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Using Data Envelopment Analysis to Optimize the Localization of Multimodal Platforms along a Railway in Northeastern Brazil

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Abstract **– The need for efficient transportation networks has grown exponentially over the past decades. Loading and unloading operations are often slow and costly, raising overall freight and cargo costs. To facilitate distribution and reduce the cost and time of loading and unloading, systems need to be optimized and well integrated. In this article we describe a study conducted at the Laboratory of Industrial Optimization and Management (LOGIN) of the Ceará State University (UECE), Brazil. Based on data envelopment analysis (DEA), a mathematical model was developed to determine the ideal locations of six multimodal platforms along the Transnordestina railway in Ceará. The multimodal platforms optimize connectivity and operations, avoid storage and bottlenecks, reduce permanence and cargo redistribution time, and speed up processing. The optimization of these processes significantly increases the flow of people and cargo.**

Keywords **– Multimodal Platforms, Data Envelopment Analysis, Logistics, Optimization.**

I. INTRODUCTION

The demand for logistic operations has increased considerably over the past few decades, especially because of the complexity of loading/unloading procedures and the introduction of new technology. Logistic operators can potentially reduce costs, improve the quality of their services and generate competitive advantages for their clients by focusing on core business, making operations more flexible and reducing investments in assets.

Modern economy requires swift adjustment to constantly changing demands. Logistic platforms provide such adjustment thanks to integrated transportation systems in which circulating information corresponds to increasingly diversified and complex physical movements. The use of logistic platforms by operators has become a trend in the sector.

An efficient transportation system is vital from both the economic and the social point of view as it favors the flow of people, products and culture throughout society. The establishment of intelligent multimodal platforms capable of networking different means of transportation is a differential for Ceará, with a significant impact on the dynamics of cargo and passenger flow[1].

The optimization of these resources will significantly increase the flow of cargo and people. The platforms will serve as vectors of socioeconomic development as regional business and service clusters develop around them. These services will attract other economic activities in the logistic chain, boosting local, national and international distribution.

However, the optimization of infrastructure should be guided by scientific studies employing multivariate analyses and decision aid methods to ensure proposals and investments are well grounded and certified. The present study identifies the optimal locations of multimodal plataforms using data envelopment analysis (DEA), a mathematical tool for decision making.

In 1978, Charnes, Cooper and Rhodes developed the production frontier technique and indicators of production efficiency. Later, Charnes and Cooper (1985) showed that production efficiency should be treated as a relative concept: full efficiency is only attained by a decision-making unit (DMU) if none of its inputs or outputs can be improved in relation to other units[2]. The concept makes it possible to distinguish between efficient and inefficient production regimens. This is one of the reasons for our choice of the DEA methodology[3].

DEA allows to quantify the relative efficiency of each DMU as a rate, identify the origin and amount of relative ineffiency in each DMU for any size of input and output, and subsidize goal setting for the dimensions maximizing DMU efficiency. Among the available DEA models, CCR was chosen because it assumes constant returns to scale and is less benevolent than the BCC model. Since the municipalities in our analysis have the same level of technology, the CCR model is the most adequate. The model will be input-oriented due to our focus on the structural and economic profile of the municipalities. This means that the DMUs (i.e., the municipalities) will attempt to attain the production frontier by reducing costs while maintaining outputs.

II. METHODOLOGY

There are some aspects we follow in this study:

1. Evaluate the economic and structural profile of the 42 municipalities located along the Transnordestina railway in Ceará to subsidize the implementation of 6 multimodal platforms. Locational conditions are considered in relation to the road network and infrastructure, i.e., the position of the municipalities in relation to highways, the railway and the airport, and the economic efficiency as expressed by social and economic indicators. The most socioeconomically active municipalities in the sample were identified.
2. Verify economic, social and geographic indicators of each municipality to obtain input for multivariate statistical models. DEA was chosen as modeling tool for this part of the study. Using DEA, data are analyzed which have been previously selected due to their influence on the

model according to correlation tables. Thus, the selection of relevant variables preceded DEA modeling.

