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## Article

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## Using MCDA-C to assess the organizational performance of industries operating at Brazilian maritime port terminals

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### ABSTRACT

This article describes the use of the constructivist multicriteria decision aid (MCDA-C) model as an intervention instrument, using a case study of a fertilizer industry located at a Brazilian maritime port terminal, with the goal of developing a customized performance evaluation model to help its management process. The sequence of steps created to develop the model occurred interactively through interviews with the decision maker. The developed model allowed the decision maker to incorporate the unique aspects of the company and environment, thereby widening the performance evaluation possibilities and enhancing organizational management.

### 1. Introduction

Data from the United Nations (UN) predict that the global population—currently around 7.2 billion people—will reach 9.6 billion people by 2050. The growth in the global population will demand a consequent increase in society's need for subsistence [1]. When referring to the supply of this demand, climate and land conditions are relevant subjects discussed by both public institutions and private organizations internationally [1].

Brazil has favourable climate conditions and a large land mass, factors that contribute to helping supply some of the global population's subsistence demand. These factors grant Brazilian agriculture an important role in this chain. According to projections from the Ministry of Agriculture, Livestock, and Supply (Ministério da Agricultura, Pecuária e Abastecimento; MAPA), by the end of 2023, agriculture and livestock production in Brazil will be able to supply 200 million people annually. It will also generate an exportable surplus, whose estimated amount could be sent to around 150 countries [2].

In this sector, fertilizer industries are responsible for the

development and production of nutrient compounds that supply soil and plants with the elements they need for sustainable growth. Owing to global competition, companies in this segment must ensure a sufficient degree of competitiveness to keep them in the market. At the micro level, factors such as infrastructure, logistics, quality, efficiency, safety, and individuals' qualifications define the final product's cost, price, and quality conditions.

The company studied herein has operated in the global fertilizer market for over 100 years. Its presence is significant in all continents, with affiliates spread over 40 countries and a workforce of over 12,000 people. The unit of analysis in this research is one of its affiliates located at a maritime port terminal in the south of Brazil. This affiliate has two granulation factories, but one of them also mixes fertilizers. It features a warehouse area in the port zone. It is located 700 metres from the ships' mooring berths and has a port operation structure with land cranes, a ship loader on wheels, stowage material, and its own labour force. This affiliate has strategic importance for the company because of the convenience of its geographical position and logistics infrastructure. At the same time, it has suffered from the economic impacts caused by the

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Brazilian economic crisis, which has led the ports in the country to lose their competitiveness following a lack of public investment.

The research problem in this study arises from the attempt to propose a structured scientific approach to help the company's managers' search for the organizational sustainability and competitiveness needed to allow them to take the lead in the market. In particular, we examine how performance evaluation can help enhance the management process of a fertilizer industry located at a maritime port terminal by developing a customized performance evaluation model to help managers to identify and promote actions that can enhance this process. Regarding the adopted scientific intervention instrument, we use the multicriteria decision aid tool from its constructivist perspective (termed MCDA-C hereafter), because of its potential for dealing with singular, complex, and multiple variable contexts as well as contexts with conflicting interests [3,4].

The remainder of this article is organized into six sections. Section 2 sets the context of the evaluation and performance indicators. Section 3 discusses MCDA-C and Section 4 shows the methodological procedures used in this research. Section 5 describes the case study and details the steps to develop the evaluation model. Lastly, Section 6 concludes.

## 2. Evaluation and performance indicators

At the beginning of the capitalist production system, institutions aimed to minimize their costs and maximize their profits. With the rise of the Industrial Revolution in the 19th century, it became important for company owners to direct capital to their production processes. According to Lacerda et al. [5], many approaches seek to define the most appropriate performance evaluation criteria. This is a complex task as such criteria vary over time, from sector to sector, and from company to company, making it impossible to generalize. Any attempt to define them must consider the sector's and the company's specific competition features [6]. In this context, indicators can be defined as the set of people, processes, methods, and tools that, together, generate, analyse, expose, describe, evaluate, and review information on the multiple dimensions of performance at the individual, group, operational, and general organizational levels [7].

Macedo-Soares and Ratton [8] highlight that indicators are clues to be followed to understand the economic, social, political, and cultural phenomena that affect society. Indicators can be quantitative or qualitative, be derived from a series of factors observed in a determined area, or point out different time units. These time units are used to represent the criteria related to them, thereby establishing patterns between the reference value of each indicator and the information source (i.e., where the data will be collected; [9]). According to Ensslin et al. [3], performance indicators are not linked to processes, but to managers' judgment. Indicators thus have the potential to suggest action plans related to the voids pointed out on the evaluation. They are also tied to long-term strategic goals.

According to Kennerley and Nerly [10], there are questions about the arbitrariness with which the indicators must be weighted when calculating the final measure. Indeed, indicators must aim for sensitivity, specificity, and frequency with which their records and control systems are available.

