

PROPOSTA DE MODELO DE ARRENDAMENTO PORTUÁRIO BASEADO EM PROGRAMAÇÃO LINEAR APLICADA A UMA SITUAÇÃO BRASILEIRA

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Resumo

Este artigo apresenta um modelo matemático de seleção do melhor licitante para a locação de áreas portuárias. O modelo visa atender a solicitação feita por uma Lei Provisória, que regula o processo de arrendamento mercantil. Eles determinam que a nova metodologia considera a tarifa mais baixa combinada com a maior manipulação de portos. Propomos uma formalização matemática adaptada aos interesses descritos. A formalização utilizada foi o LPP (Problema de Programação Linear) para calcular a tarifa mais baixa cobrada ao usuário eo manuseio mínimo de porta requerido para a demanda estimada, introduzindo custos originados de demandas previsíveis e os investimentos necessários para atender a demanda estimada. Posteriormente, foi aplicado o modelo DEA (Data Envelopment Analysis) para classificar as melhores propostas considerando a tarifa mínima calculada na

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LPP, como entrada, a demanda como saída e o investimento feito como saída. Os resultados foram satisfatórios; A DEA classificou as propostas mais adequadas dentro dos requisitos legais.

Palavras-chave: Locação de porto; Maior manuseio de embarcações; Direito provisório; LPP; DEA

PROPOSAL OF A MODEL FOR PORT LEASE BASED ON LINEAR PROGRAMMING APPLIED TO A BRAZILIAN SITUATION

Abstract

This paper presents a mathematical model of selection of the best bidder for the lease of port areas. The model aims to meet the request made by a Provisional Law⁴, which regulates the leasing process. They determine that the new methodology considers the lowest fare combined with the greater port handling. We propose a mathematical formalization tailored to the interests described. The used formalization was a LPP (Linear Programming Problem) to calculate the lowest fare charged to the user, and the minimum port handling required for the estimated demand by introducing costs originated from predictable demands and the investments needed to meet the estimated demand. Afterwards, the DEA model (Data Envelopment Analysis) was applied to classify the best proposals considering the minimum fare calculated in the LPP, as an input, the demand as an output and the investment made as an output. The results were satisfactory; the DEA classified the most adequate proposals within the legal requirements.

Keywords: lease of port; greater port handling; provisional law; LPP; DEA

⁴ It is an instrument with the force of law, adopted by the President in cases of relevance and urgency, which the term of validity is sixty days, extendable once for an equal period. It takes immediate effect, but it depends on approval of the National Congress for its final transformation into law. (Accessed in 11/20/2015, website:<http://www2.camara.leg.br/comunicacao/assessoria-de-imprensa/medida-provisoria>.)

Introduction

Brazil has been facing constant wear on the development capacity of its Urban Transportation and Logistics structure, interstate and international. The port structure in any country causes the development and growth of a nation. The optimization in the exchange of goods brings more foreign exchange, jobs and, on the other hand, produces competition and integrates new technologies with enrichment of gross capital formation. Therefore, ports are vital to the healthy competition of this process. Based on that, the government, concerned about the inefficiency and low productivity of our ports, proposed effective actions to give greater transparency and competitiveness at the international level to their processes. One of the proposals was the Provisional Measure (PM) 595 of December 6, 2012 and subsequent law passed by the National Congress number 12815/2013.

In this way, the object of this article is to draw up a model that meets the demands imposed by the provisional measure MP 595/2012 and, more specifically, the Law 12815/2013 establishing parameters for bidding of port terminals. Named as Ports Provisional Measure and in sequence, the Ports Law, this law establishes the need for a new model of selection of bidders that should consider the combination of the lower rate charged by the lessee to the user, combined with greater port handling (load and passengers) and, consequently, greater application of investment.

Compared to other international ports, if not owned or operated by the state itself, the usual method is the utilization of contracts of use or lease with simplified provisions of exploration by payment services and/or lease rates, which means, simple methodology and trivial higher price.

