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Hybrid multicriteria and economic engineering model to support decision in fleet management

Modelo híbrido multicritério e de engenharia econômica para suporte à decisão na gestão de frota

Régis F. Dantas

Government of the State of Ceará and Caixa Econômica Federal, Fortaleza, CE, Brazil

Author notes

Régis F. Dantas is now the general coordinator of the Integrated Program for the Prevention and Reduction of Violence (Programa Integrado de Prevenção e Redução da Violência – PReVio) and manager at the Brazilian Caixa Econômica Federal.

Correspondence concerning this article should be addressed to Régis F. Dantas, Avenida Barão de Studart, 598, Meireles, Fortaleza, Ceará, Brazil, ZIP code 60120-000. Email: regis.dantas@uol.com.br

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Abstract

Purpose: To provide the decision-making agency with a hybrid composite model for a qualified decision and maximize the quality of public management when challenged by the tradeoff between own and leased fleet.

Originality/value: The proposed methodology innovates by integrating a framework based on a set of quantitative and qualitative criteria, increasing accuracy of the decision-making process regarding the management of the Ceára Public Safety Secretary's fleet. With a multicriteria model, one can understand and identify the fundamental criteria in terms of management to select alternatives and avoid making these decisions based only on experience or feeling.

Design/methodology/approach: To support the decision-making process regarding the choice or combination between own and leased fleet, optimal solutions are built using a hybrid model that combines techniques from the multi-attribute utility theory (Maut) models of economic engineering with the help of the total cost of ownership (TCO). The alternatives are weighted (considered) qualitatively and quantitatively through the proposed model.

Findings: The results confirm the compatibility between the methods used, providing the agency with a methodological tool that qualifies the decision based on a model that reveals the decision-makers' preferences in terms of relevant attributes to good management, while respecting budgetary constraints.

Keywords: multicriteria model, multiobjective problem, economic engineering, total cost of ownership, fleet management

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Resumo

Objetivo: Dotar o órgão decisor com um modelo híbrido composto para decisão qualificada e maximizar a qualidade da gestão pública ante o *trade off* entre frota própria e locada.

Originalidade/valor: A metodologia proposta inova ao integrar um *framework* baseado em um conjunto de critérios quantitativos e qualitativos, aumentando a precisão do processo de tomada de decisão sobre a gestão da frota da Secretaria da Segurança Pública do Ceará. Com modelo multicritério, podem-se compreender e identificar os critérios fundamentais em termos de gestão para selecionar alternativas e evitar tomar essas decisões com base apenas na experiência ou no *feeling*.

Design/metodologia/abordagem: Para apoio à tomada de decisão quanto à escolha ou ao *mix* entre frota própria e locada, soluções ótimas são construídas com uso de um modelo híbrido que combina técnicas dos modelos de utilidade multiatributo (*multi-attribute utility theory* – Maut) e de engenharia econômica e com auxílio do custo total de propriedade (*total cost of ownership* – TCO). As alternativas são ponderadas qualitativa e quantitativamente por meio do modelo proposto.

Resultados: Os resultados confirmam a compatibilidade entre os métodos utilizados, dotando o órgão de uma ferramenta metodológica que qualifica a decisão com base em um modelo que revela as preferências dos decisores em termos de atributos relevantes para uma boa gestão, respeitando as restrições orçamentárias.

Palavras-chave: modelo multicritério, problema multiobjetivo, engenharia econômica, custo total de propriedade, gestão de frota

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INTRODUCTION

The decision between own and leased fleet goes through the choice between elements considered important by the management, optimizing efficient decision-making processes. In public agencies, it is common to use the individual experience of managers with monochromatic decisions to choose among several alternatives or leave it to the bidding process of the lowest price type that, although legal, many times does not contemplate management elements.

Fleet composition problems face multicriteria decisions such as total capacity size, selection of vehicles based on their characteristics, and the optimal fleet arrangement considering costs and revenues (Hoff et al., 2010). According to Silva et al. (2015), the decision to operate or not with one's fleet must consider several aspects, such as the level of customer service, flexibility, control, administrative skills, and return on investment. One must seek to know about the qualification and technical capacity of the companies, in addition to comparing costs with other service providers and making an analysis of economic and financial viability (Imhoff & Mortari, 2005; Moreira et al., 2016).

According to Faria et al. (2020), the literature presents several studies on the selection of alternatives in transportation decision-making, most of them based on the cost criterion, which is an efficient way to identify the investment needed to compare them. However, other relevant variables of transportation performance should also be considered (Meixell & Norbis, 2008; Garo & Guimarães, 2018).

One of the tools for strategic analysis to decide between outsourcing or not is the concept of total cost of ownership (TCO), considered: "one of the most modern and widespread concepts in the supply chain management practices of companies considered as world-class" (Amato Neto, 2014, p. 128).

According to Feldens et al. (2010), two types of models are usually suggested in the literature on fleet replacement: economic engineering (EE) and operational research (OR) models. EE models are restricted to the economic-financial aspects, considering exogenous the technology, management, and strategy variables. Traditional methods lead management to abandon formal methods of investment analysis and to use subjective unstructured analysis. Traditional OR models, despite modeling multiple variables, focus on a single objective to be maximized/minimized.

Problems with multiple objectives and criteria are generally known as multiple criteria optimization or multiple criteria decision making (MCDM)

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problems, in which they present efficient solutions that can best mirror reality, emphasizing the study of problems with multiple objectives (Gomes & Gomes, 2019).

Using multicriteria models, one can understand and identify the fundamental criteria for selecting alternatives and avoiding making decisions based only on individual experience or feeling. In a study based on multi-attribute utility theory (Maut), De La Vega et al. (2018) observed that this approach enables a robust analysis of the most appropriate decision according to the preferences and aversion of the company's decision-makers, considering a set of criteria that are simultaneously evaluated.

The Maut approach is developed to assist in the classification, selection, and/or comparison of alternatives within a finite set of criteria, so that the decision makers are comfortable with the final decision (Chen et al., 2008).

This study approaches multicriteria along with economic-financial aspects in the decision process regarding the choice between own or leased fleets in a public agency, such as the Public Safety Department. The objective is to provide the decision-maker with a methodological tool for a qualified decision and to maximize the quality of management, given the budgetary restrictions.