Specifically, in the port context, performance evaluation and its indicators have been treated as a strategic matter in the search for efficiency in the sector [11]. In this sense, Barros [12] and Ensslin et al. [13] discuss the need to employ indicators to evaluate ports. From another perspective, Gonzalez and Trujillo [14] survey industries situated in port terminals to verify the indicators they use to measure organizational performance.

Hence, performance evaluation plays a crucial role in organizational management, as it is translated into a strategy that provides management with more responsibility, transparency, and quality. However, measuring performance is a complex and multidimensional task given the diversity of management styles as well as the many definitions and

performance monitoring and evaluation models.

## 3. The constructivist MCDA approach

MCDA-C is a branch of traditional MCDA approaches [15,16] used to support decision makers in complex, conflicting, and uncertain contexts. Such settings are complex because they involve many qualitative and quantitative variables, partially or non-specified [17]. In this way, in MCDA-C, researchers encourage decision makers to actively participate in determining the problem and identifying its causes as well as formulating enhancement actions [18,19]. The relevant criteria for the decision maker are identified by the MCDA-C methodology, with the goal of generating knowledge about what aspects are important in the context, as these need to be considered in a performance evaluation model [20].

MCDA-C consists of a set of methods to help people and organizations make decisions, clarify the problem, and evaluate alternatives through multiple criteria, which are, in most cases, conflicting. Multicriteria decision aid methods typically aim to list (subjective) preferences among the alternatives being evaluated, under the influence of many criteria in the decision-making process [21].

The activities of MCDA-C are subdivided into three stages: structuring, evaluation, and recommendation development [22]. The structuring stage consists of contextualizing a problem by describing the context such as the owner of the problem, source of the dissatisfaction, and current and intended performance [19]. The evaluation stage consists of developing the multicriteria evaluation model [23] through the creation of a local preference scale for each criterion, the establishment of compensation fees among these criteria, and the aggregation of all of these factors by using a mathematical formulation that allows a global evaluation of the model. In the recommendation development stage, potential actions are suggested to improve performance. This procedure emphasizes the verification of the descriptors at a substandard performance level and of the contribution potential of a descriptor of global performance.

Regarding the indicators specifically, in MCDA-C, measurements are taken through scales that comply with measurement theory and the operationalization properties [24,25]. These scales are built through many steps [22]:

- (i) Determining the hierarchical values structure [4,26] to associate the abstract concerns of the decision maker with the context's physical properties.
- (ii) Developing the descriptor (ordinal scale).
- (iii) Identifying the reference levels (anchors) for the decision maker to stratify the sample space on the subsets of substandard, market, and excellent performance levels.
- (iv) Building a value function (cardinal scale) by incorporating data on the differences in the attractiveness of the levels provided by the decision maker [27].

## 4. Research design

This section describes the methodological procedures adopted in the development of this project, including its purpose, nature, data collection source, research logic, methodological approach, and intervention instrument used [28]. The study is characterized as applied research, as it proposes the construction of a customized performance evaluation model for the fertilizer industry located in a maritime port terminal, with the aim of identifying, operationalizing, and measuring indicators that enable the recognition of actions to improve the company's management.

Regarding its nature, this research can be classified as a case study. According to Yin [29], the employment of case studies allows the transformation of goals into feasible actions that are consistent with the reality in which the organization is embedded. Considering the whole

of the investigated subject leads to the emergence and discovery of relations that otherwise would not be established. The case described in this paper aims to investigate the ways in which decision makers perceive the possibilities of translating the management goals established based on the company's strategic planning into specific actions to achieve organizational sustainability.

The subject of this case study is a leader in the Brazilian fertilizer market. Its number of workers in the country represents approximately 30% of the company's global operation. The affiliate of the company examined herein, located in the south of Brazil, has two factories at the region's maritime port terminal. One of these factories produces 800,000 tons of mineral fertilizers per year through a combination of the production and mixture of fertilizers. Both affiliates use the port terminal for their products' logistics.

The data used are both primary and secondary. The primary data were collected directly from the company's managers. The secondary data, necessary to complement the decision maker's decisions, were obtained from the organization's documents as well as from the theoretical background.

The research logic is mixed. In the structuring stage, the logic is inductive. In this stage of MCDA-C, the primary evaluation elements are determined and the ordinal scales are developed. This does not come from principles, but from facts that result from observations and insertion in reality [28]. In the evaluation stage, the logic is deductive, because the aim of the model is to draw individual conclusions. In the recommendations stage, the logic is mainly inductive, because the analysis is based on the understanding acquired throughout the development of the model.

