$

$$u_j, v_i \ge 0 \quad \forall i, j$$

$$u^* \in \Re$$

Facing the transformation proposed by Charnes and Cooper (1962) aoud Lins (200), this model may be made linear, turning it into a Linear Programming Problem (LPP) shown in rquation (2), with a model of linear programming being consecutively resolved for each DMU.

$$
\begin{aligned}
& \max\ h_o = \sum_{j=1}^{s} u_j y_{jo} + u^* \\
& \text{sujeito a} \\
& \sum_{i=1}^{r} v_i x_{io} = 1 \\
& \sum_{j=1}^{s} u_j y_{jk} - \sum_{i=1}^{r} v_i x_{ik} + u^* \leq 0 \ , \quad k = 1,\dots,n \\
& u_j, v_i \geq 0 \quad \forall i, j \\
& u^* \in \Re
\end{aligned} \tag{2}
$$

The use of classical DMU model of multipliers, allows the calculus of the relative efficiency percent of the analyzed DMU's, this indicator shows the inefficiency degree of the worst railway concessioners in the analyzed system, as well as the weight percent attributed to each of the DMU's and respective inputs and outputs.

APPLIED STUDY

As mentioned before, the main objective of this study was to evaluate the applicability of DEA to analyze Brazilian railways' relative efficiency. For this purpose, following the methodological sequence proposed by Estellita (2000), we developed the following stages:

1. Selection of the DMU´s for analysis;
2. Selection of the variables or indicators (inputs and outputs) that are relevant and appropriate to establish the relative efficiency of the selected DMU´s;
3. Application of the DEA model.

The following items describe how each of these three stages was developed in this applied study.

Selection of DMU´s

The ANTT has published its Annual Railway Concession Oversight Report since 2002 (ANTT, 2009). This report contains information and standard statistics about the six Brazilian railroads selected, which account for about 95% of the Brazilian´s railway system:

- América Latina Logística (ALL)
- MRS Logística (MRS);
- Ferrovia Centro-Atlântica (FCA);
- Estrada de Ferro Vitória-Minas (EFVM);
- Transnordestina (TN);
- Estrada de Ferro Carajás (EFC).

Since there are standardized data for these ten railways between 2002 and 2008, we decided to consider each railway's annual evaluation as a DMU.
We decided to extend the analysis to the American railroads, since according to Santos (2005), the operational profile of American railroads, long trains with low speed, is closer to operational practiced in Brazilian railroads. Thus, there was the search for statistical data on the years between 2002 and 2008, from 5 Class I Railroads in the United States of America (USA):

- Union Pacific Corporation (UP)
- Kansas City Southern (KCS)
- Norfolk Southern Corporation (NS)
- CSX Corporation (CSX)
- Burlington Northern Santa Fe Railway (BNSF)

Thus, the applied study was design with the selection of 77 DMU's for analysis, in other words, 11 railroads were evaluated for 7 subsequent years.

Selection of Variables

In selecting the variables to be used for efficiency analysis of Brazilian and American railroads through DEA, we tried to synthesize the operational performance evaluation with some indicators that can portray important and unique aspects of railway operations in Brazil and can serve to measure future targets that may be set by the ANTT.
We selected four variables for this model, one input (X1) and three outputs (Y1, Y2 and Y3). These are shown in Figure 1. The input indicator is opereting expenses (X1) and the outputs are volume (Y1), traffic density (Y2) and capacity (Y3). These variables are described below:

- X1 – Opereting expenses: Measured in millions dollars (US$), this indicator gives a general idea of the annual expenses generated by railway operations, encompassing inputs such as fleet maintenance, consumption of fuel and lubricants, payroll, etc;
- Y1 – Volume: Measured in billions of revenue ton-miles (RTM) this is the main indicator monitored by the ANTT, which annually establishes productivity targets for the railway concessionaires according to this indicator. It indicates the transport moment of a railroad, that is, how much cargo is transported multiplied by the distance transported. According to Ballou (2006), the greater the average transport distance, the more efficient a railway is. However, in Brazil this is not necessarily true since the routes are extremely winding, and a series of projects for the transportation of cargo over short distances by railways has been implemented. So, this is an important indicator, but not necessarily the sole target to be objectified to boost the Brazilian railway system's efficiency;
- Y2 - Traffic density: Measured in millions of revenue ton-miles transported per mile (RTM/mile), this is an indicator of the potential viability of a railroad in financial terms (World Bank, 2009). The ANTT does not used this an indicator, but it deserves to be closely followed, since during the post-privatization period some railroad concessionaires have closed parts of their systems and concentrated efforts only on

main lines. Thus, this indicator can show railways that are misusing the available railway network;

- Y3 – Capacity: Measured in thousands of rail cars per year, calculated considering the time a car takes to travel 1000 miles over a determined railroad given its average speed, this indicator gives an idea of the cargo capacity of a railway, given its existing railcar fleet and the average speed of its trains. A railroad can improve its transport capacity by purchasing more cars or increasing their availability and/or increasing their average speed, by improving the railway network or other efficiency measures.