Thus, we propose a framework for the fleet problem's decision based on a set of qualitative and quantitative criteria. It is a hybrid method of decision-making support that combines Maut model techniques and EE, with the assistance of the TCO analysis, with the choice of more appropriate relation between own and leased fleet. The decision-maker is challenged by a tradeoff between the exposed alternatives.

The option choice to use the Maut intends to incorporate multiple objectives and the managers' preferences into the problem. Also, it uses a discrete method with several discrete alternatives in the choice for the leased fleet, employing weights and scores to attributes using a mathematical function. The attributes refer to characteristics and management topics considered relevant by the managers, therefore revealing their preferences.

The study used the management variable as endogenous in the model. The proposed methodology innovation is related to the integration of the EE criteria with multicriteria method fleet management, including the individual preferences of decision-makers and the observation of the TCO.

The next section presents the theoretical aspects of multicriteria and economic engineering models. In sequence, the methodology and the proposed models are described. Then, we analyze the results after the models are simulated with real data. Finally, the discussion of the results and final considerations are presented.

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THEORETICAL ASPECTS OF THE DECISION MODEL

Multicriteria models for decision support

In general, decisions are made either individually or collectively. For Kocher and Sutter (2005), in individual choices, to achieve the aimed objectives, one starts from the confrontation of the preferences, alternatives, and restrictions, in search of individual benefit. However, in group decisions, one seeks a consensual choice based on individual preferences (Hammond et al., 1999).

According to Bregalda (2017), more sophisticated techniques and models have been built, such as Pareto-optimal, developed to address the multiobjective problems, with the most feasible solutions possible. Pareto's efficient solution can be obtained so that the chosen alternative achieves a broad value in all criteria and does not have a simultaneous decrease – a value dominated by another alternative (Gomes & Gomes, 2019; Silva 2020).

The Maut is a discrete method for having a discrete number of discrete alternatives. It is used to determine the importance attributed to a certain criterion over another and to prioritize alternatives. In general, multiattribute methods refer to methods for selecting, ordering, or categorizing among a finite number of alternatives, explicitly known (Clímaco et al., 1996). As part of these optimization problems, besides the Maut method, the Analytical Hierarchy Process (AHP) and the Quality Function Deployment (QFD) have been used to apply multiple decision criteria (Matsuada et al., 2000).

In a multiple criteria context, according to Zopounidis and Doumpos (2002), decision-making problems are carried out in the following paradigm: a set A of alternatives (e.g., companies, investment projects, and portfolios) is considered, and an attempt is made to make an optimal decision considering all relevant factors to the analysis. Since these factors usually lead to conflicting results and conclusions, the optimal decision is not ideal from the traditional optimization perspective.

In Maut, the objective function is the mathematical representation of the efficiency criteria applied to the optimization problem. It is influenced by the project variables, known as decision variables of the problem (Gomes & Gomes, 2019). The solution space consists of all points that satisfy the problem's constraints. The optimal solution in the maximization problem corresponds to the point of maximum value for the objective function (Gomes & Gomes, 2019).

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Economic engineering model for decision support

For Silva et al. (2015), the EE approach observes the optimal moment of equipment replacement as the starting point of the concepts of useful life and economic life of a good. The equivalent uniform annual cost method proposes that the economic life of an equipment corresponds to the period in which this cost is minimal and, therefore, the optimal moment for its replacement (Silva et al., 2015).

In the evaluation of an equipment's economic life, the analysts should use techniques that consider the money's value over a time scale to recognize opportunities for positive outcomes when estimating the series of expected cash flows associated with the alternatives (Lima et al., 2015).

The importance of costs whether for use or ownership is observed in Souza et al. (2015), defining TCO as a complex approach in which the buying organization needs to identify all costs considered relevant in the activities of acquisition, possession, and use of a good or service, quantified for each supplier. According to Onkham et al. (2012), TCO provides metrics to assess the costs of the entire life cycle of a product by considering, besides the acquisition value, the costs associated with its use and disposal.

Thus, TCO is a tool to support strategic cost management in purchasing decisions (Ellram & Siferd, 1998). In this way, Diniz and Paixão (2017) compared the costs of own and outsourced vehicle fleets in commercial operations of a private company, verifying, through a projected scenario, that fleet ownership was more profitable. The application of the TCO analysis contributed to demonstrating the hidden costs, which are not considered in the economic evaluation of the equipment, which could have changed the purchase decision in a traditional analysis applied without the tool (Coser & Souza, 2017).

Using a vehicle as a product, "TCO covers all expenses accrued by a vehicle owner, including a one-time purchase cost and other costs such as fuel, taxes, maintenance, and repair" (Redelbach et al., 2012, p. 2).

METHODOLOGY: MAUT MODEL PLUS ECONOMIC ENGINEERING

Adapting the flowchart proposed by Belton and Stewart (2002), Figure 1 shows the methodological sequence of the decision-making process. With the problem in A, the current governance stage is shown, in which the own

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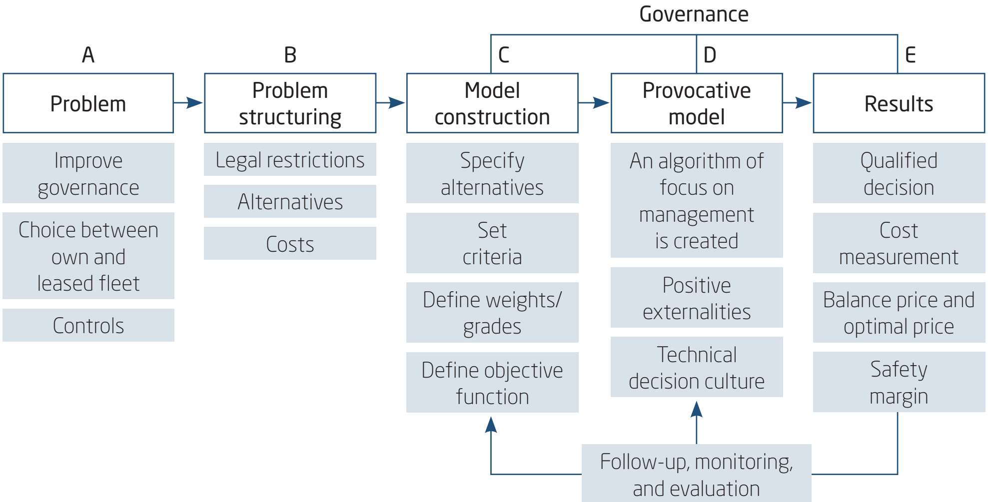
fleet is questioned in relation to the leased one and the respective management controls. In B, the problem is structured by observing legal restrictions, costs, and alternatives. In the model's construction in C, the objective function is specified with its parameters and criteria. In D, an algorithm is created, a standardized solution path for the decision. As results (E), a qualified decision is expected, costs are measured, and the optimal and equilibrium prices for possible rental contracts are verified.