The methodological approach employed in this research is characterized as qualitative/quantitative. It takes on a qualitative profile in the structuring stage based on an intervention process that promotes reflection in the identification, representation, and determination of the primary evaluation elements and their interrelations as well as the construction of ordinal scales. It can then be typified as quantitative in the evaluation stage, when the multicriteria mathematical model is developed through the transformation of the ordinal scales into cardinal scales, the determination of the compensation rates between these criteria, and the identification of the actions' performance profile.

The intervention instrument selected to develop the performance evaluation model proposed in this research is MCDA-C because of its ability to provide identification, operationalization, and action measurement conditions that represent managers' perceptions of the possible ways in which to improve organizational performance. This also provides suggestions to improve the actions when performance was below the desired level.

## 5. Case study

This section describes the development of the performance evaluation model for the management of the fertilizer industry affiliate, observing the values and perceptions of the decision makers and stakeholders as well as the individualities due to its location at a maritime port terminal. The case study was initiated in the three stages of the MCDA-C methodology: structuring, evaluation, and recommendation (Fig. 1).

### 5.1. Structuring of the model

The structuring of an MCDA-C model is operationalized in three steps: (i) contextualization, (ii) development of a hierarchical values structure, and (iii) development of the descriptors with their reference levels.

#### 5.1.1. Contextualization

In the contextualization step, it is important to identify the actors involved in the process to be managed, including their values,

motivations, and preferences. The models built through MCDA-C's theoretical source take into account the subjectivity of the actors, encompassing the internal and external individualities of the context and the manager's motivations and preferences [19]. The actors are classified as decision makers, stakeholders, recipients, and facilitators [17]. In this case study, the following actors were identified:

- Decision maker: The affiliate's general manager;
- Stakeholders: Coordinators of the processes, technology, and human resources areas;
- Recipients: Customers;
- Facilitator(s): Researchers.

Also in the contextualization step is the establishment of a label for the context. In MCDA-C, labelling the problem means naming it to customize a decisional situation. For that, it is necessary to adopt an expression that symbolizes and summarizes the decision maker's concerns and goals. In this case, after meeting with the decision maker and stakeholders, the following label was agreed: "Management aid model for the organizational processes of a fertilizer industry established at a maritime port terminal."

#### 5.1.2. Development of a hierarchical values structure

Having identified the actors and obtained a label for the problem, the next step of the structuring stage consists of developing a hierarchical values structure for the model. This structure uses decomposition logic, in which a complex criterion is decomposed into two or more criteria that operationalize its measurement. Hierarchically, a higher-level criterion must be explained by the set of lower-level criteria that compose it. Further, the lower-level criteria must be mutually exclusive and must collectively characterize the higher-level criterion [22].

The approach outlined by Bana e Costa and Beinat [26], which adopts the Value Focus Thinking principles [4], was followed in the structuring stage. From this perspective, the areas of concern (which originated in the model evaluation areas) and the model's criteria were identified and organized. Table 1 shows the hierarchical structure that results from this process for the case study, with the description of two levels (areas of concern and criteria) and the scope of each performance indicator (I).

#### 5.1.3. Development of descriptors

The last step of the structuring stage consists of developing ordinal scales (or descriptors) for each of the model criteria to evaluate the performance of all possible alternatives individually. A descriptor must have impact levels, based on the decision maker's preference, in a pair-to-pair comparison process [3]. The lower (higher) end of the scale represents the worst (best) performance. The decision maker must also point out the neutral (minimum acceptable performance) and good levels (satisfactory performance, but not excellent) of the criterion. In this case study, the decision maker (the affiliate's general manager) indicated his preferences for the 30 indicators identified by this proposed model. Table 2 illustrates the descriptor elaborated for Indicator I16 – ton/hour productivity of the port terminal.

Fig. 2 shows that for this indicator, the manager's least preferred performance ( $N_1$ ) refers to "producing less than 20 tons per hour." On the contrary, the most preferred performance ( $N_5$ ) refers to "producing more than 50 tons per hour, respecting the terminal's operational limit, which is 60 tons per hour." It is also possible to observe the reference levels, namely neutral ( $N_2$ ) and good ( $N_4$ ). This process was also used to determine the impact levels and order the decision maker's preferences for all the criteria of the multicriteria model under development.