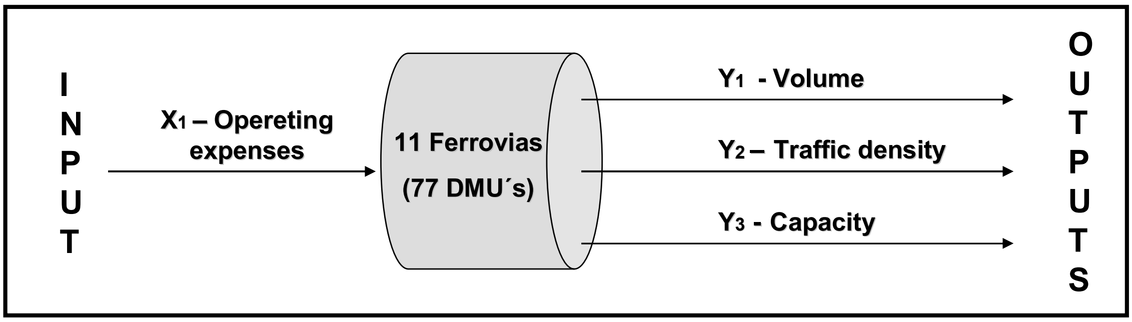

Figure 1 - Selected inputs and outputs

DEA Application

The use of the classic DEA model of multipliers allows calculating the relative efficiency percentage of railways. This percentage indicates the degree of inefficiency of the worst railroads in the model analyzed. To apply the model, we formulated the database presented in Table II, using as inputs the data for each of the 77 DMUs to be analyzed along with the input and outputs selected in previous item.

We chose the model with variable returns to scale (VRS), with multipliers, to maximize the outputs. This choice was based on the fact that in preliminary tests we obtained more consistent results with the VRS model than with the constant returns to scale (CRS) one. According to Banker et al. (1984), cited in Vasconcellos (2006), this is a common occurrence.Moreover, given the operational characteristics of the railroads analyzed, which present heterogeneous operational capacity, we conclude that use of the VRS model would be more appropriate for this study.

The perspective of maximizing the outputs stemmed from the fact that while railroads use different strategies to boost profits, transportation regulators seek to increase the cargo volume transported by rail, but both aim to increase the productivity in the railroad industry. We used the IDEAL program for the calculations.