Figure 1

Methodology flowchart for decision-making



Source: Elaborated by the author based on the process of AMD (*Multicriteria Decision Support*) by Belton and Stewart (2002).

From steps C to E, there are procedures that lead to a better governance, which, according to Machado et al. (2016), has as pillars: transparency, equity (fair treatment of all involved), corporate responsibility, and accountability. In this continuous flow, there is the follow-up, monitoring, and evaluation of the results for the decision-making and, when necessary, adjustments.

The government is challenged with several objectives for decision-making. Legal restrictions must be verified, for example, the decision-making process goes through the bidding process for being a public entity.

The alternatives are confronted and evaluated by the decision variables, which, mapped by attributes, represent the preferences of managers by criteria related to the attributes. The problem then follows the hybrid model construction flow represented in Figure 2.

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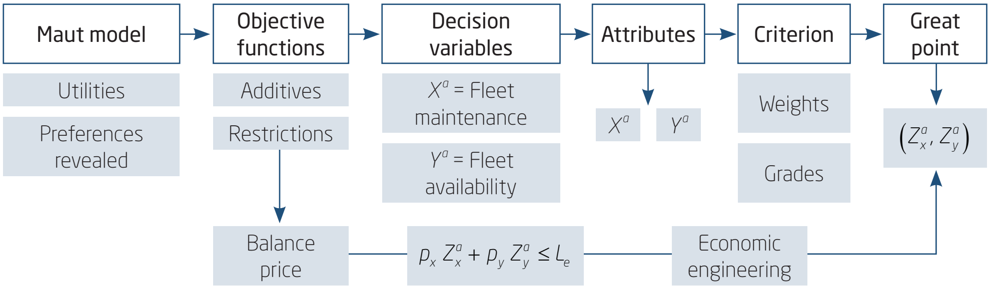
Figure 2

Hybrid model construction flowchart: Maut plus economic engineering



Source: Elaborated by the author.

Multicriteria decision model

Using the Maut to build optimal solutions, management indicators are defined. Each fleet management indicator is an attribute, such as having agility in fleet adaptation, speed in the replacement of cars with accidents, among other relevant factors for good management efficiency. Decision variables, related to a better fleet management capacity, are defined as relevant management aspects for the decision-maker. Each decision variable will be composed of a set of attributes of management indicators. The two decision variables are:

X^a = Fleet maintenance
Y^a = Fleet availability

Each objective function with its respective decision variables has its attributes that belong to the decision vector (Table 1). These attributes were selected from the literature on positive factors of vehicle leasing and ratified as relevant by the managers of the Public Safety Department of Ceará state government. The subjective preferences of decision-makers, among the alternatives, are measured or revealed by the weighting of some criteria. Each rental company that disputes the preference of the decision-maker will have its X^a and Y^a measured. The objective functions represent the decision-maker's preferences among the attributes of a set. The decision variables, X^a and Y^a, are equivalent to the sum of the weights of attributes x_i and y_i, as shown in Table 1.

The decision variables refer to the decisions to be made aiming to find the solution to the problem. To parameterize these variables, attributes will be defined according to management needs, based on the following assumptions:

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1. Fleet outsourcing companies observe the definitions of the management parameters set out in the bidding and set their prices according to their capacities and costs.
2. It is assumed that companies compete in a perfect market and that there is no corruption in bidding to misrepresent the market price.
3. Given prices in a competitive market, the proposals from outsourcing companies will have their prices directly proportional to the degree of quality imposed for each decision variable (management), connected to the attributes defined in the bid notice.

Considering the assumptions, the manager parameters the decision variables with the attributes listed in Table 1 and weights criteria according to Table 2. This is an *a priori* decision model, the manager is consulted only once, before the optimization process begins, and the information obtained regarding their interests is used to guide the search for the favorite solution belonging to the Pareto frontier.

Table 1

Attributes of decision variables

x_i	Fleet maintenance
x1	Rental with contractual security and vehicles with full coverage and free mileage
x2	Availability of quick replacement of vehicles under maintenance
x3	Transfer of bureaucracy to the rental company
x4	It will be up to the contractor to deliver the characterized vehicle
x5	All leased vehicles must receive proper preventive maintenance
y_i	Fleet availability
y1	The leased vehicles must be replaced by reserve vehicles within 48 hours
y2	Fleet adequacy to operational characteristics
y3	Availability in the fleet rental market throughout the territory
y4	Adequate dimensioning of the fleet in relation to the demand
y5	Fleet renewal at the ideal economic time

Source: Elaborated by the author.

The decision-makers defined the attributes in Table 1 with the weights for each criterion according to Table 2, creating, from the sum of the attributes for each decision variable, X^a and Y^a.

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Once each attribute of the decision variables has been defined, the process now is to define the scoring of the alternatives, therefore, the companies (alternatives) that are competing will be evaluated and scored for each attribute, using the weights in Table 2. The final score of the company is given by the final sum of the attributes of each decision variable, with the respective score ranging from 0 to 10 in X^a and Y^a.

Table 2

Weight criteria for attributes of decision variables

Weight criteria for attributes	Weight
Not significant	0
Significant	1
Very significant	2

Source: Elaborated by the author.

Given the definitions of the weights (Table 2) on the attributes in Table 1, Table 3 is used to reclassify the weights into scores from scaling intervals of the sum of the attributes by objective function, $f(X^a)$ and $f(Y^a)$. This is a discrete decision model since it has a finite number of alternatives.

Table 3

Interval scaling criteria for attributes of objective functions X and Y

Criterion	Grades	Sum intervals (X + Y)
There will be no improvement in management	0	From 0 a 4
There is improvement in management, but not marked	1	From 5 a 7
Improved management is accentuated	2	From 8 a 10

Source: Elaborated by the author.