3. Employ mathematical modeling to determine the place of each municipality on the efficiency ranking based on the collected indicators. The results may serve as subsidy for state government decision making with regard to guidelines for public and private investment.
4. Classifymunicipalities according to efficiency using decision aid methods. This is an effective strategy for identifying the municipalities with the greatest socioeconomic development without considering strictly political aspects, providing the state government with e realistic scenario of the feasibility of the platforms to be implemented.
5. Aid in the development of technical and scientific tools to deal with deficiencies in the performance of the municipalities after the analysis of the results of the models. The models are used to quantify the efficiency and development profile of the municipalities along the Transnordestina railway. The model is likely to identify some municipalities which despite indicators suggestive of development may be less efficient than expected.

Initially, we collected data on all the municipalities in the state of Ceará (n=184). In view on our focus on relevant infrastructure, we identified the municipalities bisected by the Transnordestina railway (n=42) where platforms are to be implemented. A thorough study of the indicators of this subset was performed using statistical methods, identifying parameters relevant for DEA modeling. Our interest was focused on socioeconomic indicators and government infrastructure projects in each municipality.

The indicators to be used in the model were selected by DEA, using the software DEA-Solver. Several combinations of indicators were tested through correlation matrices in order to identify the most relevant set. The indicators below were found to be sufficient to run the allocation models and identify the most socioeconomically efficient municipalities, i.e. the municipalities most suitable for the implementation of multimodal loading/unloading platforms.

Table 1: Indicators selected

Municipalities – name of municipality
(I)dd – Demographic density (area of municipality in km^2 / pop. in 2007)
(I)mdi04 – Municipal development index for 2004
(I)rank mdi04 – Place in ranking of municipal development index
(I)icms – Amount of municipal sales tax (ICMS) collected in 2007
(I)enr prim – Number of primary school enrollments in the municipality
(I)enr coll - Number of college enrollments in the municipality
(I)hosp – Number of public and private hospital beds in the municipality
(O)urb rt – Urbanization rate of the municipality
(O)grow rt – Growth rate of the municipality
(I)rev exp – Export revenues of the municipality
(I)vol exp – Volume of exports of the municipality

The variables used in the mathematical model were retrieved from the databases of IBGE (Brazilian Institute of Geography and Statistics), SEPLAG (State Department of Planning and Management) and SEFAZ (State Treasury). Thecollected data were organized in spreadsheets and processed several times. When necessary, indicators were removed by statistical methods to obtain results with acceptable levels of multiple correlations.

III. Expected Results

The study presents a classification of 42 municipalities (table 2) along the Transnordestina railway in terms of socioeconomic parameters and projected efficiency in order to identify the ideal location of 6 multimodal platforms. Our analysis identified a set of 23 municipalities with optimal resource use and 19 in a lower performance level. After the inclusion of other variables by the Ceará state government, the top six municipalities in this set will be indicated as suitable for platform implementation.

Table 2: Performance of the municipalities

Rank	Municipalities	Score
1	Senador Pompeu	1
1	Abaiara	1
1	Acarape	1
1	Acopiara	1
1	São Gonçalo do Amarante	1
1	Penaforte	1
1	Pacatuba	1
1	Banabuiú	1
1	Orós	1
1	Baturité	1
1	Maranguape	1
1	Maracanaú	1
1	Lavras da Mangabeira	1
1	Cariús	1
1	Catarina	1
1	Caucaia	1
1	Jucás	1
1	Granjeiro	1
1	Guaiúba	1
1	Juazeiro do Norte	1
1	Iguatu	1
1	Itapiúna	1
1	Jati	1
24	Várzea Alegre	0,972814
25	Quixeramobim	0,96529
26	Piquet Carneiro	0,939203
27	Caririaçu	0,908349
28	Quixadá	0,901165
29	Brejo Santo	0,898485
30	Mombaça	0,895705
31	Cedro	0,883645

32	Milhã	0,844135
33	Aracoiaba	0,834494
34	Aurora	0,805149
35	Milagres	0,762521
36	Redenção	0,759337
37	Aratuba	0,749774
38	Missão Velha	0,747043
39	Icó	0,742552
40	Barreira	0,716628
41	Capistrano	0,613526
42	Porteiras	0,532487

Table 3 shows the frequency with which each efficient municipality was used as reference for other municipalities.

