Fuzzy Model for the Priorization Analysis of Variable Quality Performance: An Approach in Shipbuilding

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ABSTRACT
The shipbuilding industry has evolved in recent years. Some quantitative and qualitative factors influence competitiveness of shipyards. The development of shipbuilding processes depends on evolution of manufacturing techniques, planning, organization and external environment. In general, regarding performance, quantitative variables are analyzed through mathematical and linear models. However, the qualitative variables, due to its subjectivity because it deals with human perceptions, it is not common for organizations to work on the performance of these factors. Then, this is the objective of the research, to analyze qualitative factors in shipbuilding in context with the Brazilian industry. The chosen that compose the proposed model are technology and industrial location. This research presents a prioritizing evaluation model of qualitative performance variables. So, presents as original the treatment by the fuzzy sets of qualitative critical factors expressed in linguistic terms by specialists working in the Brazilian sector, resulting in the prioritization of these factors. After result, the model was applied at specific shipyard. The results converge Brazil’s real scenario and show that the proposed fuzzy model might be a good qualitative performance factor evaluation tool. Finally, to identify real the distance of a specific shipyard for to this research’s model prioritization pattern by brazilian specialists.

1. Introduction
The topic of performance analysis, already discussed in several papers, has been discussed in research on productivity measurement systems. A measure of performance can be defined as a metric used to quantify the efficiency and effectiveness of a process [1]. Although numerous initiatives mention the use of several approaches to evaluation as effective tools (multicriteria models and linear programing), numerous problems have been found in the evaluation of results of a subjective nature.

The low performance and the higher prices in the international scenario call attention to the reality of Brazilian shipbuilding, according to a sector report commissioned by the
National Bank for Economic and Social Development [2]. In order to grow in this industry, Brazil needs to analyze the current performance behavior and then identify problems that hinder a better international competitiveness. This work was focused on evaluating qualitative aspects of performance in Brazilian shipbuilding.

In this article quality, qualitative variables and their respective qualitative performance will be seen more comprehensively than only according to the classical perception of product quality. Level of technology, labor quality and availability of production constraints directly linked to the region, location or industrial environment are linguistic factors of human perceptions that directly influence the competitive advantage in the naval industry.

Some studies mention the use of fuzzy logic in performance simulation, however, references related directly to the topics ‘shipbuilding, measurement or performance, fuzzy, simulation, qualitative variables’ in Brazilian reality represent rare studies, many without great impact in the academic perspective. Thus, this paper propose to contribute clearly to the literature, especially the Brazilian literature.

The goal is to find out which importance by result of attendance degree of each stage of production and of each critical factor based on the opinion expressed by experts consulted that generated a hierarchical prioritization pattern. This means that the importance that the specialist attributes to each factor can be the path to improve of performance of the organization.

A specific entropy measure for a probability distribution has been elucidated by Shannon [3]. A measure of divergence, reported by Kullback and Leibler [4], could be understood on the amount of the assumed probability distribution that diverges from the true. In parallel to probability concept, Zadeh in 1965 [5] wedges the fuzzy set theory, achieving great success in several fields. Fuzzy entropy is an important concept for measuring fuzzy information, Zadeh [6] introduced the concept as a measure of fuzziness.

In this sense, fuzzy logic, appropriate to deal with situations of uncertainty and subjectivity, would be a good alternative to deal with the problem of productivity analysis. Many measures of a qualitative and ambiguous nature can be described subjectively through linguistic terms, which is not possible with the use of traditional approaches to performance evaluation [7].

This article was divided into eight sections. Firstly, the performance in shipbuilding is presented. After we demonstrate the fuzzy logic for modeling critical factors for qualitative performance variables, then to apply the fuzzy model for the prioritization analysis of variable quality performance. Then we analysis the specific shipyard to compare with results of qualitative priorization pattern model, hierarchically. To finally explain the behavior qualitative results and present the conclusions.

2. Performance Evaluation in Shipbuilding

The performance evaluation revolution began in the late 1970s and early 1980s with dissatisfaction with traditional retrograde accounting systems. Since then, there has been development in the design of a performance measurement system (PMS), with emphasis on non-financial, external and future-oriented measures in 1994 [8]. Several methods have been proposed over the years, such as activity-based costing (ABC) by Cooper and Kaplan in 1988 [9], the Balanced Scorecard (BSC) by Kaplan and Norton in 1992 [10].
The application of hierarchical process analysis (AHP) within the BSC structure appears in many studies, as well as the application of an integrated approach using AHP and fuzzy logic. Wang and Chang in 2007 [11] propose an integrated approach of BSC with fuzzy logic to evaluate the performance of a technology organization. Seçme in 2009 [12] apply this AHP-Fuzzy technique in performance evaluation in the Turkish banking industry. Zeng et al. in 2013 [13] proposed an improved VIKOR method with enhanced accuracy (ea-VIKOR) to address moderate data in healthcare management. Lu et al. in 2013 [14] used an MCDM to evaluate the factors that influence the agreement of RFID in Taiwan’s healthcare system. Ivlev et al. in 2014 [15] proposed three combined methods, including MCDM, to select large medical equipment. In another study, AHP and Delphi techniques were utilized by Ivlev et al. in 2015 [16] to make a selection among 13 Magnetic Resonance Imaging (MRI) systems in an uncertain environment. As can be observed in the literature, many analytical models have been implemented over the years for the problem of performance evaluation.

Therefore, performance, its evaluation and its subsequent model of performance indicators have been used over time by organizations to measure and monitor their performance [17]. However, in many cases, such indicators are underutilized, limited to quantitative variables, or for the simple reason that the system produces what it consumes. They lack them to be systemically worked to provide a comprehensive view for benchmarks of performance [18].