There are two decision variables, X^a and Y^a, with three scores (0, 1, and 2), as presented in Table 3, from the weights on the attributes in Table 1. The order (X^a, Y^a) is relevant. Considering $X^a = 2$ and $Y^a = 1$, then there is the point (2, 1), which is different from (1, 2). Since the independent attributes support the two variables (X^a and Y^a) with difference in order are repeatable (1, 1), the problem will have nine alternatives, given the arrangement with repetition $A_{(n,\ p)} = n^p$.

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The multicriteria decision model is presented by the set of equations from (1) to (17). Z represents the additive utility function revealing the decision-makers' preferences by means of the management quality parameters, used to decide which company will be accepted given the change from own fleet to leased fleet (outsourced). Functions (1) and (2) are the objective functions, constant functions according to intervals for the decision variables X^a and Y^a of the alternative A. Therefore, the optimization problem is configured as follows:

- Maximize:

$$Z_x^a = f\left(X^a\right) = \begin{cases} 0 \; if \; 0 < X^a \leq 4 \\ 1 \; if \; 4 < X^a \leq 7 \\ 2 \; if \; 7 < X^a \leq 10 \end{cases} \tag{1}$$

$$Z_x^a = f\left(X^a\right) = \begin{cases} 0 \; if \; 0 < Y^a \leq 4 \\ 1 \; if \; 4 < Y^a \leq 7 \\ 2 \; if \; 7 < Y^a \leq 10 \end{cases} \tag{2}$$

$$Z^a = \left(Z_x^a, \, Z_y^a\right) \tag{3}$$

$$Z^a = \left(f\left(X^a\right), f\left(Y^a\right)\right) \tag{4}$$

$$Z^a = f\left(X^a\right) + f\left(Y^a\right) = Z_x^a + Z_y^a \tag{5}$$

- Subject to restrictions:

$$0 < X^a, Y^a \leq 10 \tag{6}$$

$$X^a + Y^a \geq 13 \; \forall \, X^a, Y^a \geq 5 \tag{7}$$

$$Z^a = f\left(X^a\right) + f\left(Y^a\right) = Z_x^a + Z_z^a \geq 3 \; \forall \, Z_x^a, \, Z_y^a > 0 \tag{8}$$

$$d_i = \left(X_x^a, \;\; Y_y^a\right) \; \in D = \text{Decision space} \tag{9}$$

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$$Z^a = \left(Z_x^a,\ Z_y^a\right)\ \in Z\ =\ \text{Objective space} \tag{10}$$

$$Z = Z_x^a + Z_y^a \geq 3 \tag{11}$$

$$Z_x^a,\ Z_y^a \in N\ /\ 0 \leq Z_x^a,\ Z_y^a \leq 2 \tag{12}$$

$$p_x Z_x^a\ + p_y Z_y^a\ \leq L_e \tag{13}$$

$$\Delta z_i \rightarrow \Delta\, Costs\ of\ \ z_i\ = \Delta p_i z_i \tag{14}$$

$$x_i,\ y_i, \in N\ /\ 0 \leq x_i,\ y_i\ \leq 2 \tag{15}$$

Considering:

$$X^a\ = \sum\nolimits_1^5 x_i = x_1\ + x_2\ + x_3\ + x_4\ + x_5 \tag{16}$$

$$Y^a\ = \sum\nolimits_1^5 y_i = y_1\ + y_2\ + y_3\ + y_4\ + y_5 \tag{17}$$

Each vector d_i (9) in the decision space domain D will have as its image a vector z from the objective space Z. The search space D is the domain (bounded or unbounded) that contains the parameter values. It corresponds to the solution space. The dimension of the search space is defined by the number of parameters involved in the solutions – for example, if each solution is formed by three parameters, the search space is three-dimensional.

For each solution $d_i\ = \left(X_x^a,\ Y_y^a\right)$ in D, there is a point $Z^a = \left(Z_x^a,\ Z_y^a\right)$ in the objective space Z, as shown in Table 3. In the case of conflicting objectives, when the optimization of one of the objectives causes the deterioration of the other objectives, single-objective optimization is not sufficient. In multiobjective optimization, the concept of optimality is based on the concept of Pareto dominance. In this particular problem, the two objective functions specify fleet management criteria where increasing the quality and quantity of the respective functions raises the company's costs. Since they will be in a competitive process, it is expected that they will take their offers in terms of quality and quantity of attributes to the boundary, therefore, to increase X they will have to sacrifice Y and vice-versa.

The concept of optimal solution is replaced by the concept of efficiency, which is related to the concept of non-dominance, the former being associated

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with the solutions space (decision) and the latter with the objectives space (criteria). The decision-maker's preference information is obtained through the choice of the objective function leading to an optimization.

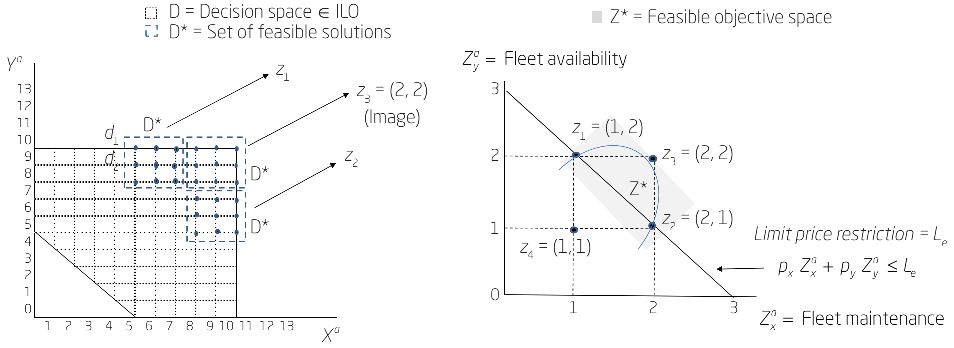
The restriction (7) in the decision space is equivalent to restriction (11) in the objectives space, meaning that the manager defined that the possibilities of acceptance for changing from own to leased fleet will occur if the variables of the attributes, summarized by Table 3, have the sum of the weights of, at least, the criteria three, which means limiting acceptance to a minimum degree of management quality.

