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DISCRETE EVENT SIMULATION COMBINED WITH MULTI-CRITERIA DECISION ANALYSIS APPLIED TO STEEL PLANT LOGISTICS SYSTEM PLANNING

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ABSTRACT

This paper aims the development and employment of a computational tool to support strategic decisions about the planning and sizing of the logistics and production elements of a steel plant (stockyards, transportation fleet, etc.). This tool corresponds to a hybrid software application able to analyze and evaluate the complex logistic problem proposed by combining the techniques of Discrete Event Simulation (DES) Modeling and Multiple Criteria Decision Analysis (MCDA). Also, are presented the proposed steel plant logistic system characteristics, as well as the methodologies applied to build the computational tool and to analyze the simulation results. The study concludes that the DES model combined with MCDA methodology is highly efficient regarding complex logistic systems major characteristics assessment.

1 INTRODUCTION

A Brazilian steel company is establishing a new plant in the country's northeast region. The inputs to the plant production, as well as the finished goods are all going to be handled through a private port, located very close to the plant.

Iron ore and coal are among the main steel making process inputs: the coal is imported originally from various locations of the world and is delivered at the terminal by a chartered vessels fleet, according to the procurement schedule; the iron ore employed in the process is owned by the company, and comes from two distinct Brazilian regions – northeast (NE) and southeast (SE), with remarkable differences in physical properties. The transportation of iron ore from their original locations to the company's private port will be performed by the company's private dedicated fleet, which will operate in a closed-loop circuit.

The company's private port operates 2 berths for inputs unloading, able to accommodate small Capesize vessels (DWT 120,000 tonnes). One berth is dedicated exclusively to iron ore unloading and the other is dedicated to coal unloading.

Thus, the main objectives of this study are: to perform sizing of the company's own vessels fleet (dedicated to the supplying of iron ore to the plant) and to determine the storage area assigned to the two types of iron ore (SE and NE - because of their physicals characteristics and properties differences, they must be stored separately), in order to avoid any kind of restriction or interruption in the plant steel making process due to failures in the input supply. This work does not cover the coal transportation, storage or processing.

A DES model was built to analyze the proposed logistic system, based on several alternatives of the system's possible configurations. From this point on, a multi-criteria analysis of the results obtained by the DES model of each proposed alternative was carried out. Through this analysis, it was possible to:

- Determine the "best" size of the iron ore supply vessel fleet, required to meet the project transportation planned cargo demand;
- Assess the capacity of the stock courts yards for the two types of iron ore (SE and NE).

The methodology applied on the study is described in the next section.

2 METHODOLOGY

The purpose of this effort is to develop a hybrid methodology to answer the logistical problem proposed by combining the techniques of DES Modeling and MCDA. Once the problem proposed is naturally complex, composed of several elements interacting among themselves simultaneously, influencing each other in a complex relationship network, often under conditions that involve randomness, and requires the observation and evaluation of numerous decision criteria, being lead by multiple goals (often intangible and even antagonistic) and commonly running in long time horizons where the risks and uncertainties are salient elements, the technique of MCDA is a strong ally in the decision making process. The MCDA is a structured technique for dealing with problems with multiple and complex criteria influencing decision making (Saaty 2001), since it allows the visualization of the rational-logical structure of the problem by representing and quantifying the importance of its elements, relating them to an overall goal.

Under the same circumstances, DES has been efficiently applied for evaluation of complex systems. DES is able to replicate the behavior of any real system very closely, providing the decision maker with valuable information about the system behavior and how it can be modified (Sweetser 1999).

2.1 Discrete Event Simulation (DES) Modeling

Regarding the development of the simulation model, the methodology applied was based on the steps proposed by Pedgen, Shannon and Sadowski (1995) and later modified by Botter (2002). Those steps are summarized and graphically represented by Chwif and Medina (2006), which divide the development of the model in three main stages (Figure 1):

a) Conception: definition of the system and its objectives, as well as data collection and conceptual modeling;
b) Implementation: preparation of the computer model itself, verification and validation;
c) Analysis: simulation runs, sensitivity and results analysis.