The main performance measure of a transformation process, as in industries, is productivity, which is the relationship between what goes out of the system and what goes in, that is, Productivity = Output / Input. In the case of shipbuilding, the performance is measured in a classical way by the ratio CT (gross tonnage = HH / Ton) Hour-Man (HH) and weight of processed steel in tons; or CGT (Gross Compensated Tonnage) which uses a correction factor that varies according to the complexity of the vessel, according to OECD [19].

The larger concept of the overall performance of the facilities, the performance can and should be evaluated in regard to the processes considered critical for the overall performance, so that there can be a directed action for improvement. It can be said that the most efficient shipbuilding unit (shipyard) will be the one with the best indices of performance, production time and quality, with needs of less physical capacity utilization and technological level, and in conditions of less favorable environments and location. Physical capacity is measured in a classical way by the level of steel processing and in mathematical form by the crisp numbers of input and output resources, since technology and location are given by linguistic terms. Through the fuzzy logic was measured the behavior of qualitative performance of these two qualitative variables, technology and industrial location.

The human judgment on qualitative attributes is always subjective and imprecise, provided normally by specialists. In this way, fuzzy set theory is regularly used in decision-making problems based on human judgments. The fuzzy numbers express the idea of confidence interval and are determined on a fuzzy subset of real numbers [20].

Many researchers developed frameworks for undertaking reviews in literature. Most of them mention the necessity of critically appraising the methodological quality. However, only seldom indicate which quality criteria can be applied to reseraches [21].

However, although evident, this is not the case in many organizations. Several decisions are made based on ‘feeling’, if they analyze data about the processes involved. This is largely due to the lack of knowledge of how to measure subjective aspects and perceptions of
quality, which change from one specialist to another. This problematic is object of study of this article, working linguistic terms is possible through the fuzzy methodology.

3. Fuzzy Logic for Modeling Critical Factors

People think creatively, quickly, inaccurately and nebulously; in contrast, machines and computers are driven by binary logic. This humanism and way of thinking motivate the fuzzy method, capable of expressing how imprecise, vague and ill-defined is something of human perception, which varies among people. Organizations that depend on evaluating qualitative variables or linguistic terms or opinions of belonging to two categories, simultaneously in different contexts, should make use of fuzzy logic.

Fuzzy logic is used to integrate imprecise data in support of decision making. Fuzzy sets are able to display uncertain parameters correctly and can be managed through different operations on fuzzy numbers. As uncertain parameters are treated as inaccurate rather than accurate values, the process will be stronger and results will be more reliable [22]. Therefore, special fuzzy numbers like triangular, trapezoidal, and gaussian fuzzy numbers were proposed to reduce the amount of computational effort [23].

According to Chamovitz and Cosenza in 2015 [24], the use of diffuse logic in complex systems is predicted when it comes to an adaptation of the reality reference. The most important objective of the concept of the fuzzy sets is the will to produce a formal quantitative structure that allows to capture the perceptions of human reasoning, that is, this reasoning is produced in natural language since: (1) it deals with uncertainty and imprecision of reasoning processes and situations; (2) it allows the modeling of the heuristic knowledge that cannot be described by traditional mathematical equations and; (3) it allows the computation of linguistic information.

In this concept there is a degree of relevance of each element to a specific set. There is no exact limit to determine when an element belongs to the set or not. The specific function (1) is able to universalize so that the values assigned to the elements of the universe set $X$ belong to the range of real numbers from 0 to 1, [0,1]:

$$\mu_A(x) : X \rightarrow [0, 1] \quad (1)$$

These values indicate the degree of relevance of the elements of the set $X$ with respect to the set $A$, how much is it possible for an element $x$ of $X$ to belong to the set $A$. This function is called the membership function and the set $A$ is determined as a fuzzy set.

A fuzzy set can be represented by a set of ordered pairs, where the first element is $x \in X$, and the second, $\mu_A(x)$, is the degree of membership or membership function of $x$ in $A$, which maps $X$ to the membership space $M$. When $M$ contains only the points 0 and 1, $A$ is non-fuzzy. In this way, we have (2):

$$A = \{(x, \mu_A(x)) | x \in X\} \quad (2)$$

A fuzzy number is a special subset of real numbers ($\mathbb{R}$). Its membership function $\mu_B$ is a continuous mapping of $\mathbb{R}$ closed interval [0, 1]. Triangular fuzzy numbers have continuous linear relevance function [25].

A triangular fuzzy number $A$ in $\mathbb{R}$ has the following membership function (3):

$$\mu_A(x) = (x - a)/(b - a), \text{ if } a \leq x \leq b$$
Figure 1. Membership function of a triangular fuzzy number \( \tilde{A} = (a, b, c) \).

\[
\frac{c - x}{c - b}, \text{if } b \leq x \leq c \\
0, \text{otherwise}
\]  

The graphical representation of the triangular fuzzy number is shown in Figure 1:

Fuzzy triangular numbers, as expressed by the prior membership function, can be denoted by \((a, b, c)\). Triangular fuzzy numbers are easy to manipulate and interpret. For example, ‘approximately equal to 5’ can be represented by \((4, 5, 6)\) and ‘exact 5’ can be represented by \((5, 5, 5)\).

We can consider a critical factor as a linguistic variable represented by the set of five linguistic terms (which are the relevancies of these critical factors). These linguistic terms can be represented by triangular fuzzy numbers. An expert is a person who has experience of a process or matter of interest. The fuzzy set theory makes it possible to demonstrate the knowledge obtained through the pertinence functions. The accuracy of the fuzzy model developed by experts depends on the number of experts recognized for their knowledge and experience in the area of interest [26].