Table II – Database used

Railways	Year	Route (miles)	Average train speed (mph)	Freight cars (units)	Opereting expenses ($ millions)	Revenue ton-miles (billions)	Traffic density (millions RTM/miles)	Capacity (thousand freight cars/year)
ALL	2002	8,032	16.3	23,980	295.36	15.3	1.9	3,385
	2003	8,032	15.7	22,253	290.99	16.4	2.0	3,022
	2004	8,032	13.9	25,563	319.01	16.8	2.1	3,082
	2005	7,254	14.6	31,350	444.22	16.7	2.3	3,966
	2006	7,254	14.5	27,485	507.05	18.1	2.5	3,441
	2007	7,278	17.3	27,013	554.46	18.4	2.5	4,049
	2008	8,653	16.8	28,403	489.10	20.5	2.4	4,125
TN	2002	2,811	10.2	1,897	13.66	0.4	0.2	167
	2003	2,811	9.4	1,925	15.91	0.5	0.2	157
	2004	2,811	8.5	1,703	19.47	0.5	0.2	125
	2005	2,628	9.1	1,703	23.44	0.5	0.2	134
	2006	2,628	10.1	1,753	27.51	0.4	0.2	153
	2007	2,628	10.5	2,271	26.49	0.6	0.2	206
	2008	2,608	10.5	2,294	25.26	0.6	0.2	208
EFC	2002	553	31.4	4,826	111.5	30.4	55.0	1,311
	2003	553	30.4	5,115	127.38	32.5	58.8	1,343
	2004	553	22.4	6,893	158.79	39.4	71.3	1,333
	2005	553	21.9	8,316	223.82	43.1	77.9	1,506
	2006	553	17.2	10,035	271.92	47.5	86.0	1,494
	2007	553	17.1	9,805	373.23	51.7	93.4	1,444
	2008	553	17.1	10,902	403.31	54.3	98.1	1,605
EFVM	2002	557	25.2	13,549	149.83	35.3	63.5	2,947
	2003	557	25.2	11,807	161.03	37.5	67.4	2,574
	2004	557	24.1	16,225	191.88	40.2	72.1	3,381
	2005	561	22.5	19,857	267.65	42.6	75.9	3,861
	2006	561	22.1	20,960	383.24	45.5	81.2	3,997
	2007	561	23.2	20,806	473.89	46.8	83.4	4,168
	2008	561	23.2	20,077	582.37	45.1	80.4	4,161
FCA	2002	4,389	15.4	10,398	110.12	5.3	1.2	1,387
	2003	4,389	15.3	10,486	172.75	4.6	1.1	1,387
	2004	4,389	14.9	12,069	185.57	5.8	1.3	1,552
	2005	5,017	13.9	12,609	271.97	6.6	1.3	1,513
	2006	5,017	13.3	13,046	298.17	5.7	1.1	1,496
	2007	5,017	14.6	11,664	311.78	8.8	1.8	1,475
	2008	5,000	14.6	11,525	340.21	9.4	1.9	1,457
MRS	2002	1,037	18.2	12,452	179.01	18.2	17.6	1,961
	2003	1,037	18.0	10,631	212.94	21.4	20.6	1,651
	2004	1,037	18.2	11,498	245.05	24.4	23.5	1,811
	2005	1,037	17.9	12,928	348.4	27.6	26.6	2,001
	2006	1,037	18.0	12,560	442.24	29.6	28.5	1,951
	2007	1,037	18.1	15,310	536.01	32.1	30.9	2,395
	2008	1,037	18.1	16,641	420.21	34.5	33.2	2,603
UP	2002	33,141	21.0	90,877	9,364.00	518.7	15.7	16,489
	2003	32,831	21.4	87,805	9,418.00	532.9	16.2	16,235
	2004	32,616	21.4	104,640	10,920.00	546.3	16.7	19,348
	2005	32,426	21,.1	106,723	11,783.00	549.4	16.9	19,456
	2006	32,339	21.4	104,725	12,694.00	565.2	17.5	19,363
	2007	32,205	21.8	94,284	12,908.00	561.8	17.4	17,759
	2008	32,012	23.5	90,005	13,895.00	562.6	17.6	18,275
KCS	2002	3,109	21.0	13,561	518.20	14.0	4.5	2,461
	2003	3,108	23.0	13,200	552.20	14.4	4.6	2,623
	2004	3,108	24.0	13,280	556.00	15.8	5.1	2,754
	2005	3,226	24.0	14,940	1,289.70	33.5	10.4	3,098
	2006	5,767	24.0	28,078	1,355.40	41.1	7.1	5,822
	2007	6,071	24.0	26,111	1,380.40	43.1	7.1	5,414
	2008	6,083	24.0	24,820	1,461.90	45.9	7.6	5,147
NS	2002	21,558	23.7	105,481	5,112.00	179.0	8.3	21,599
	2003	21,520	23.2	101,095	5,384.00	183.0	8.5	20,264
	2004	21,336	22.4	100,229	5,610.00	198.0	9.3	19,398
	2005	21,200	20.5	91,235	6,410.00	203.0	9.6	16,160
	2006	21,141	22.3	87,981	6,850.00	204.0	9.6	16,951
	2007	20,891	21.7	95,537	6,847.00	196.0	9.4	17,912
	2008	20,832	22.6	94,660	7,577.00	195.0	9.4	18,484
CSX	2002	23,000	22.5	83,761	6,826.00	262.6	11.4	16,283
	2003	23,000	21.1	81,301	7,053.00	264.6	11.5	14,822
	2004	22,000	20.3	86,016	7,040.00	284.3	12.9	15,087
	2005	21,000	19.2	84,329	7,068.00	308.6	14.7	13,989
	2006	21,114	19.8	101,602	7,428.00	314.0	14.9	17,381
	2007	21,166	20.8	94,364	7,774.00	312.5	14.8	16,958
	2008	21,000	21.6	91,350	8,487.00	314.5	15.0	17,048
BNSF	2002	25,000	22.0	88,767	7,323.00	490.2	19.6	16,873
	2003	24,500	22.0	87,549	7,748.00	508.2	20.7	16,641
	2004	24,000	22.0	87,376	9,237.00	570.7	23.8	16,608
	2005	24,000	22.0	81,881	10,060.00	596.6	24.9	15,564
	2006	23,000	22.0	85,121	11,464.00	647.9	28.2	16,178
	2007	23,000	22.0	85,338	12,316.00	657.6	28.6	16,221
	2008	23,000	22.0	82,555	14,106.00	664.4	28.9	15,692