To model the proposed transportation system, a methodological basis was sought in literature works dealing with closed-loop transportation. In the Brazilian literature some publications in this context were addressed, such as Botter, Brinati, and Roque (1988), which presents a simulation model for the design of fuel transportation through the Tietê-Paraná Waterway in a closed-loop system. They provide an extensive description of the simulation model and perform the economic analysis of various scenarios. Mendes (1999) also employs the DES methodology in the development of a techno-economic model for the design of cargo intermodal transportation through the Tietê-Paraná Waterway in a closed-loop system. The author highlights the DES support capability in the decision making process.

Following the same line, Aragão (2009) develops a DES model in order to determine the size of barges fleet necessary to operate a closed-loop in an industrial logistic transportation system on the Brazilian coast, called industrial short sea shipping. Brito (2008) develops a tool for economic and operational planning of container and vehicles terminals, justifying the use of the DES technique by the consideration of a large number of variables and allowing the assessment of the terminal resources necessity. Moreover, the DES is able to deal with the randomness of the behavior of the components of the system, representing very closely the real system behavior, justifying the use of the DES methodology.

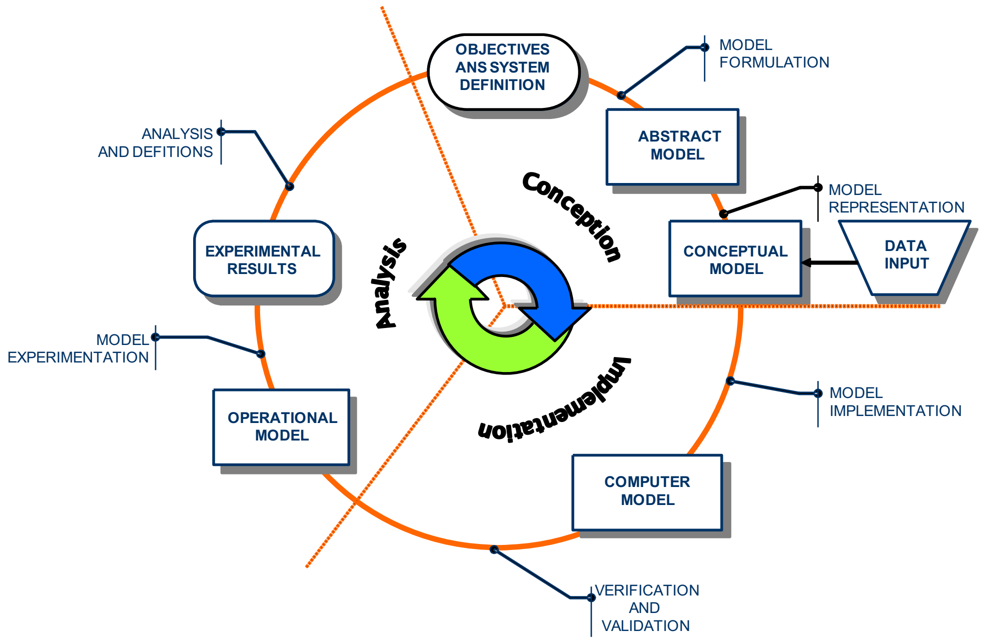

Figure 1: Development of a simulation model (Chwif and Medina 2006).

2.2 Multiple Criteria Decision Analysis (MCDA)

The history of the progress of MCDA utilization and the definition of its basic criteria are put together by Prado, Souza, and Yoshizaki (2009). The work also highlights the definition of the terminology "criterion", that in a decision making environment implies in the determination of some kind of pattern in which a particular choice may be considered more desirable than others (Belton and Stewart 2001).

The application of the MCDA methodology in this work was made using the propositions of Montibeller and Franco (2007). The work confirms the use of MCDA methodology as a supporting tool to decision makers in situations of high complexity and potentially significant and long term impacts. The methodology organizes and synthesizes information, includes measures objectively and considers value judgments of decision makers (Prado, Souza, and Yoshizaki 2009; Montibeller and Franco 2008), in an interactive and iterative process. The value judgments of decision makers are captured as preference compensation, creating a common and robust evaluation instrument. Thus, no matter how diverse is the decision makers group, all their arguments will be taken into account when structuring the decision model, what ensures the satisfaction of the chosen criteria.

The methodology described by Montibeller and Franco (2007), with the help of V.I.S.A. (Visual Interactive Sensitivity Analysis) software, allows several benchmarks and sensitivities analysis, considering the adopted parameters and taking advantage of the robustness of the decision model built.

Belton and Stewart (2001) developed a methodology that takes into account all the peculiarities of the Decision Support Theory, comprising the steps shown in Figure 2.

