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# Green supply chain management: definition of criteria and selection of suppliers in the foundry sector

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## RESUMO

**Objetivo –** Este artigo tem como objetivo propor critérios para a seleção de fornecedores verdes no setor de fundição e selecionar os melhores fornecedores para a organização onde a pesquisa foi desenvolvida, aplicando-se o método AHP.
**Desenho / metodologia / abordagem –** Foi realizada uma pesquisa aplicada onde foram consultados especialistas do setor de fundição e, após a conclusão da pesquisa, foram definidos critérios para a seleção de fornecedores verdes.
**Resultados –** Adotando-se os critérios definidos e aplicando-se o método de tomada de decisão AHP (*Analytical Hierarchy Process*), foram classificados cinco fornecedores, sendo os critérios de Ambiente, Saúde e Segurança considerados os mais importantes de acordo com a opinião dos especialistas consultados nesta pesquisa.
**Originalidade / valor –** O estudo permite que as organizações vejam a importância do processo de seleção de fornecedores no setor de fundição, onde a preocupação mundial com o meio ambiente está cada vez mais presente e as normas e regulamentações ambientais são rígidas.
**Palavras-chave –** Cadeia de abastecimento verde. Seleção de fornecedores. Método AHP.

## *ABSTRACT*

***Purpose*** *– This article aims to propose criteria for the selection of green suppliers in the foundry sector and select the best suppliers for the organization where researched, by applying the AHP method.*
***Design/methodology/approach*** *– An applied survey was carried out where specialists from the foundry sector were consulted and after the survey had been completed, criteria were defined to select green suppliers.*
***Findings*** *– Adopting the defined criteria and applying the Analytical Hierarchy Process (AHP) decision-making method, five suppliers were classified, with Environment, Health and Safety criteria being considered the most important according to the opinion of the experts consulted in this survey.*
***Originality/Value*** *– The study allows organizations to see the importance of the supplier selection process in the foundry sector, where worldwide concerns for the environment are increasingly present and environmental standards and regulations are strict.*
***Keywords*** *– Green supply chain. Supplier selection. AHP method.*

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## 1. INTRODUCTION

Green supply chain management (GSCM) is one of the initiatives that have been highlighted and contributed in a relevant way to sustainable development, as it aims to promote the reconciliation between environment and the supply chain (RIBEIRO; SANTOS, 2012). The GSCM is the integration of environmental thinking in the supply chain, including product design, selection of raw materials and their sources, manufacturing processes and product delivery to the customers, as well as environmental thinking in relation to the end of life product usefulness, including product management after its useful life (SRIVASTAVA, 2007).

In a broad sense, GSCM refers to the management between suppliers, their products and the environment. In other words, the principles of environmental protection are incorporated into the suppliers management systems. Its purpose is to make products more environmentally friendly and increase competitiveness (CHE, 2014).

In this sense, the GSCM can be classified from ecological purchases to integrated supply chains, starting with the supplier, manufacturer, customer and reverse logistics, which is “closing the loop” as defined and found in the supply chain management literature (ZHU et al., 2007).

The GSCM deals with the integration of environmental issues to improve the environmental impact of supply chain activities without compromising economic and operational performance (LEE, 2015; MENTZER *et al*., 2011).

According Yazdani *et al.* (2017), the GSCM implements several MCDM methods to select among alternative suppliers in relation to a predetermined set of criteria.

Green production has become an important factor in recent years, influencing the sustainability of the manufacturing sector. With the growing concern about environmental protection, it was found from the literature that the selection of green suppliers is one of the approaches in the solution of issues related to the environment. The selection of suppliers is a multicriteria decision problem that involves qualitative and quantitative criteria (SIVAPRAKASAM *et al*., 2015).

Several industry sectors consider green production an important factor; among them, the foundry sector has growing along the years, increasing the debate on the subject. According to Balaji *et al.* (2014), the foundry industries play an important role in the economy of a country and, therefore should start adopting GSCM as a competing strategy to build their environmental image, although in most countries it is still in its infantry.

In this sense, Balaji *et al.* (2014) estimate that foundries industries around the world have been concerned about the environment due to recent visits from environmental regulators, customers and competition in the market.

One of the methods that can be adopted to solve this decision-making problem is the analytic hierarchy process (AHP), which, according to Chen *et al.* (2016), helps identify the priority weights or vectors of alternatives or criteria using a hierarchical model that includes goals, main criteria, sub-criteria and alternatives.

As a result of this worldwide trend of awareness of the impact of the manufacturing industry on the environment, many strategies are emerging to optimize the selection of green suppliers in order to keep organizations sustainable from the viewpoint of customers, competitors and regulators. Therefore, this article aims to propose, through an applied research, criteria for the selection of green suppliers in the foundry sector and to select the best suppliers for the organization where the research was developed, using the AHP method.

The research is structured in five chapters, where the content is shown below. The first chapter is the introduction, where it presents the central theme and relevant information of the research, research problem, general objective and the research structure.

The second chapter aims to draw the reader's attention and present the literature review with information and approaches on the research topic, bringing several definitions of Green Supply Chain Management (GSCM) and Analytic Hierarchy Process (AHP).