### 5.2. Evaluation stages

The scale development process (descriptors) in the structuration

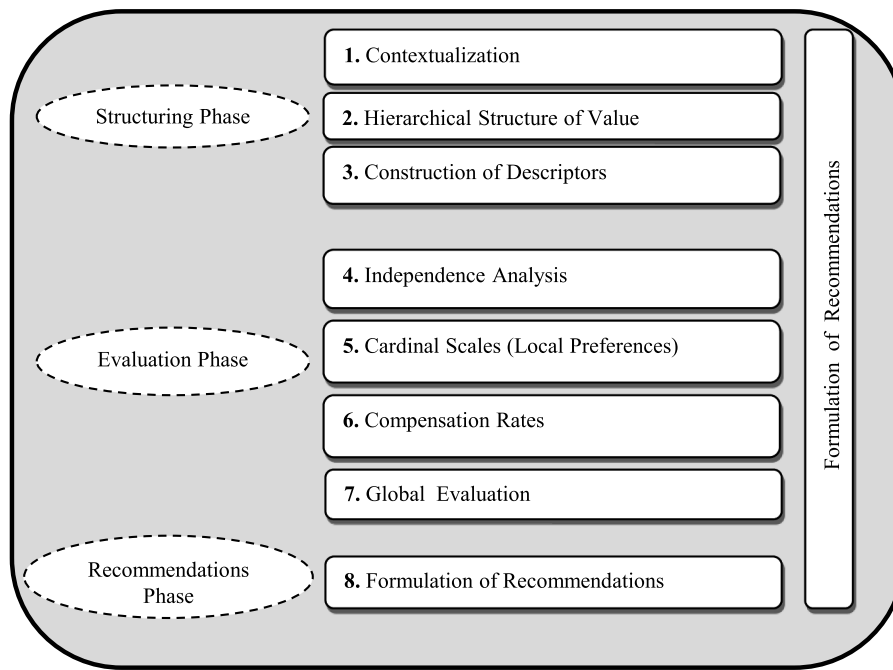


Fig. 1. Stages of MCDA-C  
Source: adapted from Ensslin et al. [22].

stage is crucial for the management of the context once it identifies and establishes the metrics to measure the operational aspects that explain the strategic goals. This process is, however, limited in two aspects: it cannot measure the strategic goals (the descriptor is a scale that evaluates the isolated impact of each criterion) and it is made up of ordinal scales (the descriptor in its ordinal form indicates the ranking between levels, without, however, allowing the measurement of the attractiveness difference between those levels). MCDA-C proposes the

transformation of these ordinal scales into cardinal scales and the aggregation of all its criteria in four steps: (i) analysis of preferential independence, (ii) cardinal scales and local preference, (iii) compensation rates, and (iv) global evaluation.

5.2.1. Analysis of preferential independence

The synthesis aggregation methods of MCDA-C allow the development of additive compensatory models, constituted by the weighted

Table 1  
Hierarchical criteria structure for the case study.

Level 1: Areas of concern	Level 2: Criteria	(I)	Indicator
Safety	C1 Absence	101	Accidents followed by absences
	C2 Inspections	102	Systematic safety inspections
	C3 Causes	103	Analysis of the causes of the accidents
	C4 Almost Accidents	104	Almost accident reports
	C5 Behaviour	105	Behaviour inspections
Environment	C6 Requirements	106	Assuring that operations comply with environmental requirements
	C7 Accidents	107	Adopt a zero environmental accidents policy
Quality	C8 Mixture	108	Mixture quality index
	C9 Granulations	109	Granulations quality index
	C10 Acidulation	110	Acidulation quality index
	C11 Training	111	Quality training that was performed
	C12 Satisfaction_PT	112	Port terminal users' satisfaction index
Efficiency	C13 Complaints_GRAN_1_2	113	Number of complaints from the granulation units
	C14 Complaints_MIX	114	Number of complaints from the mixture units
	C15 Reliability_GRAN_1	115	Reliability of the granulation 1 unit
	C16 Productivity_PT	116	Ton/hour productivity of the port terminal
Costs	C17 Productivity_MIX	117	Ton/hour productivity of the mixture units
	C18 Availability	118	Operation availability of the anchoring areas
	C19 Reliability_ACID	119	Reliability of the acidulation unit
	C20 Reliability_GRAN_2	120	Reliability of the granulation 2 unit
	C21 Breaks	121	Compliance to the maintenance break planning
	C22 Budget	122	Account control per sector (lower and exceeding costs)
	C23 Variable Cost_PT	123	Variable cost of the port terminal
	C24 Variable Cost_GRAN	124	Variable cost of the granulation units
	C25 Break Costs	125	Planned maintenance breaks cost
	C26 Variable Cost_ACID	126	Variable cost of the acidulation unit
People	C27 Consumption	127	Cost of the processes' chemical supplies consumption
	C28 Investments	128	Costs of the non-total compliance of previously agreed investments
	C29 Performance	129	Performance evaluation of the job tasks
	C30 Succession	130	Preparation for succession due to promotion, retirement, and dismissal



**Table 2**  
Descriptor elaborated for I16 – Ton/hour productivity of the port terminal.

I.16 – Ton per hour productivity of the port terminal		
Impact levels	Reference levels	Description
L5		Between 51 and 60 tons/hour (operational limit)
L4	Good	Between 41 and 50 tons/hour
L3		Between 31 and 40 tons/hour
L2	Neutral	Between 21 and 30 tons/hour
L1		Less than 20 tons/hour

sum of the context's explanatory criteria. In this way, to assure that the compensation rates remain constant, the respective criteria must be preferentially independent [22]. Therefore, it is necessary to test the preferential independence of the model's criteria.