The objective of any multi-criteria decision methodology is not to prescribe the "right" decision to be chosen, but to help decision makers find an alternative that best fits their needs and problem general understanding.

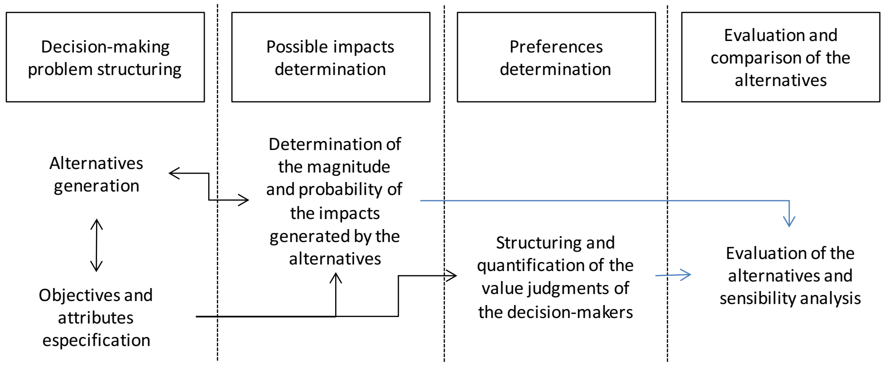

Figure 2: Structuring and resolution process of the MCDA methodology (Belton and Stewart, 2001).

Several authors have reviewed the utilization of the MCDA methodology as a tool for decision support. The 10 major advantages of MCDA, summarized by Saaty (2001), are: maintenance of the unity of the problem, complexity understanding, criteria interdependence relationship representation, capability of measuring criteria preference, maintenance of the consistency, synthesis, trade-offs evaluation, consideration of decision makers value judgments and consensus reaching.

Again, the goal sought by any decision support methods is the identification of good and robust alternatives, granting coherence and offering a good trade-off between different objectives that guide the problem resolution. In that way, the multi-criteria analysis in this work will be performed after the obtainment of the results of the DES model.

3 INPUT PARAMETERS AND ANALYSIS CRITERIA

For all simulated scenarios, an annual iron ore demand of 5 mtpy (million tonnes per year) was considered. The iron ore is supposed to be supplied by a dedicated vessel fleet operating in closed-loop system. Moreover, the project fleet is composed of Small Capesize vessels, the largest ship able to dock at the port, with 120,000 tonnes capacity. Table 1 lists the input data common to all scenarios.

Table 1: Input data common to all scenarios.

Parameter	Value	Unit
Planned Demand	5	mtpy
Vessels Capacity	120.000	tonnes
Travel Time (Plant-NE)	2.7	days
Berthing Time (NE Port)	1.5	days
Travel Time (Plant-NE)	7.9	days
Berthing Time (SE Port)	1.4	days
Berthing Time (Private Port)	3.25	days

3.1 Variables

The parameters varied in each analysis are described below:

- Fleet: number of vessels in the company's private fleet;
- Steel making process SE/NE iron ore percentage: The iron ore consumed in the steel making process is originally from either the southeast (SE) or northeast (NE) regions of Brazil, as shown in Figure 3. Due to the specifics physical and technical characteristics of each iron ore type, the percentage of SE iron ore may vary from 30 to 40% of the final composition of the steel process input. Whereas for the production department it is preferable to work with the maximum percen-

tage of SE iron ore, due to its enhanced physical properties, the procurement and transportation departments prefer working with the minimum percentage of SE iron ore (given the longer distance from company private port to the SE port compared to the NE port). It is, therefore, a conflicting decision variable;

- Stocks Capacities: Storage capacities in tonnes for each type of iron ore (SE and NE).
- Chartering: This parameter determines whether or not vessels will be chartered during the periods when the vessels of the company fleet are docked due to maintenance. The dockage occurs every 2 and ½ years, and ships may be unavailable from 7 to 40 days. This is an uncertainty parameter, since it is difficult to charter vessels with the fleet same specifics operational characteristics, especially for short time periods.