Source: ANTT (2009), UP (2009), KCS (2009), NS (2009), CSX (2009), BNSF (2009), adapted by the author

RESULTS

By analyzing the average relative efficiency of Brazilian and American railroads between 2002 and 2008 (Figure 2), it can be seen that the railway companies considered most efficient during the study interval are BNSF, EFC, EFVM and UP. With a good average relative efficiency are NS, ALL and CSX, which obtained average relative efficiency between 80% and 90%. MRS and KCS ranked in the middle, with rates ranging from 50% to 80%, whereas TN and FCA obtained low average relative efficiency, with rates below 50%.

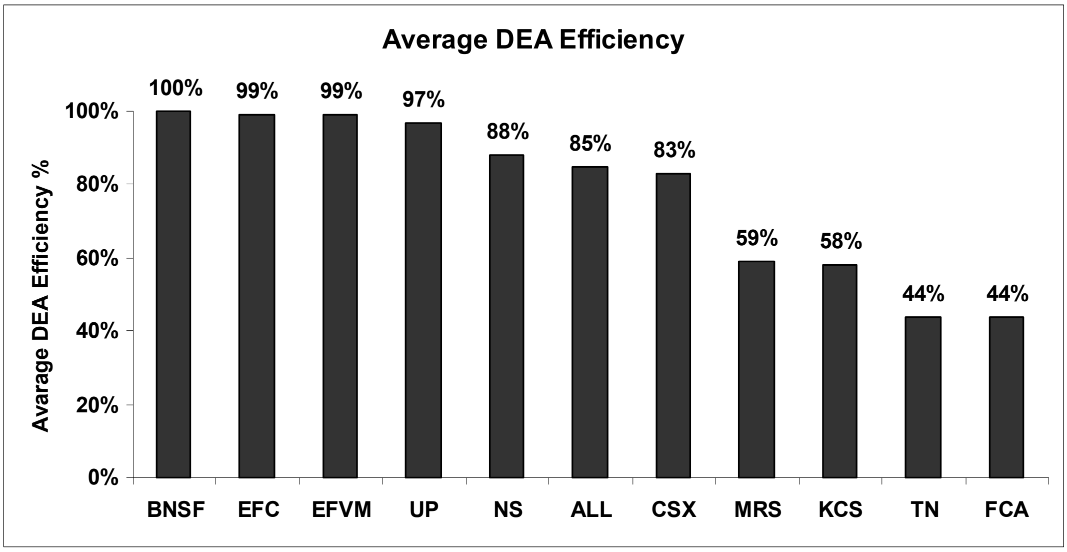

Figure 2 - Average relative efficiency of Brazilian and American railways (2002 a 2008)

Observation of Table III, which contains the average percentage weights allocated to the outputs, provides a picture of the operational characteristics of the railways. BNSF and UP, American railroads more efficient, give greater weight to volume, but also attach significant weight to capacity. MRS, Brazilian railroad with regular average relative efficiency, has the same operational profile of BNSF and UP. The EFC, EFVM, Brazilian railways more efficient, give greater emphasis to volume and density of traffic. The other railroads, the American NS, CSX, KCS and the Brazilian ALL, TN FCA and attribute greater weight to the output capacity.