Some fuzzy decision methods were found in literature, based on the expert opinion, it is worth to mention the following studies: Cosenza et al. in 1981 [27] compare both offer and demand for a list of select location factors by intensity levels, and demand is defined from projects by requirement levels. The scale level of these factors is measure by linguistic variables, and operated as fuzzy sets, as result, the hierarchical array of locations vs. projects could be obtained. Lee in 1996 [28] propose two algorithms to deal with the rate of aggregative risk in a fuzzy environment by fuzzy sets theory during any phase of the life cycle. Hsu and Chen in 1996 [29] proposed a method using aggregation of opinions individual nebulae within a group consensus and described in a procedure for aggregating expert opinions, using the concept of fuzzy number.

This approach is widely used until the present days. Yager in 2000 [30] proposed a simultaneous solution of relationships involving fuzzy models, considering the problem of
economic balance as a problem example. Jain et al. in 2004 [31] suggested a fuzzy-based approach and used a genetic algorithm for the supplier selection process. In the work of, Chen et al. in 2006 [32], they described a hierarchy model based on the fuzzy set theory and used a linguistic variable to measure the rates and weights of supplier assessment factors. Bottani and Rizzi in 2008 [33] used fuzzy logic and created an integrated approach that encompasses cluster analysis and AHP to group and classify alternatives for the supplier selection process. Grecco in 2012 [34] presents a method for assessing resilience in configurations based on the concepts and properties of fuzzy set theory to deal with the subjectivity and consistency of human judgments in the evaluation of indicators. Ohlan in 2015 [35] presented a new parametric generalized measure of fuzzy divergence with the proof of its validity. Chatterjee et al. in 2018 [36] indicates a method for analyzing expert comments and the company standpoints, using the rough approximation of a fuzzy soft set.

The literature review explains that the opinions of experts are in the center of many literatures. In common, all decision-making methods use fuzzy sets theory to find the best alternatives according to the criteria defined for decision-making originated by expert opinion.

Hsu and Chen [29] presented a methodology combining the group’s individual vulnerabilities with nebulous opinions and presented a process of integrating the concept of a fuzzy number based on expert opinion. Thus, we have used the Hsu and Chen method [29] in conjunction with the application of the same method by Grecco [34] because it is appropriate to the proposed method to establish a model of technology evaluation and industrial location of yards, being possible to measure and evaluate the performance of the shipbuilding industry from the point of view of qualitative variables, based on the opinion of experts working in the area, through the process of aggregation, equality and agreement of opinion.

Usually, the fuzzy editorial model is performed in three phases. The first is a fuzzification phase, met clear entry crisp (numerically speaking) is converted into fuzzy sets. The second is the inference step, where the fuzzy rules are used to aggregate import data from fuzzy operators and fuzzy rules it produces fuzzy export results. Defuzification is the last phase one is of the turnover of fuzzy results in clear results presentation to decision-makers.

Therefore, this research uses the fuzzy logic theory approach to develop a method for the prioritization analysis of variable quality performance using two qualitative variables in context shipbuilding, technology and industrial location. The fuzzy logic theory approaches, described in Section 5, provides an appropriate logical mathematical framework for dealing with the uncertainty and imprecision of the reasoning processes that shape people’s perceptions. Other specific limitations indicated in previous studies on fuzzy logic including the need to use specific measures to assess consistency among different evaluators in order to minimize the problem of subjective judgments and evaluations. We describe the use of the proposed method in a Brazilian context shipbuilding that attend offshore organizations, main client of shipbuilding in Brazil.

4. Methods for Qualitative Performance Variables

In the model proposed in this article, it is possible to analyze the input qualitative variables in a systemic way, since the fuzzy modeling logic itself is based on a view of interconnected
processes, structured through input variables – fuzzification, inference and variables output – defuzzification.

This article is about also the procedures chosen in the data collection, in a typical case study, for the analysis of the Brazilian shipbuilding industry, according to the research delimitations and available resources. These linguistic terms, treated by the Fuzzy Logic rule, formed a role, for each attribute, where, by ranking of relevances, the priorities demanded by the several factors pointed out were identified, which may allow, after due process, from the result defuzzification the direction of new strategies, as well as analysis of critical factors for better performance in the field of shipbuilding [37].

The selection of experts is a decisive factor, since the credibility and the quality of results depends on the quality of the specialists. In general, however, all persons with recognized knowledge and experience who are or have been directly or indirectly involved in the field of interest are candidates for the evaluation process. In this research, according to availability criteria, a group composed of eleven specialists working in the shipbuilding market in Brazil, in different geographic regions of the country, with different positions and academic qualifications participated. All work directly in the offshore context, a criteria established by being the offshore industry the main demander of naval orders in Brazil and also by the availability of the specialists who attended the knowledge and experience in the area that could be based with perfect understanding that their opinion is used in a work research, not a knowledge assessment.

As for the procedure, a group of eleven specialists that attended main criterias of this research, thus had knowlodgement in differents academics degrees working in the area of interest in shipbuilding, all of them working in the area professionally, with different weights adopted according with to the degree in the academic and the professional position occupied, called ‘specialists’, answered a structured questionnaire. The group of experts scored on the questionnaire according to their personal perceptions of professional experience.

The technology evaluation system of the naval industry used consists of the evaluation of activities, or factors of the shipyard’s technology, with a range between 1 and 5, where 5 corresponds to the state of the art, for each element [38]:

- Level 1: The shipyard has several berths in use, low capacity cranes and very little mechanization. Outfitting is largely curried out on board ship after launch. Operating systems are basic and manual.
- Level 2: There would be Fewer berths in use, possibly a building dock, larger cranes and a degree of mechanization. Computing would be applied for some operating systems and for design work.
- Level 3: There would be a single dock or level construction area with large capacity cranes, a high degree of mechanization in steelwork production and more extensive use of computers in all areas.
- Level 4: Generally a single dock, with good environmental protection, short cycle times, high productivity, extensive early outfitting and integration of steel and outfit, together with fully developed CAD/CAM and operating systems.
- Level 5: It is developed from level 4 by means of automation and robotics in areas where they can be used effectively, and by integration of the operating systems, for example, by the effective use of CAD/CAM/CIM. There would be a modular production philosophy...
in design and production. The level is also characterized by efficient, computer-aided material control and by fully effective quality assurance.