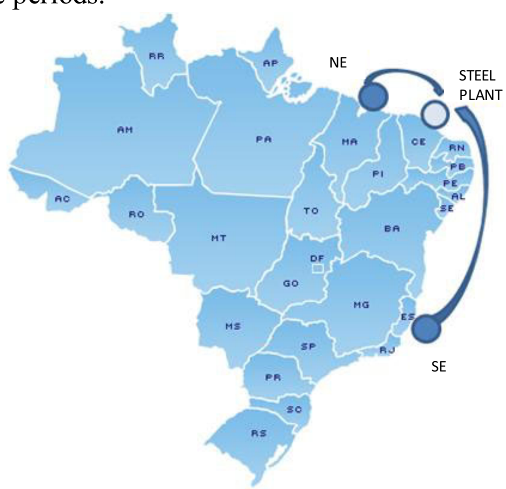

Figure 3: Representation of the iron ore transportation process from the SE and NE port to the company's private port.

3.2 Scenarios Description

From all the originally simulated scenarios, 10 viable scenarios were selected for further evaluation with the multi-criteria methodology support. These scenarios cover all the variation range of the input parameters of the DES model described in item 3.1 and their descriptions are listed in Table 2 .

Table 2: Description of the scenarios analyzed.

Scenarios	Vessels Fleet	% Min. SE Iron Ore	Stock Capacity (tonnes)		Rely on chartering ?
			NE	SE	
Scenario 1	2	30	550,000	225,000	No
Scenario 2	2	30	550,000	225,000	Yes
Scenario 3	2	35	500,000	275,000	No
Scenario 4	2	35	500,000	275,000	Yes
Scenario 5	2	40	475,000	300,000	No
Scenario 6	2	40	475,000	300,000	Yes
Scenario 7	2	35	375,000	275,000	Yes
Scenario 8	3	30	185,000	235,000	No
Scenario 9	3	35	170,000	275,000	No
Scenario 10	3	40	155,000	315,000	No

In Table 2, the first 7 scenarios simulate 2 vessels fleets operation, and the last 3 scenarios encompass a 3 vessels fleet. Next, the first alternated variable is the necessity or not of vessels chartering during the fleet docking period. Thereafter, until scenario 6, the proportion of iron ore from each source (NE and SE) is changed. Scenario 7 is a sensitivity analysis of scenario 4, with reduced storage capacity. From the 8th to the 10th scenarios the proportion of iron ore from SE and NE is altered, but with a 3 vessels fleet operation.

One can identify a clear tradeoff between the number of vessels in the company fleet and the storage capacity required for each iron ore type, just by, for example, comparing the 1st scenario with the 8th scenario. The simulation results are presented in Section 5.

4 DECISION CRITERIA – VALUE FUNCTIONS

As detailed in Section 2.2, the decision making process includes capturing the value judgments of the decision makers. Those are captured through the assignment of value functions for the relevant criteria and sub-criteria and later positioning of the scenarios result in value function scale. The value functions are built with the support of the software V.I.S.A.. All evaluations and considerations were performed with the participation of representatives of the following areas of the company: Operations, Procurement, Transportation (Railroad and Navigation), Inventory Management and Finance.

The relevant criteria and sub-criteria considered in the system characterization, their descriptions and value functions building process are described below:

- Power Plant Stoppages: Number of days per year that the plant stops production due to the lack of any input supply (iron ore). The value function of this criterion is given as follows: when no interruption occurs in the steel plant operation (0 days of interruption), the scenario gets maximum score (1). If there is only 1 day of interruption, the scenario gets a score of 0.5. Two days of interruption corresponds to a score of 0.25 and 3 days to a score of 0.125. Thereafter, the score varies linearly till the scenario with more days of interruption (in this particular case, 18), which gets score 0. Between intervals, the value function varies linearly. The value function aims at representing the extremely high costs of production resuming after any stoppage.
- Investment Net Present Value (NPV): As the system modeled represents an internal logistic operation of the company, there is no revenue generation. The Investment NPV is therefore directly related to the need of financial investment of the company on the project (size of the company's fleet, need for vessel chartering and others). The Investment NPV results are obtained based on parameters provided by the company, presented in Table 3.

Table 3: Economic parameters of the investment.

Parameter	Unit
Vessel Acquisition Value	Mi US$
Financed Percentage	%
Interests	%
Amortization Period	years
Grace Period	years
Vessel's Service Life	years
Return Rate	%/year
NPV Financed (per vessel)	Mi US$
NPV Own Capital (per vessel)	Mi US$
Chartering Costs (per vessel)	US$/day

The Investment NPV value function has linear behavior, with maximum score (1) assigned to the lowest total Investment NPV scenario and minimum score (0) for the highest Investment NPV.