To perform this step, these criteria are tested to determine the isolation of their performance for the interval of the established reference levels (good and neutral) when there is performance variation on the remaining criteria for the range of their reference levels [4]. This test assures that the tested criterion is not affected by the performance of the other criteria. The test was carried out for all 30 indicators of the model (broken down into descriptors, as illustrated in Fig. 2), finding that they are all mutually and preferentially independent, both ordinarily and cardinally. Therefore, their compensation rates were deemed to be constant for all the tested conditions.

5.2.2. Cardinal scales and local preferences

Having performed the preferential independence test for all descriptors, the next stage of the MCDA-C evaluation consists of transforming the ordinal scales into cardinal scales to enable us to attribute a performance measure (attractiveness difference) to each level of a descriptor. Among the possible methods to perform this transformation are direct rating, a widely used numerical method because of its

mathematical robustness, the bisection method, which is useful when the descriptors are mainly formed by continuous scales, and the semantic judgment method, in which the scale levels of a descriptor are a representation rather than countable levels with a determined meaning given by the person who built it (i.e., the difference between two impact levels cannot be established by the subtraction of their numerical representation; [21,30]).

In this project, the researchers chose to use a mathematical approach based on the semantic judgment method to transform the ordinal scales into cardinal interval scales: the Measuring Attractiveness by a Categorical Based Evaluation Technique (MACBETH), developed by Bana e Costa and Vansnick [23,31].

To determine the function of a value, which is what Bana e Costa [32] calls the cardinal interval scales, MACBETH compares the attractiveness difference between the scale levels in a way that the decision maker expresses the intensity of his or her preference of a level above all the others. A semantic scale with seven categories is used to convey the absolute judgments of attractiveness differences:  $C_0 \rightarrow$ Void attractiveness difference;  $C_1 \rightarrow$ Very weak attractiveness difference;  $C_2 \rightarrow$ Weak attractiveness difference;  $C_3 \rightarrow$ Moderate attractiveness difference;  $C_4 \rightarrow$ Strong attractiveness difference;  $C_5 \rightarrow$ Very strong attractiveness difference; and  $C_6 \rightarrow$ Extreme attractiveness difference. Mathematically, the MACBETH algorithm is made up of four minimization linear programming problems (LPPs) solved sequentially: LPP 1 performs the cardinal consistency analysis, LPP 2 is responsible for building the cardinal value scale, and LPP 3 and LPP 4 reveal the sources of inconsistency [23,31].

In this way, the researchers used the semantic ordinal scales developed in the structuring stage (descriptors) for the decision maker to qualitatively express his preference intensity, or attractiveness difference, for the impact levels of each of the descriptors, pointing out if the difference was void, very weak, weak, moderate, very strong, strong, or extreme. From the decision maker's answers, it was then possible to