There are two criteria that represent the decision-makers' preferences, given in the objective functions and restrictions: 1. according to the sum of the weights assigned to the attributes, there will be a scale of scores that will show the degree of improvement in management expected with that alternative; and 2. the sum of the decision variables should be at least 3, which means imposing that no alternative with a score of zero in the decision variables will be accepted, corresponding to a minimum degree of acceptable management quality.

Once the parameters defined in tables 1 to 3 are used, along with the objective function and constraints of the model, it is possible to calculate the feasible outcomes and the respective optimal solutions (Figure 3), given that the budget constraint (13) will be found in the EE model using the TCO.

Figure 3

Decision space and model objectives



Source: Elaborated by the author.

In Figure 3, each vector $\vec{Z}^a = \left(Z_x^a, Z_y^a\right)$ is the pair of decision variables chosen from X^a and Y^a of alternative A, which is the set of management indicators that make up the fleet management preferred by the decision-

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maker. Since it was decided that the vector should be greater than or equal to 3 (the sum of the management grades revealed in the sequential indicators of the vector), $\vec{Z}^a \geq 3$, any two or more sets of decision variables that have as sum 3, the decision-maker will be indifferent, (2, 1) ~ (1, 2), $Z_1 \sim Z_2$, because they lie on the indifference curve imposed by the constraint (13). A vector $\vec{Z}^a$ with a sum above three will be preferable to one with a sum 3, $\vec{Z}^a = 3$, therefore, $(2,2) \succ (1,2)$, meaning that the decision-maker strictly prefers Z_3 = (2, 2) to Z_2 = (1, 2).

According to the assumptions, since the costs of each decision variable increase proportionally to the quality grade of the respective item, there will be an increase in the total cost $\Delta p_i z_i$ which can overcome the constraint that is the cost (price) limit L_e. This L_e limit, given in Equation (13), is the current cost of maintaining one's fleet. The central idea is that, in order to change from own to leased fleet, besides the management improvement criteria, costs will not increase. The idea is to focus on efficiency and increase the quality and quantity of services without increasing costs. In (14), it is stated that variations in Δz_i will cause changes in costs $\Delta p_i z_i$.

The curve (Figure 3 – objectives space), formalized by restriction (13) of the cost limit L_e, has a negative slope, indicating that whenever the decision-maker (government) gives up a certain degree of quality in a management indicator X, it will be necessary to compensate with a certain degree of improvement in another management indicator Y. For example, for them to accept reducing the liquidity of the reserve car, they must increase the fleet's adequacy capacity.

The problem exposed here has multiple objectives, translated into the vector $\vec{Z}^a$ with indicators and their acceptable management degrees that are in the set of optimal solutions, called the Pareto-optimal, or non-dominated, frontier. The objective functions amount to wanting concomitantly a better management with Z_x^a = fleet maintenance and Z_y^a = fleet availability. In addition, the manager is challenged by the restriction that the management change cannot increase current costs. In this context, $Z^a = \left(Z_x^a, Z_y^a\right)$ is the maximization of the management function, given the criteria translated into the indicators.

In Figure 3, the objectives space is plotted with the functions that aim to maximize the fleet management model, given the possibility of the decision on relevant management aspects, defined *a priori*. The objective functions (1) and (2) map the feasible points in the decision space. The cost parameter is the cost of own fleet, so the change to leased fleet has the

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restriction equivalent to the costs of remaining with the own fleet of vehicles. The function Z^a maps the decision space in search of its images, given its constraints, creating Z* as the feasible objectives space.

Given restriction (11), the two vectors $\overrightarrow{z_1}$ and $\overrightarrow{z_2}$, plotted in Figure 2, have by the decision-maker indifference in preference. At the point (2, 2), there is a bundle with attributes of the degree of change management better because it is above the constraint. However, for outsourced companies to work at this point, the cost would be higher, causing a prohibitive price (above the limit price). At the point (1, 1), there is a bundle with attributes of a lower degree of change, which would cause outsourcers, given lower requirements, to work with a lower cost, leading to a price below the limit price.

A vector $\overrightarrow{z_i}$ with a sum of attributes above 3, $(2,2) \succ (1,2)$, will be preferable over one with a sum $\overrightarrow{z_i} = 3$, but, as the costs $p_i z_i$ of each decision variable increases proportionally to the degree of quality, there may be an increase in total cost that can overcome the restriction imposed by the price limit L_e plotted in Figure 2. As for vectors with equal sums, such as (2, 1) ~ (1, 2), $Z_1 \sim Z_2$, the decision-maker will not have a preference. Although (2, 2) may be preferred, it is not possible given the restrictions and the possibility of higher costs, so the vectors $\overrightarrow{z_1}$ and $\overrightarrow{z_2}$ have optimal solutions. Since only one solution is chosen, the set of tie-breaking criteria, translated into the bidding notice, will consider the casting vote.

Given the prices p_x and p_y, which are equivalent to the companies' revealed costs to make the items available, as presented in Table 1, the alternative $\left(Z_x^a, Z_y^a\right)$ has revealed preference. The management indicator degree bundles of the two vectors $\overrightarrow{z_1}$ and $\overrightarrow{z_2}$, given the constraint, revealed a preference for the bundle $\overrightarrow{z_4}$, which could be chosen.

Pareto efficient situation is the frontier line bounded by the restriction; along with this line one has the situation of guaranteed efficiency in fleet management change. Since the acceptable sum of the criteria scores is above 2 and the score function is in Z+ (non-negative integers), it is a multiobjective integer linear programming problem.

Economic engineering model

In the pursuit of the equilibrium price or limit (Le), it is necessary to evaluate the projects or investments in question. It is known that the principle of efficiency should lead to a decision that maximizes the cost-benefit ratio. The efficiency of the means, with a significant reduction in waste,

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should contribute to increasing social benefits with the same amount of resources, without increasing costs.

Thus, the evaluation by the TCO provides metrics to measure these costs. TCO involves life cycle costing, evaluating the "zero margin" price and assessing the total costs involved (Ellram & Siferd, 1998).

The projects are not mutually exclusive, that is, the option for one does not necessarily cancel the other. There is the option of using a mix between the two options, 60% of option A (own fleet) and 40% of option B (leased fleet) or another ratio. One must be careful when analyzing exclusively the cost, taking the decision to the lowest cost option, neglecting the focus when it comes to a public good, which is the service to society.