- Annual Fleet Operational Costs: Takes into account all the operational costs of the company fleet, such as fuel, port costs and running costs (crew, insurance, administrative costs, taxes, etc.). The components of the fleet operational costs are presented in Table 4.

Table 4: Components of fleet operational cost.

Parameter	Unit
Fuel Cost (at route)	(US$/day)/vessel
Fuel Cost (at port)	(US$/day)/vessel
Running Costs	(US$/day)/vessel
Mooring Cost at Plant Port	(US$/mooring)/vessel
Mooring Cost at NE Port	(US$/mooring)/vessel
Mooring Cost at SE Port	(US$/mooring)/vessel

  Identically to the NPV, the value function of this criterion is linear, with maximum score (1) assigned to the scenario with lowest total operational costs and minimum score (0) assigned to the highest operational cost.
- Stock below the safety level: time percentage that the plant's stock remains below the minimum inventory safety level, but results in no interruption in the steel making process. The safety stock level is defined as 15 days of the plant input consumption. This parameter aims at representing the risk of interruption of plant production. A value function of this criterion assigns maximum score (1) to a zero percentage (0%) of observation days of stock below the safety level, and minimum value (0) to the highest percentage. The variation between the extremes is linear.
- SE/NE iron ore percentages: Operationally, the plant, due to physical characteristics, would rather be working with the SE than with NE iron ore. The scenarios are simulated within a discrete distribution of the percentage of SE iron ore (40%, 35% and 30%) and the value function is given as follows: 40% - valued as maximum (1), 35% - assigned with an intermediate score (0.5) and 30% - valued as minimum (0).
- Stock Capacity: The company project encloses a courtyard area able to store 775,000 tonnes of iron ore. For obvious reasons, the preferred configurations are the ones with lower storage capacity, what represent less area commitment. Thus, in accordance with the established value function, the scenario with lower storage capacity gets maximum score (1) and the one with higher capacity, gets minimum score (0), with linear variation between extremes;
- Average supported queuing time: the average supported queuing time refers to the average time that the vessels can wait in queue at the terminals of iron ore origin that do not affect input delivering. The vessels have to obey the queuing disciplines in both iron ore origin terminals. This is an uncertainty parameter, since a scenario that supports lower queues is riskier than one which supports high levels of the queue regarding planned demand fulfillment. Moreover, the behavior of the queues patterns at Brazilian iron ore terminals is regulated by fluctuations of global demand. The scenario with largest average supported queuing time scores 1 (maximum), and the shortest time scores 0 (minimum).
- Chartering: the criterion under discussion assumes only binary values - relying or not on spare vessels chartering. Thus, scenarios with no chartering relying receive maximum score (1) and scenarios where chartering spare vessels is considered an option receive minimum score (0). As previously mentioned, such behavior of the value function is due to the difficulty in chartering vessels that meet the specific operational characteristics demanded, especially for short time periods.
- New mission allocation waiting time: represents the number of hours, on average, that each vessel of the company fleet waits to be allocated to a new mission (new route) to any of the iron ore suppliers. Thus, a higher new mission waiting time, if on one hand means fleet idleness, on the

other hand represents less risk to the plant input supply. The value function assigns, for the lowest waiting time value observed the maximum score (1), and to waiting times greater than 24 hours the minimum score (0). Between 0 and 24 hours, the variation of the value function is linear.

5 SIMULATIONS RESULTS

20 replications (of 25 years each) of the simulation model developed in Arena ® were run for each scenario described in Section 3.2. The results are shown in Table 5.

Table 5: Results obtained by the DES model.

Scenarios	% Demand Met	Lack of Inputs (days/year)	NPV Total (norm.)	Total Annual Operational Costs (norm.)	% Time Below Safety Stock	Average Suppported Queuing Time (days/cycle)		New Mission Allocation Time (h/cycle)
						NE	SE	
Scenario 1	99	2	0.65	0.68	5	1.75	1.25	44
Scenario 2	100	0	0.70	0.69	0	3.50	2.50	11
Scenario 3	99	1	0.66	0.69	5	1.75	1.25	35
Scenario 4	99	0	0.71	0.69	2	3.50	2.50	7
Scenario 5	99	12	0.66	0.70	13	1.75	1.25	22
Scenario 6	100	0	0.72	0.71	3	1.75	1.25	29
Scenario 7	99	18	0.71	0.69	25	1.75	1.25	4
Scenario 8	100	0	0.99	0.95	0	5.25	3.75	161
Scenario 9	100	0	1.00	0.97	0	5.25	3.75	146
Scenario 10	100	0	1.00	1.00	0	5.25	3.75	118