Regarding industrial location, a list of critical factors was compiled based on the hierarchical analysis model COPPE-Cosenza [39], where the factors considered are those with the highest frequency and high degree of support. Briefly, they are:

- Elements linked to the production cycle.
- Elements related to transport.
- Services of industrial interest.
- Industrial integration.
- Labor availability.
- Electric Power (supply availability and regularity).
- Water (supply availability and regularity).
- Population general living conditions.
- Elements of the climate and soil characteristics.
- Other restrictions and ease of installation.

5. Fuzzy Model for the Priorization Analysis of Variable Quality Performance

The model proposed in this article, developed for the evaluation of prioritization, is presented in a systematic way, integrating technological and industrial location factors for shipbuilding organizations that deal with these qualitative variables. The evaluation method was developed in three stages: (1) elaboration of a structure of critical factors, based on the levels of international naval technology [38] and the principles of industrial location [39]. (2) determination of the critical factors and their importance, a baseline of organizational assessment according to specialists working in the Brazilian shipbuilding industry. (3) evaluation of results and qualitative prioritization.

The international technological levels were divided by the main standard stages of production of naval vessels, based on an industry study by BNDES [2], the following attributes: main structure, cargo handling, steel processing and computerization. The industrial location attribute was composed of a list of critical factors based on the hierarchical analysis model COPPE-Cosenza [39]. The linguistic terms were distributed by the stages, and resulted in twelve critical technology factors and ten critical factors of industrial location, according to Table 1:

The critical factors quoted through linguistic terms based the questionnaires sent to specialists working in areas of interest in shipbuilding. The data worked by the fuzzy methodology is not probabilistic by judgment, since important interested parties were consulted within the universe of the shipbuilding. The instruments used in this work were structured questionnaires, questions with closed answers, structured on interval scales with linguistic terms, and subsidized structured qualitative interviews [40].

An adapted version of the quality evaluation procedure of Belchior [41] and Moré [42] and also the organizational resilience evaluation procedure of Grecco [34] was used. Based on research qualitative methods available in the literature researchers should thoughtfully create designs and models that effectively address their research objectives, purposes and issues [43]. The objective were to discover the importance of each stage of production
Table 1. Critical factors assessed in the case study.

| Attributes                     | Critical factors                                                                 |
|-------------------------------|---------------------------------------------------------------------------------|
| Technology – Main structure    | 1.1 Quantity of labor 1.2 Block Construction 1.3 Portfolio of the yard to be specialized 1.4 Concern about environmental protection 1.5 Qualification of the workforce 1.6 Degree of automation and robotics |
| Technology – Load Handling     | 2.1 Crane capacity 2.2 Control of the time of movement of load                   |
| Technology – Steel Processing  | 3.1 Steel workshops and integrated finishes 3.2 Control of the assembly time of the blocks |
| Technology – Informatization   | 4.1 Integration of operational areas with CAD / CAM systems 4.2 Advanced use of technology in business process systems and manpower management |
| Industrial location           | 5.1 Elements linked to the production cycle 5.2 Transport elements 5.3 Services of industrial interest 5.4 Industrial integration 5.5 Availability of labor 5.6 Electrical energy (availability and regularity of supply) 5.7 Water (availability and regularity of supply) 5.8 General living conditions for the population 5.9 Elements of climate and soil characteristics 5.10 Other restrictions and facilities related to the industrial installation |

and each critical factor based on the opinion expressed by experts consulted so that a prioritization pattern is generated, hierarchically. This means that the importance that the specialist attributes to each factor is the path to the best performance of the organization. The determination of the qualitative prioritization pattern is divided into seven steps, which are shown in Figure 2.

5.1. Definition of Critical Factors

This step was demonstrated in the previous item. These critical technology and industrial location factors will be the language variables of the method, as seen in Figure 2.

5.2. Selection of Specialists

The selection of specialists is a decisive factor, since the credibility and the quality of the results depend on the quality of the specialists. In general, however, all persons with recognized knowledge and experience who are or have been directly or indirectly involved in the field of interest are candidates for the evaluation process. In this research participated a group composed of eleven specialists who work in the shipbuilding market in Brazil, in several geographic regions of the country, with different positions and academic qualifications.

5.3. Determination of the Degree of Importance of Specialists

To determine the importance of the specialist, a data acquisition tool was required. This data collection tool is a questionnaire (Q) to identify the expert’s profile. Each questionnaire
contains information from a single specialist. The amounts vary according to position and your degree of their education.

The relative importance of each expert, $\text{RI}_i$, which is its relative importance compared to other specialists, is determined by Equation (4):

$$\text{RI}_i = \frac{\Sigma (W_t + W_o)}{\Sigma \text{Weight}}$$

Whose: $W_t$ = Academic title weight; $W_c$ = Occupied position weight; $\Sigma \text{Weight} = \text{Total Sum of Weights}$

Following the following criteria of classification, with regard to the titration: Doctorate = weight3, Master = weight2, Graduation = weight1; in terms of positions: Director = weight3, Management = weight2, Engineer = weight1. Table 2 shows the representation of the degrees of importance of the eleven experts in this article.