It must be considered that the former Brazilian bidding model is unique and outdated. This bidding system of port terminals used to reward the bidder offering the highest value of the grant, i.e., in practice it was considered the greatest amount of rent to the bidder area. The new system gives priority to the bidder who submits the most efficient capital structure. In order to meet the objective of the new port structure, a model using the LPP (Linear Programming Program) in Operations Research was built. As Silva et. al. (1998) said, the ideal scientific method for decision making should be simple, i.e., "*a good model is the one that is sufficiently close to reality performance and of easy experimentation.*" (Silva et. al. 1998). Specifically, LPP is used to approach the bidding proposals to results which favors the smaller port service fares with major investments for the growth in cargo handling. Competitors develop and present their STFEE (Studies of Technical, Economic and Environmental Feasibility) in which their resulting values are subjected to linear programming models.

Afterwards, due to the differences in scale and units (tariffs, investments in money value and tons of cargo for port handling) the DEA is applied, model known as Data Envelopment Analysis for classification and ranking of results obtained by DEA via efficiency planning technique. Therefore, the proposal chases for a more efficient model of billing relationship, based on a lower fare with larger cargo handling and investments in ports made by interested investors. Charnes, Cooper and Rhodes (1978), Banker Charnes and Cooper (1984), precursors of the model, stand out among the most prominent scholars in the literature regarding the measurement of efficiency. Because of them, several other works on the subject were made. However, this article only highlights those concerning the classification of ports in Brazil and abroad.

With these two results, comparative analysis of the DEA were done in descending order with the results of the Objective Function of Linear Programming and the applied investments.

This article, therefore, is divided into five sessions. The Section 2 introduces the needed concepts to understand the model used in Linear Programming (LP), explains the DEA and its use for ranking techniques of the proposals. Section 3 deals with the practical application of the models. Section 4 makes analysis and simulations. Finally, in the last section there are conclusions and suggestions.

The Linear Programming Models and DEA

According to the model of Operations Research (OR) or Linear Programming (SILVA et. al., 1998; HILLIER and LIEBERMAN, 2005), there are some steps to be accomplished in the models. Among them are:

- The formulation of the problem;
- The construction of the model;
- Calculus of the solution through the model;
- Establishment of the solution controls and,
- Implementation and monitoring

The purpose and importance of the model used in this article is to maximize one main function, called Objective Function or Function Efficiency, subject to other equations, which are constraints to the model.

The problem studied in this case is the most general optimization (maximize or minimize) in which the objective and constraints are expressed as mathematical functions and functional relations as follows:

Optimize: $z = f(x_1, x_2, x_3, \dots, x_n)$

Subject to: $g_1(x_1, x_2, x_3, \dots, x_n) \leq b_1$
(1)

$g_2(x_1, x_2, x_3, \dots, x_n) \leq b_2$

...

$g_n(x_1, x_2, x_3, \dots, x_n) \leq b_n$

Each one of the m constraint relations of equation (1) involves one of three signals \leq , \geq , or $=$. As can be seen above, these applications are maximizing the objective function Z and the signals used in the constraints are \leq . This means, it maximizes the port handling and the inverse of the rate (the lowest possible). In this way, it avoids the "explosion" of the function, the constraints are limited to a value b_i ($i = 1, 2, 3, \dots, n$), except for the constraints of nullity, since no variable can be less or equal to zero, otherwise there would be error in the model (HILLIER and LIEBERMAN, 2005).

Some advantages are perceived and justify the use of LPP:

1. Possible comparison between variables with different units of measurement;
2. Mathematical formalization with rough calculations considering the real needs of a problem situation;
3. Flexibility limited to definition of constraints;
4. Simplicity in formulation and,
5. Widely known Model.

Data Envelopment Analysis

Berger and Humphrey (1997) researched parametric and non-parametric models for measuring of efficiency. One of the problems of parametric techniques is the necessity of knowing the production function, as well as the statistical distribution of the deviations (residues) between the expected and observed values. On the other hand, the non-parametric technique requires no assumption regarding the production border format.

The popularity of technical measures of nonparametric efficiency, such as DEA (Data Envelopment Analysis), comes from its operational flexibility. In the original DEA, the exception happens through the property of convexity assumption, and the requirement of correct definition of outputs and inputs.

The basic concept deals with the production border (or frontier production function), which is by definition the maximum amount of output (or goods) that can be obtained given a number of inputs (inputs) or used resources. As defined by Sousa and Stosic (2005): "The production possibility

frontier shows the maximum production quantities that can be earned by an economy or firm, given its technological knowledge and the amount of available inputs."