The analysis of Table 5 reveals that scenarios operating with fleets of 3 vessels (Scenarios 8, 9 and 10) reached a higher performance level regarding operational criteria and service levels (average supported queuing time, time below safety stock level, days of input lacking). Furthermore, these scenarios are less risky to the system, less susceptible to uncertainties, less demanding for storage areas and more tolerant to queues formation at the iron ore supplier's terminals. However, the costs of these configurations are higher compared to other scenarios, either regarding the initial investment needed or the operational costs.

Among the first 7 scenarios, which rely on the operation of a 2-vessels fleet, the comparison of similar scenarios, in which variations happen only regarding the reliance or not on spare vessels chartering (e.g. scenarios 1 and 2, 3 and 4, 5 and 6), leads to the conclusion that the chartering process is responsible for operational results improvements, despite leading to costs increases.

Moreover, it is noticeable that a higher percentage of SE iron ore incurs higher costs, due to the greater distance between the input supplier and the steel plant. Additionally, scenario 7, which is a sensitivity analysis of scenario 4 with reduced storage capacity, corresponds to the worst operational performance.

Section 6 contemplates the multiple criteria model analysis.

6 MULTI-CRITERIA ANALYSIS

As described in section 2.2, the decision making process is made based on the assignment of weights to the decision criteria listed in section **Error! Reference source not found.** above. The process is now presented. The following methodological step is the assignment of scores associated to all the decision criteria in each of the 10 previously considered scenarios.

Table 6 shows the importance classification of the decision criteria and the calculation of the normalized weights associated to each of them. The criteria importance order has been defined in cooperation and unanimously by the group of decision makers.

Table 6: Importance classification of the decision criteria and normalized weights.

Criterion #	**Criterion**	**Priority**	**Weight (100/Priority)**	**Normalized Weight**
1	Power Plant Stoppages	1	100.0	30
2	Net Investment Present Value (NPV)	2	50.0	15
3	Total Annual Operational Costs	2	50.0	15
4	% Time Below Safety Stock	3	33.3	10
5	Average Queuing Supported Time	4	25.0	8
6	Stocks Capacities	5	20.0	6
7	NE/SE Iron Ore Input Proportion	5	20.0	6
8	Vessels Chartering	6	16.7	5
9	New Mission Allocation Time	6	16.7	5
	Sum		**332**	**100**

The criterion considered most important for the company is the number of days per year when the plant stops production due to the lack of any of the two types of iron ore. This is an extremely critical criterion. Subsequently, the criteria related to costs are the most important ones (NPV and Operational Costs), followed by the criteria related to operational risks - the safety stock and the uncertainty related to the average supported queuing time at the SE and NE iron ore terminals. After those criteria, the following priorities are the storage capacity, the proportion of NE/SE iron ore input, the stipulation of vessels chartering reliance and the new mission waiting time.

From the simulation results (Table 5), the scores associated to all considered scenarios are calculated and shown in Table 7.

Table 7: Score by scenario by criterion.

Scenario	**Criterion 1**	**Criterion 2**	**Criterion 3**	**Criterion 4**	**Criterion 5**	**Criterion 6**	**Criterion 7**	**Criterion 8**	**Criterion 9**
Scenario 1	0.38	1.00	1.00	0.80	0.00	0.00	0.00	1.00	0.00
Scenario 2	1.00	0.86	0.97	1.00	0.00	0.00	0.50	0.00	0.65
Scenario 3	0.50	0.97	0.97	0.80	0.50	0.00	0.00	1.00	0.00
Scenario 4	1.00	0.83	0.97	0.92	0.50	0.00	0.50	0.00	0.85
Scenario 5	0.10	0.97	0.94	0.48	1.00	0.00	0.00	1.00	0.10
Scenario 6	1.00	0.80	0.91	0.88	1.00	0.00	0.00	0.00	0.00
Scenario 7	0.00	0.83	0.97	0.00	0.50	0.35	0.00	0.00	1.00
Scenario 8	1.00	0.03	0.16	1.00	0.00	1.00	1.00	1.00	0.00
Scenario 9	1.00	0.00	0.09	1.00	0.50	0.93	1.00	1.00	0.00
Scenario 10	1.00	0.00	0.00	1.00	1.00	0.86	1.00	1.00	0.00

Following, the application of the normalized weights considered for each criterion (Table 6), results in a final score result for each scenario. Thus, the scenarios are ranked in Table 8.