### 5.4. Choice of Language Terms and Membership Functions

From the point of view of fuzzy theory, any critical factor can be considered as a linguistic variable in relation to a set of linguistic terms regards with pertinence functions in a predetermined reference set. Each factor is composed of linguistic terms obtained in an evaluation process performed by expert opinion. That is why they will also be fuzzy numbers.
Table 2. Importance of each expert.

| Experts | Academic title weight | Occupied position weight | Total Sum of Weights | Importance of each expert (GIEi) |
|---------|-----------------------|--------------------------|----------------------|---------------------------------|
| 1       | 3                     | 1                        | 4                    | 0.13                            |
| 2       | 1                     | 2                        | 3                    | 0.10                            |
| 3       | 1                     | 1                        | 2                    | 0.07                            |
| 4       | 1                     | 3                        | 4                    | 0.13                            |
| 5       | 1                     | 1                        | 2                    | 0.07                            |
| 6       | 2                     | 1                        | 3                    | 0.10                            |
| 7       | 2                     | 1                        | 3                    | 0.10                            |
| 8       | 1                     | 1                        | 2                    | 0.07                            |
| 9       | 2                     | 1                        | 3                    | 0.10                            |
| 10      | 1                     | 1                        | 2                    | 0.07                            |
| 11      | 1                     | 1                        | 2                    | 0.07                            |
| Total   |                       |                          | 30                   |                                 |

The linguistic terms of this research were determined as: Crucial Relevance (CR): for critical factors that are considered crucial, they are of great importance for the best performance in shipbuilding; Quite Relevance (BR): for the critical factors that are judged to be very relevant, they are important for better performance in shipbuilding; Moderate Relevance (RM): for critical factors that are judged to be only relevant, they have little relevance to the best performance in shipbuilding; Little Relevance (PR): for the critical factors that are judged to be of little relevance, have almost no importance for the best performance in shipbuilding; No Relevance (NR): For critical factors that are judged to be zero relevant, they have no significance for the best performance in shipbuilding.

The language terms determined at this stage have been widely used in many studies and research, particularly in behavioral measures in organizations [44]. These linguistic expressions are represented by triangular fuzzy numbers that indicate the degree of importance of each factor in question. According to Pedrycz [45], the triangular fuzzy numbers process important information with a high degree of uncertainty and indefiniteness, as well as the linguistic variables that translate the opinions of specialists.

The Figure 3 shows the linguistic variables, the linguistic terms and the graphs of their membership functions and Table 3, then the triangular fuzzy numbers for the linguistic terms.

The membership functions of the linguistic terms have been proposed by Lee [28]. The graphic presentations of membership functions for the linguistic terms NR (No Relevance), LR (Little Relevance), MR (Moderate Relevance), VR (Very Relevance) and CR (Crucial Relevance) are shown in Figure 3.

5.5. Determination of the Degree of Importance of Critical Factors

This step is intended to obtain from the experts the levels of importance of each critical factor, of each concept of technology and industrial location, using the set of linguistic terms indicated by the triangular fuzzy numbers in Table 2.

5.6. Treatment of Data Collected From Experts

To combine the experts’ opinions represented by triangular fuzzy numbers we used the similarity aggregation method [29]. The agreement degree (AD) between expert Ei and expert
Table 3. Importance degrees and triangular fuzzy numbers for linguistic terms.

| Importance degree | Linguistic terms        | Triangular fuzzy numbers |
|--------------------|-------------------------|--------------------------|
| 0.0                | No Relevance (NR)       | $\tilde{N}_1 = (0.0, 0.0, 1.0)$ |
| 1.0                | Little Relevance (LR)   | $\tilde{N}_2 = (0.0, 1.0, 2.0)$ |
| 2.0                | Moderate Relevance (MR) | $\tilde{N}_3 = (1.0, 2.0, 3.0)$ |
| 3.0                | Very Relevance (VR)     | $\tilde{N}_4 = (2.0, 3.0, 4.0)$ |
| 4.0                | Crucial Relevance (CR)  | $\tilde{N}_5 = (3.0, 4.0, 4.0)$ |

$E_j$ is determined by the ratio of intersection area to total area of the membership functions. The agreement degree (AD) is defined by (5.2):

$$ AD = \frac{\int_x \left( \min\{ \mu\tilde{N}_i(x), \mu\tilde{N}_j(x) \} \right) dx}{\int_x \left( \max\{ \mu\tilde{N}_i(x), \mu\tilde{N}_j(x) \} \right) dx} $$

(5)

If two experts provide the same estimates, $AD = 1$. In this case, the two estimates of the experts are consistent, and therefore the agreement degree between them is one. If two experts give completely different estimates, the agreement degree is zero. If the initial estimates of some experts have no intersection, then we use the Delphi method to adjust the opinion of the experts and to get the common intersection at a fixed a e level cut [28]. The higher the percentage of overlap, the higher the agreement degree. After all the agreement
degrees between the experts are calculated, we can construct an agreement matrix (AM), which gives us insight into the agreement between the experts (5.3).

\[
\text{AM} = \begin{bmatrix}
1 & AD12 & \ldots & AD1j & \ldots & AD1n \\
ADi1 & ADi2 & \ldots & ADij & \ldots & ADin \\
ADn1 & ADn2 & \ldots & ADnj & \ldots & 1
\end{bmatrix}
\]  

(6)

The relative agreement (RA) of expert Ei \((i = 1, 2, 3, n)\) is given by Equation (7).

\[
RAi = \frac{1}{n-1} \star \sum_{j=1}^{n} (ADij)^2
\]  

(7)

Then we calculate the relative agreement degree (RAD) of expert Ei \((i = 1, 2, 3, n)\) by (5.5).

\[
RADi = \frac{RAi}{\sum_{i=1}^{n} RAi}
\]  

(8)

Now we can define the consensus coefficient (CC) of expert Ei \((i = 1, 2, 3, n)\) by (5.6).

\[
CCI = \frac{RADi \star Rli}{\sum_{i=1}^{n} (RADi \star Rli)}
\]  

(9)