Table 3 - Average relative efficiencies and average percentage weights of the outputs by railway

Railway	Average DEA Efficiency	Avarage weights of outputs		
		Revenue ton-miles	Traffic density	Capacity
BNSF	100%	61%	12%	27%
EFC	99%	60%	36%	4%
EFVM	99%	50%	30%	20%
UP	97%	51%	0%	49%
NS	88%	3%	10%	88%
ALL	85%	0%	0%	100%
CSX	83%	14%	13%	73%
MRS	59%	69%	0%	31%
KCS	58%	5%	0%	95%
TN	44%	0%	0%	100%
FCA	44%	0%	0%	100%

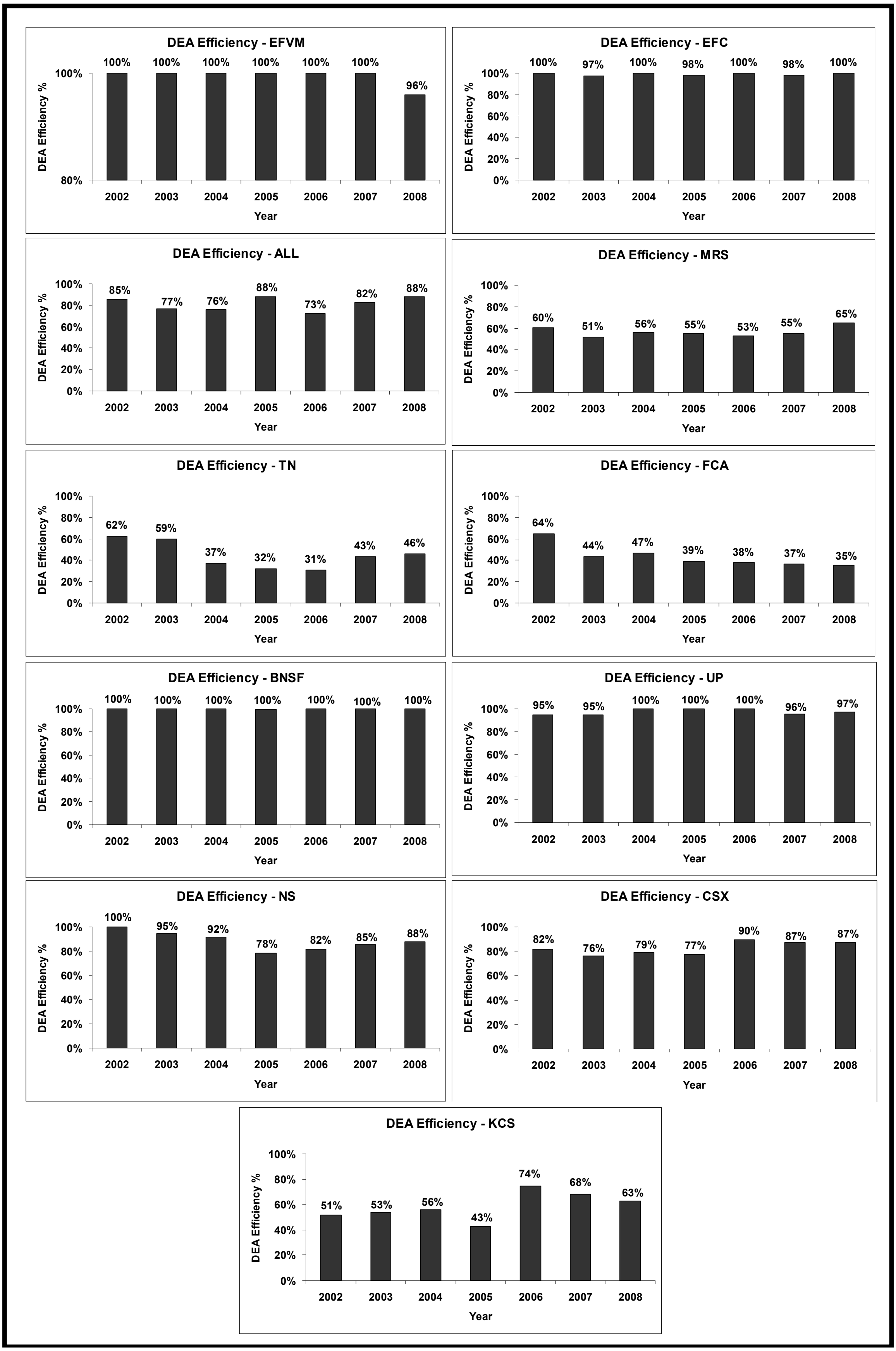

Figure 3- Relative efficiency of Brazilian and American railroads between 2002 and 2008

Figure 3 shows the yearly relative efficiency rates allocated to each railroad through DEA. Among the more efficient railroads, the Americans BNSF and UP and the Brazilians EFVM and EFC , notes that BNSF, has kept 100% the relative efficiency index between 2002 and 2008. UP obtained relative efficiency idex of 100% in 2004, 2005 and 2006, years that had a fleet of freight cars about 10% higher than in other years analyzed, reflecting in greater capacity and therefore higher relative efficiency index.