The output flows are clear, deterministic, since they are related to the various expenses involved in the options of own or leased fleets and must be measured in the product's life cycle. The benefits, in turn, are difficult to measure, since they do not involve inflows of financial resources, but the satisfaction of the population with a service. At this point, one can compare the cash flow outflows by the net present value (NPV) and, then, weigh them with a comparative analysis of the qualitative benefits among the options, such as greater agility in the decision and fleet flexibility, as defined in Table 1.

Own fleet assessment

The economic life of a good is characterized by the optimal point of substitution in which the cost is minimal. In this study, the optimal point of substitution is given, that is, it is an exogenous variable. This happens because the historical data analysis of the Ceará's state police shows that, after two years, the several costs involved in the own fleet grow exponentially, so 24 months is the time of use. Equation (18) defines the NPV.

The NPV equation:

$$VPL = -I + \sum_{t=1}^{n} \frac{R_{Lt}}{(1+k)^t} + \frac{Rs_t}{(1+k)^t} \tag{18}$$

in which: I is the initial investment; R_{Lt} is the expected net returns; t is the project review deadline; k is the cost of capital defined by the discount rate; and Rs_t is the residual value of the project at time t.

Once expenditures are analyzed, and since the benefits are incommensurable in monetary terms, Rs_t is taken to zero in the NPV calculation. The

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benefits must be measured and weighted in the basic model assumptions in a qualitative way, which is done by multiobjective and multicriteria analyses.

Considering R_{Lt} as the expected net return flows (revenue minus costs), when you take Rs_t to zero, the costs (and expenses) incurred with the own fleet (C_t) and NPV becomes present value of own vehicle (VP_p), as per Equation (19):

$$VP_P = -I - \sum_{t=1}^{n} \frac{C_t}{(1+k)^t} + \frac{Rs_t}{(1+k)^n} \tag{19}$$

As part of the expenses incurred during the maintenance period of the fleet itself, straight-line depreciation is defined from a lifespan of N periods (years, months). Depreciation is the process through which investments made in assets necessary for operation are transformed into costs or expenses, then:

$$C_{dT} = \frac{1}{N} \tag{20}$$

$$D_T = \frac{P}{N} = P \,.\, C_{dT} = P \,.\, \frac{1}{N} \tag{21}$$

$$DT_T = \sum_1^T D_T = D_1 + D_2 \ldots + D_T \tag{22}$$

in which:
P = price of new vehicle;
N = service life in years;
T = period (year, month etc.) of depreciation calculation;
C_{dT} = depreciation coefficient for period T;
D_T = depreciation that the vehicle will suffer in period T;
DT_T = total depreciation that the vehicle will suffer in its useful life up to period T.

The residual value of the project at time T (R_{st}) is calculated as follows:

$$Rs_T = P - DT_T \tag{23}$$

$$Rs_T = \left(P - \sum_1^T D_T\right) = P - D_1 + D_2 \ldots + D_T \tag{24}$$

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$$Rs_T = P - \left[D_1 + D_2 \ldots + D_T\right] \quad (25)$$

The market, besides the depreciated value of the vehicle, buys it with a haircut, (Dg_T), due to the perception that police cars deteriorate and that the final price of use, already discounting the depreciation, cannot translate the state of the car, leading to a haircut on this price.

It is possible to calculate the total haircut (Dg_T) that the vehicle will suffer in its standardized lifespan until the T. The Txg_{mT} is the average haircut rate at the end of the standardized lifespan, perceived as compatible by the market. From the Txg_{mT}, the basic haircut factor in period T (Fbg_T) is calculated. This factor will accumulate in an exponentially increasing haircut until period T, assuming that the public safety car has an increasing deterioration, therefore, an increasing haircut. Accumulating the factor (Fbg_T) over time, we reach the accumulated rate Txg_T, which is the haircut rate (percent) until period T. When T = N, one has $Txg_{mT} = Txg_T$. Equations (26) and (27) below demonstrate these definitions:

$$Fbg_T = \left(\frac{Txg_{mT}}{100} + 1\right)^{\frac{1}{N}} \quad (26)$$

$$Txg_T = \left[\left(Fbg_T\right)^T - 1\right].100 \quad (27)$$

Once the haircut rate is defined, the total haircut that the vehicle will suffer in its lifespan up to period T(Dg_T) can be calculated.

$$Dg_T = Rs_T \,.\, \frac{Txg_T}{100} = \left(P - DT_T\right).\frac{Txg_T}{100} \quad (28)$$

$$Dg_T = \left(P - \sum_1^T D_T\right).\left[\left(F_{bg}\right)^T - 1\right] \quad (29)$$

in which:
Rs_T = residual value at the end of period T;
Fbg_T = basic haircut factor in period T;
Txg_T = haircut rate up to period T;
Txg_m = average haircut rate at lifespan end N;
Dg_T = total haircut that the vehicle will suffer in its useful life up to period T.

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Incorporating the haircut (DgT) in Equation (19), it is possible to reach the definitive VP_P equation, as shown in equations (30) and (31):

$$VP_P = -P - \sum_{t=1}^{n} \frac{C_t}{(1+k)^T} + \frac{Rs_t}{(1+k)^T} - \frac{Dg_t}{(1+k)^T} \tag{30}$$

$$VP_P = -P - \sum_{t=1}^{n} \frac{C_T}{(1+K)^T} + \frac{\left(P - \sum_1^N D_T\right)}{(1+K)^T} - \frac{\left(P - \sum_1^N D_T\right) \cdot \left[\left(F_{bg}\right)^T - 1\right]}{(1+K)^T} \tag{31}$$

C_T incorporates costs and expenses inherent to the own fleet, and it may include:

$$C_T = \sum_1^T D_T + \sum_1^T TI_T + \sum_1^T Sg_T + \sum_1^T Mn_T + \sum_1^T Vr_T + \sum_1^T Cad_T \tag{32}$$

in which:
C_T = costs and expenses incurred with the own fleet until period T;
D_T = depreciation that the own fleet will suffer until period T;
TI_T = fees and taxes that the own fleet will suffer until period T;
Sg_T = insurance with the own fleet until period T;
Mn_T = maintenance (tires, oil, parts etc.) the own fleet will undergo up to period T;
Vr_T = cost of reserve vehicles for replacement availability until period T; and
Cad_T = costs and administrative expenses that the own fleet will have until period T.