Let \(\tilde{N}\) be a fuzzy number of combined expert opinions. So, \(\tilde{N}\) is the fuzzy value of each factor which is also a triangular fuzzy number. By definition of the consensus coefficient (CC) of expert Ei \((i = 1, 2, 3,n)\), \(\tilde{N}\) can be defined by Equation (8). Referring to Equation (8), \(\tilde{n}_i\), is the triangular fuzzy number relating to the linguistic terms, NR (No Relevance), LR (Little Relevance), MR (Moderate Relevance), VR (Very Relevance) and CR (Crucial Relevance). The result of the evaluation of the critical factors will determine the fuzzy value of each factor related to the concepts of technology and industrial location that will be given by \(\tilde{N}\), which is a triangular fuzzy number, Equation (10):

\[
\tilde{N} = \sum_{i=1}^{n} (CCI \star \tilde{n}_i)
\]  

(10)

Whose: \(\tilde{n}_i\) is the triangular fuzzy number relative to the linguistic terms (NR, LR, MR, VR, CR) used by specialists in the evaluation of critical factors.

5.7. Qualitative Prioritization Pattern in Shipbuilding

To establish the qualitative prioritization pattern in shipbuilding, the basis for assessing the prioritization of a business unit is the degree of importance of each critical factor, which forms each concept of technology and industrial location. The qualitative prioritization pattern as a reference for performance in shipbuilding is established by calculating the normalized importance degree (NID) of each critical factor that makes up each attribute relevant to qualitative performance in shipbuilding. The normalized importance degree (NID) of each critical factor is given by defuzzification of its triangular fuzzy number \(\tilde{N}\) \((a_i, b_i, c_i)\),
Table 4. Values of the qualitative prioritization pattern in hierarchical order.

| Critical factors                                           | ai  | bi  | ci  | NIDi |
|------------------------------------------------------------|-----|-----|-----|-------|
| Electrical energy (availability and regularity of supply)  | 2.82| 3.82| 3.93| 1.000 |
| Crane capacity                                             | 2.58| 3.58| 3.90| 0.936 |
| Block Construction                                         | 2.49| 3.49| 3.95| 0.913 |
| Availability of labor                                      | 2.48| 3.48| 3.81| 0.910 |
| Water (availability and regularity of supply)              | 2.45| 3.45| 3.91| 0.904 |
| Qualification of the workforce                             | 2.40| 3.40| 3.81| 0.891 |
| Degree of automation and robotics                          | 2.36| 3.36| 3.93| 0.881 |
| Integration of operational areas with CAD / CAM systems     | 2.23| 3.23| 3.86| 0.845 |
| Quantity of labor                                          | 2.19| 3.19| 3.55| 0.836 |
| Control of the assembly time of the blocks                  | 2.17| 3.17| 3.64| 0.829 |
| Advanced use of technology in business process systems and manpower management | 1.97| 2.97| 3.63| 0.776 |
| Industrial integration                                      | 1.94| 2.94| 3.82| 0.770 |
| Control of the time of movement of load                     | 1.92| 2.92| 3.63| 0.766 |
| Transport elements                                          | 1.75| 2.75| 3.60| 0.719 |
| Portfolio of the yard to be specialized                     | 1.70| 2.62| 3.35| 0.686 |
| General living conditions for the population                | 1.62| 2.62| 3.30| 0.686 |
| Elements linked to the production cycle                     | 1.55| 2.55| 3.55| 0.668 |
| Concern about environmental protection                      | 1.48| 2.48| 3.39| 0.650 |
| Steel workshops and integrated finishes                     | 1.30| 2.30| 3.18| 0.603 |
| Services of industrial interest                             | 1.26| 2.26| 3.20| 0.591 |
| Elements of climate and soil characteristics                | 1.14| 2.14| 3.14| 0.560 |
| Other restrictions and facilities related to the industrial installation | 1.05| 2.05| 3.00| 0.538 |

where bi represents the importance degree. Then, NID can be defined by (5.8), can see in hierarchical order in Table 4.

\[
NID_i = \frac{b_i}{\text{highest value of } b} \tag{11}
\]

6. Comparatives Results of the Qualitative Prioritization Pattern Model with a Specific Shipyard

Once the objective of the prioritization pattern was reached, we expand our motivations to analysis the specialist model presented in this paper was applied to a specific shipbuilding unit, a shipyard located in the state of Rio de Janeiro. The application was main driven by the response of a specialist working in the unit on the degree of attendance of the critical factors in their specific workplace, compared to the model prioritization standard. This specialist participated in the previous process of model construction, but the key question changed: instead of analyzing his perception of the relevance of critical factors in the Brazilian context, he was asked to evaluate whether the elements listed as critical factors of technology and of industrial location are present at the place of operation (the plant site).

The results of the expert’s perception were compared to the qualitative prioritization standard in shipbuilding established in the previous item, resulting, therefore, in degrees of compliance with the standard, in order to evaluate the performance of the critical factors present in the shipbuilding unit. These grades measure how much the yard achieves, by and large, the ideal standard established, which has an index equal to 1. The phases of application of the method are:
In this phase, it is proposed to use the following linguistic terms to evaluate the degrees of attendance of the critical factors of technology and industrial location in shipyard: totally disagree (TD); partially disagree (PD); do not agree or disagree (NAD); agree partially (AP) and totally agree (TA). The linguistic terms are represented by triangular fuzzy numbers, denoting the degree of attendance of each indicator considered. Figure 4 and Table 5 show the linguistic terms represented by fuzzy numbers, with their relevance functions adapted from [28].