Analyzing Table 8, one can verify that the scenario with the highest final score is Scenario 4. Scenarios 2 and 6 final scores are, however, close to Scenario 4 final score. Scenario 2 differs from scenario 4 only by a smaller proportion of SE iron ore, while scenario 6 employs a higher proportion of SE iron ore than scenario 4. However, scenario 6 supports less queuing time than scenarios 4 and 2.

Scenario 10 is ranked fourth, virtually tied with Scenarios 9, 8 and 3. Scenario 3 is very similar to Scenario 4, but with no vessels chartering and lower average supported queuing time. The difference between Scenarios 10, 9 and 8, which are scenarios with a dedicated 3-vessels fleet operation, is the proportion of SE iron ore employed in the steel making process: 40, 35 and 30% respectively.

Table 8: Scenarios final scores ranking .

Rank #	Scenario	Final Score
1	Scenario 4	0.78
2	Scenario 2	0.74
3	Scenario 6	0.72
4	Scenario 10	0.64
5	Scenario 9	0.62
6	Scenario 3	0.61
7	Scenario 8	0.60
8	Scenario 1	0.55
9	Scenario 5	0.50
10	Scenario 7	0.38

Given the proximity of the final scores of the 3 best ranked scenarios (Scenarios 4, 2 and 6), a reasonable configuration is supposed to be chosen between them. The 3 scenarios are composed by fleets of 2 vessels – what comprehends to a very close NPV value and annual total operational costs, have the same total storage capacity (775,000 tonnes), rely on chartering of vessels during the fleet docking periods and their steel making process is subject to no interruption. Therefore, the final pick between these 3 scenarios will be based on the average supported queuing time in the supplier's terminal and the SE iron ore percentage.

Scenario 2, second final score overall place, is the scenario with lowest SE iron ore percentage (30%) while scenario 6, third final score overall place is the scenario with highest SE proportion (40%). However, scenario 6 supports only 50% of the average queuing time of scenarios 2 and 4 (1.75 days versus 3.5 days).

The final recommendation is for the pick of the first final score overall place, Scenario 4, basically because its high average queuing time supported compared to Scenarios 2 and 6, and its intermediate percentage of SE iron ore employment in the steel process.

Moreover, key findings and further recommendations are presented in Section 7.

7 CONCLUSIONS AND RECOMMENDATIONS

The final conclusion of this paper is that, given the model assumptions, the decision criteria analysis and weights evaluations, the system will perform adequately according to the scenario 4 configuration (with no expected interruption on the steel making process and only 2% of the plant operation time below the input safety stock level), with a 2-vessels company fleet, 65% of NE and 35% of SE iron ore supply origin and storage capacity of 500,000 tons (NE iron ore) and 275,000 (SE iron ore). Furthermore, the system is supposed to rely on the chartering for temporary replacement of the vessels of the company fleet vessels during the docking periods. The expected average queuing supported time in this scenario is about 3.5 and 2.5 days in the NE and SE iron ore origin terminals, respectively.

The analysis of storage capacities were based on the availability of the company areas and the existing equipment in the site. The possibility of studying other areas and storage equipment acquisition (increasing the storage capacity or reducing the store area demanded) is a possible recommendation for further works.

Other additional recommendation is the possibility of a sensitivity analysis of the decision criteria weights realization, in order to test the MCDA model robustness or just test the model response subjected to other decision-makers' evaluation.

The DES and MCDA combined methodology proved to be effective as a complex logistic problem decision-making support. This analysis tool (DES + MCDA), with some minor modifications, is applicable to other similar logistics systems evaluation. Furthermore, it was possible to base the selection of alternatives in a set of quantitative criteria, a process usually neglected in a conventional DES analysis. The DES analysis usually classifies the evaluated scenarios as viable or unviable, and the choice is usually based on a single and "obvious" decision criteria (i.e: lower total cost, higher profit margin, etc.). Thus, the use of a multi-criteria model emerges as an effective option for complementing the DES model.

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