The VP_P incorporates all the costs of the lifespan of the product of the decision, it is then the present value of a series of payments of expenses made during the use of own fleet vehicles, discounted by a discount rate k.

The disbursements made in the project period refer not only to cost, but to outlay costs, expenses, or investments, and the total effective expenses of period T (Ge_T) variable Ge_T shows these disbursements brought to period T as an average per period, using the capital recovery factor (CRF) – in this case, it can be called cost of capital recovery (CCR). This can be considered the amount spent per period for the use of the own fleet. Ge_T is the same concept as the uniform equivalent annual cost (Ueac) for period T.

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$$VP_P = -P - \sum_{t=1}^{n} \frac{C_t}{(1+k)^T} + \frac{Rs_t}{(1+k)^T} - \frac{Dg_t}{(1+k)^T} \tag{33}$$

$$C_T = \sum_1^T D_T + \sum_1^T TI_T + \sum_1^T Sg_T + \sum_1^T Mn_T + \sum_1^T Vr_T + \sum_1^T Cad_T \tag{34}$$

$$Ge_T = \left[-P - \sum_{t=1}^{n} \frac{C_T}{(1+K)^T} + \frac{R_{ST}}{(1+K)^T} - \frac{Dg_T}{(1+K)^T} \right] \cdot \left[\frac{K.(1+K)^T}{(1+K)^T - 1} \right] \tag{35}$$

$$FRC_T = \frac{K.(1+K)^T}{(1+K)^T - 1} \tag{36}$$

Leased fleet assessment

The difference between the leased fleet and the own fleet is the absence of expense variables that will not be present in the former. In the leased fleet, the lessee receives from another party (the lessor) a good or a service, by means of a leasing contract, being obliged to pay the adjusted price. Hence, the present value of the leased vehicle (VP_L) is the present value of a series of payments related to the leasing contract established during the use of the leased fleet vehicles, discounted by a discount rate k, which can be the opportunity cost.

$$VP_L = \sum_1^T \frac{L_T}{(1+K)^T} \tag{37}$$

in which:
VP_L = present value of the leased vehicle;
L_T = lease price per period T (L_T = L for installment, fixed payment);
T = period (year, month etc.) of the lease;
K = the cost of capital defined by the discount rate.

Limit (equilibrium) price, optimum price, and margin of safety

There will be an equilibrium situation when the present value of the disbursements of both options is equal – equilibrium in the sense that, if

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the values are equal, financially it would not make a difference to choose one or the other. In this case, the decision would be based on the perception of which option would bring more social returns and better levels of management of the process.

Even though not measurable quantitatively, it is possible to qualitatively measure the social and management benefits by the variables: satisfaction of police officers and the community, response time, larger time of use, fleet usability, assurance that the cars will always be available, among others. Equalizing the equations, one has:

$$VP_L = VP_P \tag{38}$$

$$\sum_1^T \frac{L_T}{(1+K)^T} = -P - \sum_{t=1}^{n} \frac{C_T}{(1+K)^T} + \frac{\left(P - \sum_1^N D_T\right)}{(1+K)^T} - \frac{\left(P - \sum_1^N D_T\right).\left[\left(F_{bg}\right)^T - 1\right]}{(1+K)^T} \tag{39}$$

For a fixed L lease installment, there is equilibrium:

$$L_T = VP_P \tag{40}$$

$$L_T = -P - \sum_{t=1}^{n} \frac{C_T}{(1+K)^T} + \frac{R_{ST}}{(1+K)^T} - \frac{Dg_T}{(1+K)^T} \tag{41}$$

$$L_T = L_e = Ge_T + \frac{R_{ST}}{(1+K)^T} \tag{42}$$

in which:
VP_P = present value – own vehicle;
VP_L = present value – leased vehicle;
L_T = lease price per period T – monthly lease or other period T;
L_e = balance lease amount;
K = opportunity cost or discount rate;
Ge_T = total effective expenses up to period T;
Rs_T = residual value at the end of period T;
Dg_T = total haircut that the vehicle will suffer in its useful life up to period T.

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The L_e shows the result of the cost-benefit analysis between own or leased fleets. For values of $L_T > L_e > VP_p$, there will be no financial advantage in choosing the leased fleet. For values of $L_T < L_e < VP_p$, it is financially advantageous to choose the leased fleet.

The limit equilibrium price (PL_T) is the price that equalizes the costs between the own and leased fleet, according to Equation (43). It is also called a prohibitive price, since, after this point, it would bring losses as it would exceed the costs of the own fleet.

The safety margin was defined as an insurance against adversities and unexpected situations, such as breach of contracts. The parameter used to define the margin was also the historical percentage of unserviceable cars. With a percentage over the PL_T, the state would have a margin of safety for the risks involved. The optimal price would be the limit price minus the safety margin.

$$PL_T = L_e \tag{43}$$

$$PO_T = (1 - ms) \, . \, L_e \tag{44}$$

$$MS_T = PL_T - PO_T \tag{45}$$

$$PO_T = (1 - ms) \, . \, L_e \tag{46}$$

in which:
PL_T = limit equilibrium price;
PO_T = optimum equilibrium price;
MS_T = safety margin value;
ms = unit percentage of the safety margin;
L_e = balance lease amount.

RESULT OF THE PROPOSED MODEL USING REAL DATA

Assuming that the agency will evaluate the possibility of hiring, by leasing, a KX9 4x4 diesel 16v vehicle – in order not to expose the models used in the state of Ceará, a fictitious car model is used – or will purchase and incorporate it to its own fleet, the car has the following characteristics, which are distributed for calculation in Table 4:

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1. Market value of BRL 100,000.00 and depreciation according to a lifespan of four years.
2. Mandatory insurance plus motor vehicle property tax (imposto sobre propriedade de veículo automotor – IPVA) is equivalent to approximately 2% of the vehicle's value.
3. Maintenance costs are equivalent to approximately 1.5% of the car's value.
4. Insurance, given the characteristics of use, is around 2.5% of the vehicle's value.
5. Administrative costs of managing the own fleet around 0.2% of the vehicle's value.
6. Reserve vehicle: a percentage of the fleet that should be kept in stock for immediate use due to unavailability caused by preventive services, corrective services, or damage caused by crashes, among other adversities. A rate of 10% of the fleet will be used, equal to the average number of unavailable vehicles in the state police of Ceará.
7. A discount rate of 1% per month was used as opportunity cost.
8. The analysis was made for two years of car use.