At this stage the expert opinion that operates on the specific shipyard was recorded as to the degree of attendance that your shipyard meets from the qualitative prioritization pattern. The opinions, interpreted as linguistic terms totally disagree (TD); partially disagree (PD); do not agree or disagree (NAD); agree partially (AP) and totally agree (TA), are then evaluations of the presence of critical factors in the plan, that is, the result was the degree of attendance of each of the factors to the prioritization pattern.
Table 6. Degrees of attendance of critical factors the presence of critical factors in the plant in fuzzy numbers.

| Factors critical to the prioritization pattern | N (números fuzzy) |
|----------------------------------------------|-------------------|
| Regarding the Technology in the Main Structure are the elements present in the shipyard? |                      |
| Quantity of labor                            | 0.50              |
| Block Construction                           | 0.75              |
| Portfolio of the yard to be specialized       | 0.75              |
| Concern about environmental protection        | 0.75              |
| Qualification of the workforce               | 0.75              |
| Degree of automation and robotics            | 0.75              |
| Regarding the Technology in Load Handling are the elements present in the shipyard? |                      |
| Crane capacity                               | 0.50              |
| Control of the time of movement of load      | 0.50              |
| Regarding the Technology in Steel Processing are the elements present in the shipyard? |                      |
| Steel workshops and integrated finishes       | 0.75              |
| Control of the assembly time of the blocks   | 0.50              |
| Regarding Technology in Informatization the elements are present in the shipyard? |                      |
| Integration of operational areas with CAD / CAM systems | 0.75 |
| Advanced use of technology in business process systems and manpower management | 0.50 |
| Regarding the Industrial Localization are the elements present in the shipyard? |                      |
| Elements linked to the production cycle      | 0.75              |
| Transport elements                           | 0.75              |
| Services of industrial interest              | 0.50              |
| Industrial integration                       | 0.25              |
| Availability of labor                        | 0.50              |
| Electrical energy (availability and regularity of supply) | 0.75 |
| Water (availability and regularity of supply) | 0.75 |
| General living conditions for the population | 0.75 |
| Elements of climate and soil characteristics  | 0.25              |
| Other restrictions and facilities related to the industrial installation | 0.25 |

(3) Treatment of collected data

Each linguistic term used in this evaluation was represented by a triangular fuzzy number (Figure 4), which was converted into a numerical format, a degree of attendance (Table 4) that corresponds to the value with degree of pertinence equal to 1.

In Table 6 shows the degrees of attendance of the critical factors in fuzzy numbers, according to expert opinion.

(4) Defuzzification

The purpose of this phase is to obtain a degree of attendance of the critical factors present in the specific shipbuilding unit in relation to the prioritization pattern of these qualitative

Table 7. Compliance degree of the specific shipyard unit in relation to the object of this research – the model of prioritization of qualitative variables.

| Attributes                      | Compliance degree |
|--------------------------------|-------------------|
| Technology – Main structure     | 0.71              |
| Technology – Load Handling      | 0.50              |
| Technology – Steel Processing   | 0.61              |
| Technology – Informatization    | 0.63              |
| Industrial location             | 0.57              |
variables. How far would be the reality of the shipbuilding unit than would be the standard for better performance.

Table 5 shows the fuzzy numbers of the factor attendance grades, regards to expert opinion. Considering the values presented in Table 6 and the values of the degree of importance of the factors (Table 3), the values of the compliance levels of the specific shipbuilding unit were calculated using the area center method (Equation (12)), in relation to the object of this research – the model of prioritization of qualitative variables. These values are shown in Table 7.

\[
Ai = \frac{\sum_{j=1}^{k} NID_j \times aj}{\sum_{j=1}^{k} NID_j}
\]  

Whose: \(Ai\) = Compliance degree of the specific shipbuilding unit \(i\) in regards the prioritization pattern of qualitative variables; \(aj\) = degree of compliance of the critical factor \(j\) in regards the attribute \(i\); \(NIDj\) = normalized importance degree of the critical factor \(j\) of attribute \(i\), calculated by Equation (11)

7. Results

In relation to the global analysis of the two main qualitative issues in shipbuilding, technology and location, we have the qualitative prioritization of the hierarchical order in Table 3.

For this article, the analysis of the prioritization result regards the proposed point-to-point model is equivalent to making a strong \(\alpha\) cut, with \(\alpha = 0.8\). It is based on the COPPE-Cosenza model, where it is verified that the values have their representations in pertinence given by specialists who naturally have difficulties in assigning crucial values and / or much greater, their real distances. The approximation is simplified through an \(\alpha\)-cut \(= 0.8\), to balance deviations that usually occur in the dimensioning of the general factors, normalizing within the modeling structure [39].

7.1. Electric Power (Supply Availability and Regularity)

The industrial sector is the largest energy consumer in Brazil. It is not by chance that the energy supply is one of the services that most threaten the Brazilian industrial park. The common failures in the Brazilian universe it is not a coincidence and cause great losses. Ensuring the availability of electricity at competitive prices is an extremely important factor for companies that require a lot of electrical energy in their production processes, such as the naval industry [46].

7.2. Capacity of the Cranes

Cranes are crucial to the performance of a shipbuilding unit because the equipment, materials and systems must be moved and lifted during assembly. The larger the crane in a dam, the more productive the yard can become by the amount of steel that can be processed [47].
7.3. Building by Blocks

The entire production process of a ship (production of parts and initial steps from construction to final installation in dikes and careers) is carried out in the area of the shipbuilding industrial park area. We can subdivide the industrial areas of the shipyards into seven sites or work areas normally used: processing and sheet metal profiles; pipe; painting; mechanics; electric / electronic; subset and assembly [48].

7.4. Labor Availability

Within this critical factor of industrial location includes two other critical technology factors: quantity and quality of manpower available, which are described in items 6 and 9 below. In this factor, a macro view will be presented. In general, labor costs in industries have a considerable cost. That is why it is extremely advantageous to build your business in a region with large population, because wages are lower as more people become available. It should be noted that, directly related to the quantity and qualification of the labor force, its availability in this sense is measured by the unemployment rate and the educational structure of the region for training and professional development, such as technical schools, universities and universities. research centers close to the industrial location [49].