Over this context, DMUs - Decision Making Unit - are defined as a company, a department, an administrative division and in the case of empirical application of this paper, bidding proposals of competitors for evaluation. The set of DMUs adopted for DEA analysis should have in common the use of these inputs and outputs, as well as being homogeneous and autonomous in decision-making. The measurement units of the equal variables should be the same, but may be different among the others.

Banker Charnes and Cooper (1984) stand out among the most prominent scholars in the literature about the measurement of efficiency. To them followed several other authors and works on the subject (BERGER and HUMPHREY, 1997; KANTOR and MAITAL, 1999; THANASSOULIS, 1999; ZENIOS et al., 1999). Later, Berger and Humphrey (1997) consolidated and evaluated studies about technical efficiency in production and logistics processes.

Many methods that include DEA, or based on DEA, have emerged to determine efficiency: Method for evaluation of performance, for selection of efficient units, for price determination, for risk assessment and selection of outliers, among other applications (SILVA and AZEVEDO, 2004; WHEELLOCK and WILSON, 2003; ROSA and MAZZON, 2003). Currently, a wide variety of theoretical basis and practical applications are available, among which stand out, of interest to this work, some international studies of ports efficiency rating, logistics and distribution of containers or efficiency of port production through the DEA (PANAYIDES, 2009; COOPER, SEIFORD and ZHU, 2004; CULLINANNE, SONG and WANG, 2004; ITOH, 2002; TONGZON, 2001).

Normally, the DEA presents in the results, especially in situations where the decision units are well behaved and the input and output variables are balanced, variables without major dispersions. However, if any or some units show optimum performance there will be alteration in the results of the other units indicating they have low efficiency. The distribution of the frequency of efficiency becomes highly asymmetric and with non-linear scaling. A lot has been done to resolve this effect. However, this often depends on a visual inspection of the data, which is virtually impossible for large databases or data set (SOUSA and STOSIC, 2005), but is not this case.

Some Brazilian authors as Junior Souza et al (2013), Hawk and Correia (2012), Costa (2007) have been working on studies on the efficiency of seaports and applied DEA to classify them. Hawk and Correia (2012) use other efficiency frontier comparative methods for this classification.

However, in research on the subject, it was not found the utilization of this method in applications for investment selection and investors in private or public bidding.

Models - CRS e VRS

The original model CCR, also known as CRS (Constant Returns to Scale), works with constant returns of scale (CHARNES et al., 1996), from the viewpoint of multipliers and input. The DEA suggests two models: Focusing on the Input oriented or Output oriented. In the first case it is desired to minimize the use of resources in order to keep the level of outputs or products the same. That is, it wonders how much I can reduce the inputs without affecting the quantities of outputs produced? In the case of output orientation, the goal is to maximize the products obtained without changing the current level of inputs (ESTTELLITA LINS and MEZA, 2000). The model used in the orientation of this paper is the CRS oriented to the input.

It is considered that each DMU k is a production unit that uses n inputs x_{ik} , $i=1, \dots, n$, to produce m outputs y_{jk} , $j=1, \dots, m$. This model maximizes the quotient of the linear combination of the *outputs* and the linear combination of the *inputs*, with the constraints that for any DMU this quotient can not be more than 1.

This linear programming problem assumes constant returns of scale (CRS) from multipliers applied to the inputs and outputs.

The model can be represented by:

The minimum value of θ

So that:
$$\theta x \geq \sum \mu_k x_k$$

$$y \leq \sum \mu_k y_k$$

at where:
$$\mu_k \geq 0 \quad \forall k \quad \text{and};$$

(2)

$$\theta \geq 0$$

Where: θ is interpreted as an efficiency indicator of the DMU analyzed, all based on the possibility of inputs reduction to obtain maximum efficiency.

This is the perspective of the input with constant returns to scale when the set of points such that $\theta = 1$, is defined as the efficient frontier, although not always Pareto-efficient (CHARNES, COOPER, LEWIN and SEIFORD, 1996).