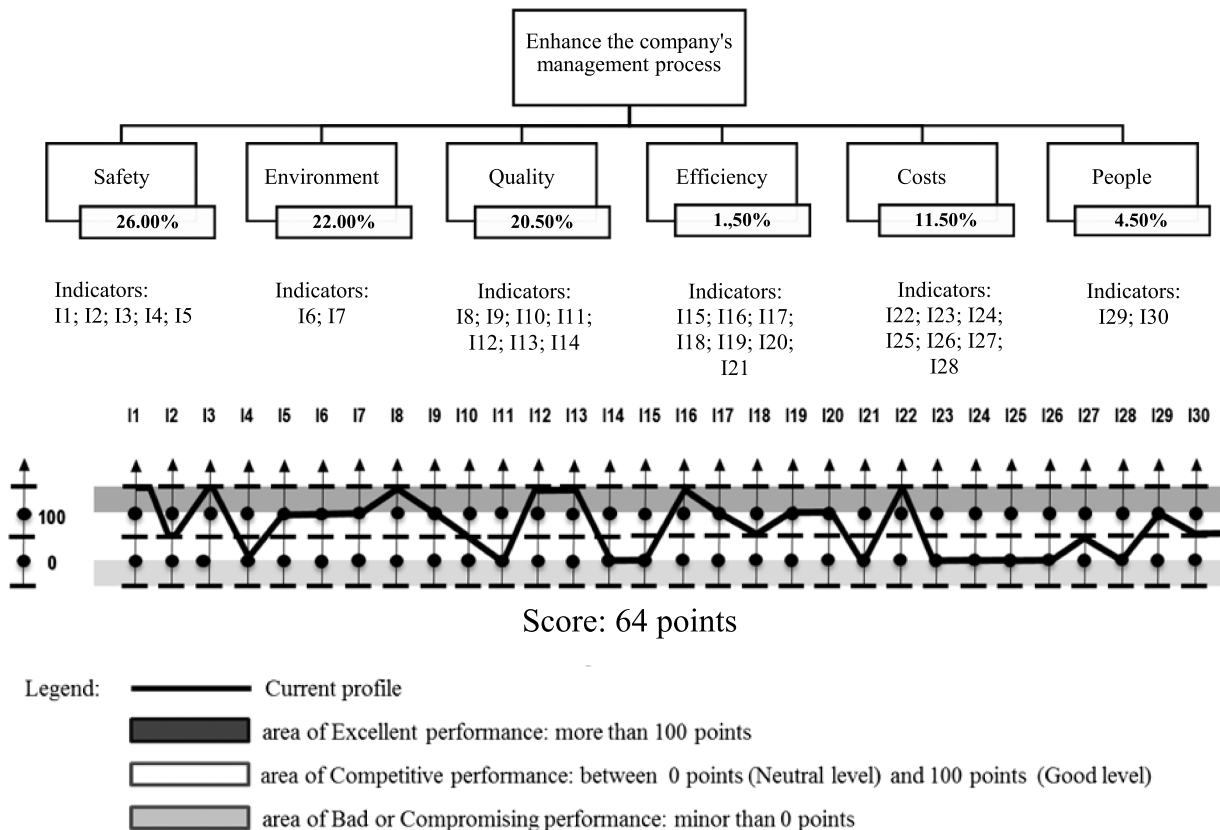


Fig. 2. Performance profile of fertilizer industry management in the port terminal.

**Table 3**  
Value function for I16 – ton/hour productivity of the port terminal.

I.16 – Ton per hour productivity of the port terminal								
Description	MACBETH matrix					Local preferences		
	Level	L5	L4	L3	L2	L1	Scores	Normalized scores
L5 - Between 51 and 60 tons/hour	L5		very weak	weak	strong	very strong	100	112,60
L4 - Between 41 and 50 tons/hour	L4			weak	strong	very strong	94,70	100,00
L3 - Between 31 and 40 tons/hour	L3				strong	very strong	84,20	75,10
L2 - Between 21 and 30 tons/hour	L2					very strong	52,60	0
L1 – Less than 20 tons/hour	L1						0	-124,90

build the MACBETH judgment matrix. With the defined interval scales, each descriptor had a numerical value of 0 for the neutral level and 100 for the good level to calculate the scale normalization. To operationalize the calculations, the M-MACBETH software was used [33]. Table 3 illustrates the result of the transformation process of the ordinal scale into a cardinal scale for I16 – ton/hour productivity of the port terminal.

Table 3 shows the cardinal scale for I16, with the judgments obtained on the MACBETH matrix and their respective scores (local preferences) from each level. The last column show the scores for the positive linear transformation of type  $f(x) = \alpha x + \beta$  performed to anchor the neutral (L2) and good (L4) levels of the descriptor and recalculate the remaining levels. The results in Table 3 infer, for example, that performing an action on the descriptor, promoting the change from L2 to L3, will locally impact it by 75 points, which is considered to be a relatively acceptable impact by the decision maker. This transformation process was carried out for all the other descriptors to quantify the operational aspects of the actions and thus evaluate the performance of the actions against a certain criterion [34].

5.2.3. Compensation rates

Having determined the interval cardinal scales for all the descriptors, the next step was to establish the compensation rates between the areas and criteria of the model. For that, the MACBETH method was used with the addition of two procedures: a) the creation of actions (Ai) to simulate the impact of the good and neutral levels of the criteria to be judged and their ordination (creation of the ordinal scale) through Roberts’ [25] matrix and b) the inclusion of a potentially fictitious action in the judgment matrix (establishment of a necessary A0 action to allow the decision maker to evaluate the attractiveness difference between going from the good level to the neutral level in the least important criterion and keeping all the other criteria at the neutral level). The remainder of the process to calculate the compensation rates followed the same premises described for the value functions [35].

In this sense, two interviews were conducted, each lasting approximately two hours, during which the decision maker expressed his judgments to obtain the compensation rates of the fertilizer industry’s management performance evaluation model. Table 4 shows the compensation rates for the criteria in the “Efficiency” area of concern: “C.15 Reliability GRAN\_1,” “C.16 Productivity\_PT,” “C.17 Productivity\_MIX,” “C.18 Availability,” “C.19 Reliability\_ACID,” “C.20 Reliability GRAN\_2,” and “C.21 Breaks.”

The same procedure was employed to determine the compensation rates for the other criteria, between their subcriteria, and between the model’s areas of concern. Table 5 shows the compensation rates for all the model’s areas of concern.