Table 4

Variables used in the evaluation

1	Own fleet	Base	Month 0	Month 1	Months 2-24	Month 25
2	Car value (market)		100,000			0
3	Depreciation (4 years) for 2 years	50,000		2,083	2,083	
4	Car value after depreciation – two years	50,000				
5	30% haircut on total depreciation	7,000				
6	Final sale value (depreciation and haircut)	43,000				43,000
7	Taxes + fees (2% of current value per year)		2,000			
8	Maintenance (1.5% of the car's value)			1,500	1,500	
9	Insurance (2.5% of the car's value)		2,500			
10	Administration (0.2% of the car's value)		200	200	200	
11	Reserve vehicle (unavailability) 10%		417	417	417	
12	Subtotal		-102,617	-2,117	-2,117	43,000

(continue)

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Table 4 (conclusion)

Variables used in the evaluation

	Own fleet	Base	Month 0	Month 1	Months 2-24	Month 25
13	Total	-114,022	-102,617	-2,117	-2,117	43,000
14	Present value (rate and 1% am)	-117,241	-102,617	-2,096	...	33,530
15	Leased fleet	Base	Month 0	Month 1	Months 2-24	Month 25
16	Balance lease value	-5,519		-5,519	-5,519	
17	Total	-132,456		-5,519	-5,519	0
18	Present value (rate and 1% am)	-117,242		-5,464	-5,410	0
	L_e = balance lease amount	5,519				

Source: Elaborated by the author.

After the cost flow is brought to the present value, the limit equilibrium price (PL_T) is the one that equalizes the costs between own and leased fleet (Equation 43). This price is BRL 5,519.00 of the monthly cost for the leased fleet for the leasing to be viable, and, from this point on, it would bring losses because it would exceed the costs of the own fleet. The cost of maintaining a model KX9 car for two years, brought to the present, equals BRL 117,241.07.

A margin of safety was defined (Equation 45). The parameter used to define the margin was also the historical percentage of unserviceable cars. Assuming 10.0% over the limit equilibrium price, the state would have a margin of safety for the risks involved. The calculated Margin of Safety is BRL 552.00 (10.0% over BRL 5,519.00) for the KX9 model, and it is translated into the optimal equilibrium price of BRL 4,967.00, this value being the optimal economic point at which the state establishes a safety line of 10.0% below the limit, or prohibitive price, to face adversities. For prices below the optimal equilibrium price (BRL 4,967.00), we will have an additional safety margin, according to Figure 4.

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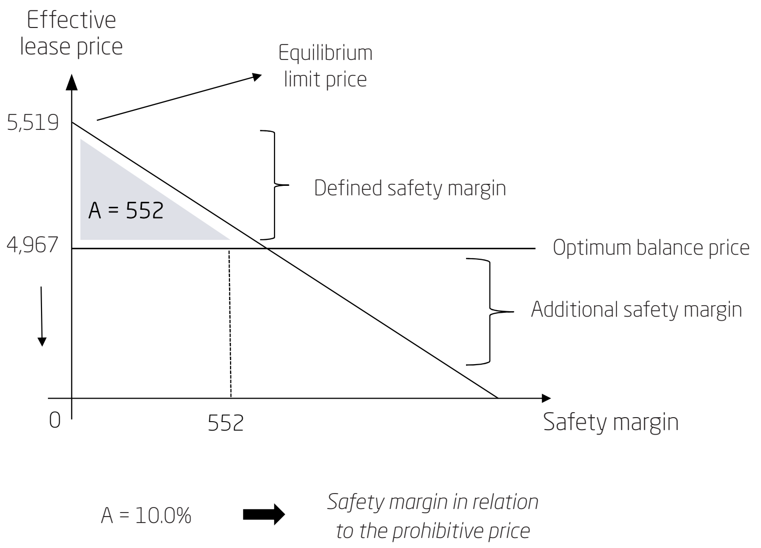
Figure 4

Limit equilibrium price* versus *optimal equilibrium price



Source: Elaborated by the author.

RESULTS AND DISCUSSION

The key parameter of the proposed model is the limit equilibrium price (L_e), demonstrating the set of optimal solutions. In the result, one can observe that L_e is BRL 5,519.00. This price is prohibitive because it equalizes the costs of owning or renting a car, so, the lower L_e is the leasing value, the better. For the government to have a safety parameter, the optimal price should be BRL 4,967.00, a value 10.0% below the limit equilibrium price, creating a margin of safety for the risks involved.

Therefore, it is suggested that, in the decision for a leased fleet, a percentage of the vehicle fleet should continue to be owned to give security to the agency that there will be no lack of service to society, in case there is a breach of contract by the rental companies.

The department's decision should be guided by the following parameters:

1. Limit equilibrium price (prohibitive price) and optimal equilibrium price: this is the constraint imposed by the multiobjective criterion in Equation (13) and models the Pareto-optimal frontier.

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2. Management criteria defined in Table 1, which will serve to safeguard efficiency in the leasing contract and generate benefits to society beyond the financial ones.
3. Selection of a Pareto-optimal vector $\vec{Z}^a = \left(Z_x^a, Z_y^a\right)$, with attributes from Table 1, weight criteria from Table 2 and interval scores from Table 3. The optimal points (1, 2) and (2, 1) should be chosen for the companies that are competing in the bidding. In the case of a tie, tie-breaking criteria can be defined in the bidding notice.

FINAL CONSIDERATIONS

A hybrid multicriteria and economic engineering model was presented to support the fleet management decision, aiming to qualify the governmental decision in face of the management options, maximizing the management quality.

Using Maut in the construction of optimal solutions, management indicators were defined as endogenous to the model. The integer linear programming was used in a multiobjective model in complement to the cost-benefit analysis using the EE method.

The proposed methodology innovates by integrating economic-financial and fleet management criteria with a multicriteria method. It also incorporates the analysis of the equilibrium point and the margin of safety for the decision.

The results confirm the compatibility between the methods, providing the public agency with a methodological tool that qualifies the decision based on a model that reveals the preferences in terms of attributes relevant to good management while respecting budgetary constraints.

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