In the elimination of the property of unlimited radius (constant returns to scale) the DEA model becomes BCC \equiv VRS (variable returns to

scale), starting to consider the possibility of increasing or decreasing returns to scale in the efficient frontier. The coefficients μ_i are replaced by λ_k , which define a convex linear combination. The LPP and the border that involve the viable points are defined as:

The minimum of θ

So that: $\theta x \geq \sum \lambda_k x_k$

$$y \leq \sum \lambda_k y_k$$

at where: $\lambda_k \geq 0 \quad \forall k$ and ;

$$\theta \geq 0$$

$$\sum \lambda_k x_k = 1$$

(3)

The Models

Objective Function and its Constraints

The Objective Function (OF) was built taking into account the two variables elucidated by PM 595/2012, which are: price and port handling. The objective function is:

$$VALOR_COEF = a (1/fare) + B \ln (movements)$$

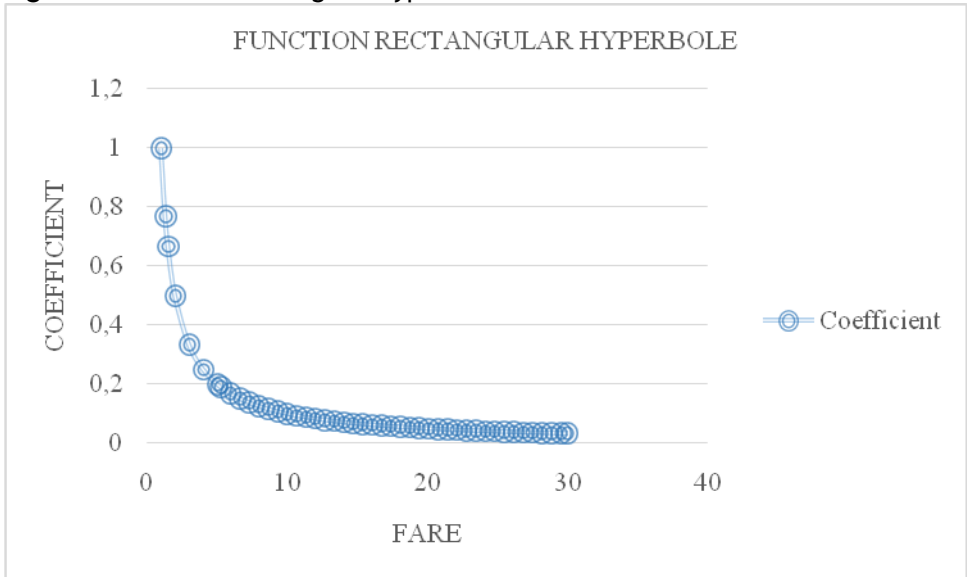
(4)

Where: a and B are coefficients determined by the model or discretionary by the government authorities.

The formula aims to maximize the variable $VALOR_COEF$ to determine the best contender participating in the bidding.

The structure of the functions $(1/fare)$ and $\ln (movements)$ aim, in this format, to find bidders who present fares that are more competitive according to the market. Also, it aims to drive away the adventurers who present unrealistic low fares and that after winning the bid, will ask government authorities for the economic and financial balances.

The function $(1/fare)$ is termed a rectangular hyperbolic function and according Chiang (2004), the rectangular hyperbola is a decreasing function and asymptotic, that does not allow the value of the fare to be zero, as well as decreases the value of the coefficient when the value of rate rises. Another feature of this function is the fact that it presents unit elasticity at any point of the curve. The variable favors agents who work in the center of the curve because their marginal gains are higher than users who operate in the extremes.

Figure 1: Function rectangular hyperbole

Source: Made by authors

The function *ln (movements)* is a logarithmic function, which has the characteristic of the decreasing marginal gains (CHIANG, 2004), i.e., its gains decrease in relation to the coefficient with the increasing of port handling. The mentioned peculiarity of the function is important because the marginal gain will tend to zero as the amount of port handling approaches its maximum capacity. Therefore, it favors the bidding competitors who provide more reliable values of port handling.

A major contribution of the Operational Research model is to have constraints to the base model (Objective Function), where the constraints ensure that the solutions comply with the technical limitation imposed by the system (SILVA et al., 1998). The model constraints are:

1. Total revenue is equal to or greater than zero.

The constraints ensures that the fare multiplied by quantity of port handling will be a positive number.

$$\text{Fare} \times \text{quantity} \geq 0 \quad (5)$$

2. Annualized Cash Flow is equal or greater than zero.

The Total Revenue Value brought to the Present Value less the Total Costs, also in Present Value, will be equal or greater than zero.