**Table 4**  
Compensation rates between the criteria of the efficiency area.

Area	Compensation rates between criteria	%
Efficiency	C15 Reliability GRAN_1	21.5
	C16 Productivity_PT	12.5
	C17 Productivity_MIX	24.0
	C18 Availability	17.5
	C19 Reliability_ACID	6.00
	C20 Reliability GRAN_2	16.0
	C21 Breaks	2.5

**Table 5**  
Compensation rates between the model’s areas of concern.

Goal of the model	Compensation rates between areas of concern	%
Enhance the company’s management process	Safety	26.0
	Environment	22.0
	Quality	20.5
	Efficiency	15.5
	Costs	11.5
	People	4.5

5.2.4. Global evaluation

The last evaluation step was the aggregation of all the model’s criteria into a single general criterion in two stages [32]. In the first stage, the partial values of an action in an isolated criterion (C) and its subcriteria (i) were aggregated, using Eq. (1):

$$VC_k(a) = \sum_{i=1}^{nk} w_{i,k} \cdot v_{i,k}(a) \tag{1}$$

where:

- $V_{Ck}(a)$ : global action  $a$  value of the  $C_k$ , for  $k = 1, \dots, m$ ;
- $v_{i,k}(a)$ : partial action  $a$  value on the subcriterion  $i$ ,  $i = 1, \dots, n$ , of the  $C_k$ , for  $k = 1, \dots, m$ ;
- $a$ : action  $a$  impact level;
- $w_{i,k}$ : substitution rates of the subcriterion  $i$ ,  $i = 1, \dots, n$ , of the  $C_k$ , for  $k = 1, \dots, m$ ;
- $n_k$ : number of subcriteria of the  $C_k$ , for  $k = 1, \dots, m$ ;
- $m$ : number of criteria in the model.

By employing Eq. (1), it was possible to obtain the aggregation formulas for each of the areas of concern, as shown below:

$$VSafety(a) = [0, 21. (v11) + 0, 14. (v12) + 0, 13 (v13) + 0, 24 (v14) + 0, 28. (v15)]$$

$$V_{Environment} (a) = 0, 045 [0, 52. (v_{I6}) + 0, 48. (v_{I7})]$$

$$V_{Quality} (a) = [0, 255. (v_{I8}) + 0, 225. (v_{I9}) + 0, 065 (v_{I10}) + 0, 045 (v_{I11}) + 0, 165. (v_{I12}) + 0, 10. (v_{I13}) + 0, 145 (v_{I14})]$$

$$V_{Efficiency} (a) = [0, 215. (v_{I15}) + 0, 125. (v_{I16}) + 0, 24 (v_{I17}) + 0, 175 (v_{I18}) + 0, 06. (v_{I19}) + 0, 16. (v_{I20}) + 0, 025 (v_{I21})]$$

$$V_{Costs} (a) = [0, 205. (v_{I22}) + 0, 17. (v_{I23}) + 0, 235. (v_{I24}) + 0, 105. (v_{I25}) + 0, 065. (v_{I26}) + 0, 08 (v_{I27}) + 0, 14 (v_{I28})]$$

$$V_{People} (a) = [0, 60. (v_{I29}) + 0, 40. (v_{I30})]$$

In the second stage, the weighted sum of the partial values obtained using Eq. (1) was calculated. The weighting was made by applying the compensation rates of each criterion in Eq. (2):

$$V(a) = \sum_i^n v_i(a) \cdot w_i \quad (2)$$

where:

$V(a)$ : global value of action  $a$ .

$v_i(a)$ : partial value of action  $a$  on the  $i$ th criterion in which  $i = 1, 2, \dots, n$ .

$w_i$ : weight of the compensation rate of the  $i$ th criterion in which  $i = 1, 2, \dots, n$ .

$n$ : number of criteria in the model.

Once the areas of concern, which incorporate the criteria, sub-criteria, and model's descriptors, were aggregated, it was possible to aggregate the performance of an action ( $a$ ) into an individual performance  $V(a)$  by using Eq. (3):

$$V_{global} (a) = 0, 26. V_{Safety} (a) + 0, 22. V_{Environment} (a) + 0, 2050. V_{Quality} (a) + 0, 155. V_{Productivity} (a) + 0, 115. V_{Costs} (a) + 0, 045. V_{People} (a) \quad (3)$$

Once the mathematical aggregation equating the action's performance was established (i.e., the global formula for the evaluation of the context under analysis), the development of the multicriteria model was concluded, ending the evaluation stage.

### 5.3. Recommendations stage

The MCDA-C recommendations stage aims to support the decision maker use the global evaluation model [36]. It does not intend to prescribe orientations, but rather help the decision maker develop alternatives and understand their consequences. The operationalization of this process can be made in many ways, including [21]

- Identifying the performance of each cardinal scale to know the specific performance for a determined criterion;
- Establishing different strategies to identify the impact on global performance evaluation;
- Analysing the cost–benefit relation for implementing a strategy;
- Prioritizing the strategies and actions to be implemented through the goals with a higher level of contribution (compensation rates); and
- Evaluating the performance of each level (strategic, tactical, and operational).