Table 3: Frequency and referanse set

Reference	**Frequency to other DMUs**
Abaiara	0
Acarape	5
Acopiara	0
Banabuiú	1
Baturité	1
Cariús	5
Catarina	15
Caucaia	0
Granjeiro	1
Guaiúba	1
Iguatu	0
Itapiúna	2
Jati	1
Juazeiro do Norte	0
Jucás	0
Lavras da Mangabeira	0
Maracanaú	0
Maranguape	0
Orós	16
Pacatuba	0
Penaforte	7
São Gonçalo do Amarante	0
Senador Pompeu	2

A. Municipalities with higher development indexes

The municipalities of Abaiara, Acarape, Acoipiara, Banabuiú, Baturité, Carius, Catarina, Caucaia, Grangeiro, Guaiuba, Iguatu, Itapiuna, Jati, Juazeiro do Norte, Jucás, Lavras, Maracanaú, Maranguape, Orós, Pacatuba, Penaforte, São Gonçalo and Senador Pompeu were found to be efficient. The variables attain the projection levels expected by DEA, i.e., resources are optimized, with no idle elements or deficits. These municipalities are at the efficiency frontier (no difference between the variables and the projection). The table 4 shows the data of a municipality called Senador Pompeu as example.

Table 4: Municipality at the efficiency frontier.

Municipality I/O	Score Data	Projection	Difference	%
Senador Pompeu	1			
dd	25,239521	25,239521	0	0,00%
mdi04	22,46	22,46	0	0,00%
Rank mdi04	0,618	0,618	0	0,00%
icms	1224,7197	1224,7197	0	0,00%
Enr primar	7051	7051	0	0,00%
Enr coll	0	0	0	0,00%
Hosp	57	57	0	0,00%
Rev exp	3516138	3516138	0	0,00%
Vol exp	321691	321691	0	0,00%
Urb rt	57,6	57,6	0	0,00%
Grow rt	0,26	0,26	0	0,00%

The table 5 below shows a municipality less efficient than its projection. Values with negative signs indicate excesses that need to be eliminated to attain efficiency. Values with positive signs indicate scarcity that needs to be addressed. The percentage is the proportion of these values in relation to the results of the projection.

Table 5: Municipality less efficient than its projection

Municipality I/O	Score Data	Projection	Difference	%
Porteiras	0,532487			
dd	67,85321	20,478851	-47,37436	-69,82%
mdi04	18,86	10,042705	-8,817295	-46,75%
Rank mdi	0,644	0,3429216	-0,301078	-46,75%
icms	1087,2616	541,66905	-545,5925	-50,18%
Enr primar	5076	1749,5877	-3326,412	-65,53%
Enr coll	0	0	0	0,00%
hosp	28	7,6959803	-20,30402	-72,51%
Rev exp	0	0	0	0,00%
Vol exp	0	0	0	0,00%
Urb rt	28,61	28,61	0	0,00%
Grow rt	0,46	1,1315042	0,671504	145,98%

Most of the variables of the less efficient municipalities are below the efficiency curve (SUM inputs/SUM outputs <=1). Thus, resources are not optimized because they are either idle or spent unnecessarily, indicating a poor cost/benefit ratio.

IV. Conclusions and Recommendations

DEA, a multi-criterion decision aid tool, was essential to the evaluation of socioeconomic performance of 42 municipalities in Ceará. The method allowed to select attributes highly relevant to the implementation of multimodal loading/unloading platforms along the Transnordestina railway. DEA is based on linear programming models and is currently used by many developed countries as a management tool in multiple sectors.

Each municipality in the sample was analyzed with regard to 11 socioeconomic indicators and had its efficiency frontier plotted. The results showed that 23 municipalities qualified for the implementation of multimodal platforms. In the text, we take for example two municipalities, table 4and 5, that shows great differences. The municipality in the table 4, has a considerable volume of exportation, good hospital structure, substantial collection of taxes andurbanization rate. The success with the choice of this municipality to the installation of a multimodal plataform is ensured by the study and data analysis of the chosen indicators

It is hoped that our results will serve as scientific subsidy in the decision making process of the Ceará state government, once the proper administrative components have been taken into account.

The main purpose of this study was to present a modern and efficient decision aid methodology capable of objectively identifying the municipalities along the Transnordestina railway most suitable for the implementation of multimodal platforms.

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