Annuity:

$$\text{fare} \times \left[\frac{\text{quantity}}{(i - g)} \times \left(\frac{(1+g)}{(1+i)} \right)^n - 1 \right] - \left[\frac{\text{cost}}{(i-g)} \times \left(\frac{(1+g)}{(1+i)} \right)^n - 1 \right]$$

or

$$\text{annualized_total_revenue} - \text{total_annualized_cost} \quad (6)$$

Where: g is the growth rate, or gradient from the quantity of port handling.

If there is not an estimated rate of constant growth, the proponent fills out an estimated demand flow and therefore $g = 0$. In the following example it is considered $g = 0$.

The discount rate i is provided by ANTAQ (National Waterway Transport Agency). The model will be tested with the value of 11.0% per nominal year.

The Annualized Cash Flow constraint when equal or greater than zero ensures that the project is feasible, because, when brought to present value, the cash flows will be positive.

3. The Investment Flow must be greater than the Minimum Investment.

These constraints ensure that the investment in the project is the minimum required for the projected demand for the area. Such Minimum Investment is calculated by the company responsible to elaborate the EVTEA of the leased area. According to the constraints, the greater the investment is, the bigger will be the weighting on the value of the coefficient calculated by the objective function.

$$\text{investment_flow} \geq \text{minimum_investment} \quad (7)$$

4. The fare and the quantity OF PORT HANDLING must be equal or greater than zero.

The positivity constraint of the variables ensures that won't be any negative values in the main variables of the model. It is elucidated only for modeling purposes, the variable fare will always be greater than zero due to the formulation of the objective function, so:

$$\text{fare} \geq 0 \quad \text{e} \quad \text{quantity} \geq 0 \quad (8)$$

5. The parameters α and β of the model are between zero and one.

Ensures that the weights act in a way to not extrapolate the actual values of the variables, assigning greater importance for a proper variable, or keeping them equally in a case that α and β are equal to 0.5. To ignore any weight, it is determined that $\alpha = 0$ and $\beta = 0$. However, one can

assume different values for any parameter according to the discretion of the manager.

$$0 \leq a \leq 0 \quad e \quad 0 \leq b \leq 0 \quad (9)$$

6. The port handling cannot be greater than the effective capacity.

Ensures that the port handling revealed by the bidder won't be greater than the effective port handling that the competitor can perform due to investments made in the leased area. This effective capacity will be determined by engineers linked the company that will elaborate the EVTEA of the area.

$$\text{port handling} \leq \text{effective_capacity} \quad (10)$$

Application by the Data envelopment analysis

In the DEA model, it is important to define the *input* variables, the *output* variables and the DMUs:

DMU: five proposals that were submitted by the LPP (Linear Programming Program) were set up, which results generated, for each DMU (proposal), a minimum fare, as well as a minimal of port handling for each competing proposal. The result of the spreadsheet also generates the investment needed to sustain the quantity of port handling proposed. The investment is indicated by the bidding applicant.

Input: Fare found by PPS for each DMU. This fare is how much the tenant bidder will charge for its port services. With minimal handling these variables make up the tenant revenue.

Output: Minimum transaction calculated by LPP according to the demand estimation placed by the bidding applicant considering its investments, given costs and revenues.

Simulation and Analysis

The first model tests were performed with the elaborate EVTEA's elaborated for the areas of leases :TMU 2/Vila do Conde - PA, Tecon II/Suape - PE, Teconbel/Belém - PA, Área do Meio/Itaguaí - RJ e Rodrimar/Santos - SP.

Table 1: Simulation for the area TMU 2/ Vila do Conde - PA

Objective Function	Alpha:	Beta:
	0	0
	Fare:	Port handling:
	41,71	117.178.880
	Coefficient	18,60

Source: Made by the authors

The fare is expressed in REAIS (R\$) - Brazilian Currency - and the port handling is expressed in tonnes (total port handling, considered the sum of the values of all the contract period). The total investment over the 25 year of project is R\$ 1.157.660.432, 50.