In this stage, the generated understanding is reflected in the elaborated performance evaluation model, which allows us to identify those aspects where the organization is competitive, excellent, and substandard. To illustrate the case study, the decision maker scored the

current profile right after the end of the development of the multicriteria model (Fig. 2).

Fig. 2 summarizes the judgments made by the decision maker, showing the model's global score and representation of the results achieved for each of the 30 performance indicators. Globally, the company's performance profile obtained a score of 64 points on the multicriteria model. When the decision maker analysed this in an isolated way, this performance was considered to be competitive. However, the decision maker was concerned about the need to increase global performance at the next evaluation (this model will be used for trimester evaluations). According to the decision maker, the affiliate must optimize its management. The fact that it is located at a maritime port terminal distinguishes it from the other affiliates of the company. As a consequence, the company's headquarters places higher demand on its results.

At the segment level, the indicators for the safety, environment, and people segments had a positive performance level (excellent or competitive). Only the performance indicator (I4) "evaluate almost accident reports" was at a substandard performance level. The performance of the quality and efficiency areas was satisfactory. However, it is necessary to monitor the following indicators: (I11) "Quality training performed," (I14) "number of complaints in the Mixture units," (I15) "reliability index of the granulation unit n. 1," (I21) and "compliance to the maintenance breaks planning" because of their low performance levels.

Regarding the cost performance indicators, five out of the seven indicators obtained a substandard performance result: (I23) "variable cost of the port terminal," (I24) "variable cost of the granulation unit," (I25) "ensuring predicted costs of the annual break," (I26) "variable cost of the acidulation unit," and (I28) "cost of the non-compliance of the agreed investments." This shows that the company significantly reduced its financial return, because their main expenses were above the predicted amounts.

The described analysis is only one of the possibilities of using the model to generate knowledge on the actors and enhance the actions to be taken. Since the recommendations stage in MCDA-C is not prescriptive, other analysis [35] can be carried out. For example, the robustness of the cardinal scales could be examined and the sensitivity of the compensation rates analysed, among others.

## 6. Conclusions

This article described the development of a customized performance evaluation model to help the manager of a fertilizer industry affiliate located at a maritime port terminal identify and promote actions that could enhance his management process. The case study was performed on a large fertilizer industry located at a maritime port terminal in Brazil's south, which works on the plant nourishment segment, supplying over 10 countries in South America. As the data collection source, non-structured interviews were conducted to obtain primary data; documents were gathered and bibliographic research carried out to obtain secondary data.

The intervention instrument employed in this research was MCDA-C because of its capacity to provide identification, operationalization, and criteria measurement conditions that represent the perception of the decision maker regarding the performance evaluation of the company's activities. This method also made it possible to incorporate improvement suggestions through alternatives, with a performance profile inconsistent with the expectations of management.

The research's goal was reached through Fig. 2, which identified the global aggregation formula of the model for the evaluation of possible potential actions (alternatives). The specific goals were reached throughout the development of the model. In the structuring stage, the actors involved in the process were identified, the context under analysis labelled, and, finally, the model's hierarchical structure developed. Thereafter, the ordinal scales were built. In the evaluation stage, the



researchers employed the MACBETH method to transform the ordinal scales into cardinal scales, establish the compensation rates between the criteria, and build the aggregation model. Finally, in the recommendations stage, it was possible to present the current performance profile in the developed model and identify and analyse those elements that deserved enhancement actions.

The multicriteria model was validated by the decision maker and stakeholders for all execution stages. At the end of its development, the decision maker obtained a formal performance evaluation instrument to improve the company's management as well as a method of negotiating strategic matters with the board of directors and company's council.

The main theoretical contribution of this project is its ability to itemize all the stages in which MCDA-C was developed. As a practical contribution, this research allowed the decision maker to participate in all stages of the model's development, which provided greater knowledge about the complex problematic situation in which he was embedded and gave the developed model legitimacy.

Among the project's limitations are the time provided for interviews with the decision maker and stakeholders, the need for the commitment of the decision maker throughout the research process, and the singularity of the developed model, which cannot be generalized. It is stressed that the process can be replicated in other contexts, but not the model developed, as this was developed to meet the environment's specific needs.

Future projects could employ MCDA-C to evaluate the performance of the management activities in other branches of the company not located at maritime port terminals. Another possibility is the replication of this research in a different affiliate also located at a maritime port terminal and the performance of a comparative study. Lastly, it would be interesting to include other stakeholders from the fertilizer logistics chain as well as clients, retailers, and distributors in the analysis.

## Supplementary materials

Supplementary material associated with this article can be found, in the online version, at [doi:10.1016/j.orp.2019.100109](https://doi.org/10.1016/j.orp.2019.100109).

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