7.5. Water (Supply Availability and Regularity)

Besides drinking water for consumption by the workforce in the industrial unit, salt water is also used as heat exchangers, for cooling of various equipment, such as compressors and evaporators, for fire systems of vessels, equipment tests such as boilers and corrosion, the launch of the ship, which will be submerged in the water. Clearly, the availability of this resource is taken into account by the need for a large amount of water to execute its production processes [46].

7.6. Workforce Qualification

With the growth of the naval industry, new jobs have been created and are not fully available in a qualified way, it is common in this industry that organizations struggle to find specialized professionals in the market. This has already led organizations to import labor. Therefore, it is important to prioritize industrial location according to educational level. Another relevant point to emphasize, which should receive attention, is the learning / experience curve. Shipyards with specialized portfolio tend to leverage performance with a more productive workforce. The experience curve is related to costs and experience. The average cost of a production unit will decrease steadily based on experience. The person learns to do the tasks better and more efficiently as they become more experienced.

7.7. Degree of Automation and Robotics

First, the modular construction of blocks of battery processing units, as well as the development of semi-automatic welding systems of high quality. The efficiency of systems and the
production of machines and controls flexibly electronics is increasingly changing the competitive axis for management. This means that the pursuit of performance improvements is greater than the requirements for a good product. All this is related to innovation [50].

7.8. Integration of Work Areas with CAD / CAM Systems

To design a ship, must-seel look for best set of its technical characteristics (resistance, buoyancy, sealing, minimum strength and others). As metal sections that should be presented in their project. Contrary to CAD, CAM is associated with the production process, while working on CAD mathematical models for machine processes, providing movement information, of great relevance for that the components and their adequacy to provide the proposal of drawings and in the photographic techniques to vessel [51].

7.9. Quantity of Labor

To this end, emphasis is placed on the industrial location, which is a strategy for the inhabitants of the area, determining to predict a quantity of manpower available at the site. The existence of a good network of education, public safety, housing, transportation, recreational facilities, lifestyles, etc. is important for an offer of human capital. Norms for organizational development are more onerous and faster for organizations [52].

7.10. Block Time Rhythm Block

In block construction, they are executed in the workshop and, at the same time, as building parts, machines and other nets are built inside the blocks and installed so that, in a second stage, they are transported to careers or building dykes. The technological development in welding processes and also in terms of the capacity of the ship cranes allowed, over time, the application of block construction occurred. If you are able to do a training job, such as doing a painting, for example, which increases the performance of the integrated design [51].

So, it was compared the model of qualitative prioritization pattern with a specific shipyard, according to Table 6, the attendance degrees presented unsatisfactory values for all following elements, Technology in Main Structure (0.71), Technology in Cargo Movement (0.50), Technology in Steel Processing (0.61), Technology in Computerization (0.63) and Industrial Location (0.57). In addition, \( \alpha \)-cut = 0.75 was considered, since this is the value referring to the linguistic term ‘partially agree’, which evaluates the presence of the critical factor in the plant. This corresponds to making a strong \( \alpha \)-cut, with \( \alpha \)-cut = 0.75. Therefore it is understood that a value less than 0.75 means that the plant does not have the elements that compose the critical factors minimally satisfactory, in relation to result the model of prioritization pattern of this research based on consulted specialists. Thus, a core finding in this study is concerning the it can be concluded that no element of qualitative variables were met in this specific plant consulted.

According to what was exposed throughout this research, can be explained by related to the lack of study about qualitative matters of this industrial area that the article proposes to contribute in the delivery of theoretical literature, and as also significantly Brazil’s industry underdeveloped position. Moreover, the approach we propose in this paper shows
promising in providing an independent and impersonal prioritization, avoiding cognitive bias, could have potential usability in the future enabling a more acute discussion among decision-makers, and resulting in more coherent results on the performance of these qualitative factors.

8. Conclusions

The overcoming of the qualitative challenges regards naval industry are decisive for the conquest of international competition. The evaluation of the behavior of diagnoses regards these relations with stakeholders, important for the sustainability of the development of shipyards and to improve performance.

In order to achieve the main objective of this article we use the concept of fuzzy logic to develop a model to evaluate the qualitative variables of shipbuilding and to relate critical factors in the technology and industrial location areas. A fuzzy approach supporting the weaknesses in the context of naval performance evaluation when dealing with qualitative values, which depends on diverse human perceptions and can be expressed in linguistic terms.

On a decreasing scale from the standard prioritization model result, this article explored each of the ten factors prior to the use of $\alpha$-cut $= 0.8$. The Brazilian case of manpower stands out. Shipbuilding is as a labor-intensive industry, highly dependent on the workforce and its qualifications, is a key factor. As shipbuilding projects become more complex and specific and for a required specific technology, a properly and available workforce ratio becomes even more relevant.

In the industrial location aspect, one professional well trained, is difficult to be attended by wage costs, where is a lower ratio in Brazil. In the manufacture industrial is common few expenses with modernization, automation, robotics in detriment of paying more for a worker that knows how to use high technology, which is difficult to find or is not available such trained professional. For example, according to data from Euromonitor International published in Financial Times in 2017 [53], the Brazilian industrial worker is already cheaper than the Chinese, the main competitor in the naval market.

The combination of criteria has one restriction. According to some interviewees, the relative importance of some criteria might change due to combination of criteria, mostly regarding in industrial location aspect. Then, for future studies, this research will be extended to implement the relations of criteria in the fuzzy model in order to support this issue and provide a more consistent hierarchical prioritization pattern. Finally, the main infrastructure of our study could be applied to different problems, in all vague analysis, method and complex problems.

Disclosure statement

No potential conflict of interest was reported by the author(s).

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