Supposing that the function developed by EVTEA for the area TMU 2 results in maximum fare charged and minimum of port handling. It is presented, as an example, five bidders competing for the lease, the competitors are called: A, B, C, D and E. For better exemplification are despise the values a and b in OF which in the model OP (operational research), it is ignored the weighting or the importance level of the fare in relation to the port handling and vice versa, since these values do not change competitor's classification.

The Competitors present the following results in linear programming:

Table 2: Objective Function result with the investment

Competitors	Fare R\$	Port handling (ton)	Coefficient	Investment R\$
A	41,71	117.178.880	18,60	1.157.660.432,50
B	40,25	122.560.000	18,65	1.195.073.817,43
C	41,67	126.560.000	18,68	1.408.311.159,95
D	29,25	160.800.000	18,71	1.047.301.501,65
E	31,09	117.040.000	18,61	1.081.929.263,08

Source: Made by the authors

To obtain the fare values and the minimum of port handling, the bidders need to insert the proposed total of costs and expenses consistent with the estimation of the total quantity of port handling, as well as the minimum investment proposed for the estimated quantity of port handling. The LP maximizes its coefficient subjected to the constraints presented. The competitors Data are launched in the software MS_EXCEL © in extension tool called SOLVER, in a spreadsheet assembled and made by government authorities.

As can be noticed, the bidder D presents the best proposal because its coefficient is the greatest. The followed order is D, C, B, E and A. It is noteworthy that, in this example of LPP, the investments are required only to meet the constraint of minimum values, which are suggested by the competitor himself, thus, there is little influence on the OF final result.

With the entry of the variable Investment, which is used in the LPP only as the minimum value required to meet the demand suggested by the proponents, the DEA model is needed for relative comparison between the proposals. Thus, the coefficient is not necessary, since it is only a function of the fare and port handling.

Table 3: DEA Result

Competitors	Fare R\$	Port handling (ton)	Efficiency	Investment R\$
A	41,71	117.178.880	92,51%	1.157.660.432,50
B	40,25	122.560.000	94,31%	1.195.073.817,43
C	41,67	126.560.000	98,13%	1.408.311.159,95
D	29,25	160.800.000	100,00%	1.047.301.501,65
E	31,09	117.040.000	99,06%	1.081.929.263,08

Source: Made by the authors

As shown in Table 3 the priority order is D, E, C, B and A. The difference presented by the exclusive use of the LPP results from the inclusion in the comparative and relative DEA model of the variable Investment. This variable is needed to enable all the port handling, but also to set the fare needed for the project.

Conclusions and Suggestions

One of the questions that can be asked is: why couldn't we only use the DEA model for classifying efficiency among tenant's proponents, since it is originated by a linear programming with comparative constraints of DMUs?

However, it is worth clarifying that both the rate as the port handling is calculated by LPP and all came from demand variables and investments given by the competitors and subjected to the constraints of minimums values of demand and investments. Therefore, the DEA should be applied on the outcome of these variables. Thus, the models do not compete, but complement each other.

The use of DEA for ranking was relevant, because it ranked in relative comparison between the DMUs, a great combination of the variables *PRICE*, *HANDLING* and *INVESTMENT*.

As the government expected, the paper presents a mathematical model of choosing the best bidder to lease the areas provided by the Port Authority for exploration. The model described aims to meet the request made by the new provisional measure and its law, which deal with the Brazilian port system. The PM 595/2012 and the Law 12815/2013 state that the new methodology must encompass the minimum fare combined with the greater port handling. Thus, we propose a mathematical formalization suited to the legal interests.

The Initial calculations performed and the model tests made for the leases here listed were satisfactory. The model was able to maximize the value of the coefficient, and classify them in order of effectiveness of the lower fare proposals, projected demands and applied investment, reaching the expected goals.

One suggestion for future research is to simulate the LPP model replacing the variable *PORT HANDLING* by the variable *INVESTMENT* as proxy of quantity of port handled, because it is a better measurement variable, due to the fact that its realization occurs in the first years of the project; and the quantity is the total sum of the time of contract binding, enabling greater risk measurement. The results can change the fare value and, hence, affect positively the final value of the coefficient that selects of bidders.

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