EFVM kept the relative efficiency index of 100% between 2002 and 2007. In 2008 EFVM obtained a 4% fall in this index in consequence of increases in operating expenses together with the reduction in volumes, traffic density, and capacity.

ECF obtained relative efficiency index of 100% in the years 2002, 2004, 2006 and 2008. In the other years analyzed, the relative efficiency index was slightly lower in consequence of increases of opereting expenses due to higher volumes and higher density of traffic in greater proportion than observed in the other efficient years.

Analyzing the railroads with good efficiency, the Brazilian ALL and Americans NS and CSX, note that the relative efficiency index of these railways is directly proportional to their output capcity. NS reached highest relative efficiency index in 2002, when it obtained 100% relative efficiency. Since then the condition of his track not reached the same level as in 2002, when the average speed in track was of 23.7 miles per hour. In addition, NS´s freight cars fleet is currently 10% lower than in 2002.

CSX reached its highest relative efficiency index in 2006, when it obtained 90% relative efficiency. Increments CSX´s capacity, or by increasing its freight cars fleet or by increasing the speed average in track can improve the relative efficiency index on the CSX in the coming years.

ALL reached its highest relative efficiency index in 2008, when it obtained 88% relative efficiency. This strategically important railroad for the distribution of cargos from south-central, soutweast and west Brazil, has been investing heavily in new cars to increase its volume carried. On the other hand, investments in track maintenance are still unremarkable, with average speed in 2008 about 16.8 miles per hou, which substantially undermines their transport capacity.

Among the intermediate efficient railroads are the the Brazilian MRS and the Americans KCS. MRS, a carrier that links three of Brazil's main economic centers, the cities of Rio de Janeiro, Sao Paulo and Belo Horizonte, has a remarkably large part of its operations based on transporting iron ore and containers (it hauls highest number of containers in Brazil). MRS has been increasing its efficiency index annually by augmenting both the volume transported and capacity. MRS reached highest relative efficiency index in 2008, when it obtained 65% relative efficiency. When compared to more efficiente railways, BNSF, EFVM, EFC and UP, MRS presents average speed smaller than these railroads, around 18 miles per hour against 22 miles per hour of these railroads, which reflects its capacity and therefore MRS's relative efficiency index.

KCS reached highest relative efficiency index in 2008, when bought the Mexican railroad Ferrocarril, doubling its freight cars fleet. Note that the relative efficiency of KCS is directly proportional to your capcity. So investments in freight cars and on the track conditions can increase KCS's relative efficiency index.

Analyzing the railroads with low efficiency, the Brazilians FCA e TN, the relative efficiency index of FCA has been steadily falling because its increase in transport capacity over the years has not kept pace with recurring increases in the cost of services provided. In order to increase its relative efficiency, FCA should attempt to increase its transport capacity by improving its network, which has na average speed of 14.6 miles per hour, and by increasing its rolling stock. Furthermore, FCA can try to lessen the expenses for services provided, which would substantially contribute to its relative efficiency index.

TN's relative efficiency index also fell between 2002 and 2006. In 2007 it began to recover after receiving financial help from the federal government, and in 2007 it approached its highest relative efficiency index of 62%, obtained in 2002. The best results obtained by TN occurred in years when it was able to reduce its opereting expenses. When compared to EFC and EFVM referential railways, TN has less capacity and traffic density than the other two railways. It can substantially increase these indicators by increasing its average, which in 2008 was 10.5 miles per hour, as well as purchasing more railcars and attracting new cargos.

FINAL CONSIDERATIONS

The main objective of this study, to evaluate the applicability of DEA for analysis of the relative efficiency of Brazilian and American railways, was achieved, since the results obtained through the modeling allowed a comparative analysis among Brazilian and Amercian railways.

Other DMUs could be included in the model, either by stratification of the railroad network into route segments or by the inclusion of railways from other countries with operational profiles similar to those in Brazil and in United States of América.

DEA has other possibilities, such as to calculate productivity to minimize the inputs, deimitation of weight bands for the variables and analyze the achievement of targets, in other words, how improvements in inputs or outputs would impact the efficiency of a DMU. These possibilities could be discussed in other studies.

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