In the third chapter, the research methodology, presents the AHP method. Eight experts of foundry sector were consulted to define the criteria for the selection of green suppliers, applying the AHP decision making method and ranking the green suppliers. This chapter includes four sections to complement the development of the research, being:

- Section 1: Search for articles on green suppliers and the AHP method;
- Section 2: Analyze the criteria for selection of green suppliers presented in the literature and the definition of the criteria for this article;
- Section 3: Submit the criteria for the selection of green suppliers to specialists in the foundry sector to define the criteria to be used in this study;
- Section 4: Apply the AHP method for selection of green suppliers in the foundry sector.

The fourth chapter shows the results found, including consistency analyzes, presentation of comparative tables among suppliers and ranking the top five suppliers.

In the fifth and last chapter, we present the final considerations of the research, showing its contributions and possibilities for future research.

## 2. THEORETICAL FOUNDATION

The literature review of this article addresses the key concepts of the green supply chain and supplier selection, in addition to the multicriteria AHP decision-making method.

In this chapter, a literature review was guided to present the theoretical concept of this research. Each section presents the main definitions, practices and studies relevant on the topic. The main concepts covered are:

- Green Supply Chain and Supplier Selection;
- AHP - Analytic Hierarchy Process.

### 2.1. Green Supply Chain and Supplier Selection

Supply chain operation with sustainable considerations has become an increasingly important issue in recent years (TSAI; HUNG, 2009). In a broad sense, the green supply chain refers to management of suppliers, their products and the environment. In other words, the principles of environmental protection are incorporated into the management systems of suppliers. The green supply chain purpose is to make products greener and to increase competitiveness (CHE, 2010).

According to Chen *et al.* (2016), because of the challenge of raising public awareness about environmental issues and government regulations, GSCM has become an important issue for companies to achieve environmental sustainability. Selecting suppliers is one of the key operational tasks required to build a green supply chain.

Mavi (2015) states that in today's highly competitive environment, selection of appropriate suppliers is a significant decision for effective and efficient supply chain management. In order to select the most appropriate suppliers, many economic and environmental criteria should be considered in the decision-making process. Although numerous studies have used economic criteria such as: cost, quality and delivery time in the supplier selection process (CHEN *et al.*, 2016). According to Chang and Hung (2010), the main criteria adopted in the selection of suppliers are:

- quality (assesses the quality of the product supplied);
- cost (evaluates the cost invested by the company in the purchase of the product);
- performance on delivery (evaluates the on-time delivery by the supplier);
- service (evaluates the after-sales service and support provided by the supplier);
- flexibility (assesses the ability of the vendor to support the plan to change the company's production).

In particular, Freeman and Chen (2015) argued that GSCM allows the integration of environmentally friendly suppliers in the supply chain to be systematized to suit specific environmental policies and regulations. More persuasively, GSCM enables companies to improve their bottom line while reducing the impacts on the global environment.

### 2.2. AHP

The AHP is one of the methods of multicriteria decision making (MCDM) that was originally developed by Thomas L. Saaty. This is an eigenvalue approach for the pairwise comparisons. In short, it is a method to derive ratio scales from paired comparisons for the measurement of quantitative and qualitative performances (SIVAPRAKASAM *et al.*, 2015). One of the main advantages of the AHP method is the relative ease with which it handles multiple criteria. In addition, it can effectively deal with qualitative and quantitative data (MAVI, 2015).

In the literature, numerous techniques have been developed to select the most suitable suppliers or green suppliers based on specific methods including AHP (GOVINDAN *et al.*, 2015). According to Sivaprakasam *et al.* (2015), applying the AHP to a complex problem generally involves four steps: step 1 – establish the structure of the hierarchy, step 2 – construct a paired comparison matrix, step 3 – test the consistency of each comparison matrix by calculating the eigenvector and maximum eigenvalue and step 4 – estimate the relative weights of the elements of each level.

There is a continuing need for robust evaluation models that effectively incorporate various vendor criteria. With its need to compensate for several criteria that exhibit imprecision, supplier selection is a highly important multicriteria decision problem (MAVI, 2015).

Sivaprakasam *et al.* (2015) noted that manufacturing industries are increasingly managing environmental performance suppliers to ensure that the materials and equipment they supply and produce are environmentally friendly in nature. In this sense, it was defined 11 criteria involved in the implementation of GSCM, as shown in Table 1.

**Table 1**: Criteria involved in the implementation of GSCM.

| N º | Criteria | Description | References |
|---|---|---|---|
| 1 | Quality (Q) | Quality refers to the conformance and reliability of the product. The factors assessing quality include mainly quality systems, process quality, total quality management and rate of certified product. | Kannan et al. (2008)<br>Lee (2009)<br>Chan and Kumar (2007) |
| 2 | Cost (C) | It refers to the costs investing in environmental management of its processes or it may be a source of environmental costs because of its destructive processes. | Humphreys et al. (2003)<br>Chiou et al. (2008) |
| 3 | Technology Capability (T) | It refers to the availability of technical manpower, state-of-art reprocessing technology, R&D facilities, capability to perform reverse logistics function, etc. | Handfield at al. (2002)<br>Choi and Hartley (1996) |
| 4 | Service (S) | The performance of the supplier in providing service to the manufacturer is the prime criteria to decide its suitability for a particular product. | Lee (2009)<br>Chan (2007)<br>Muralidharan et al. (2002) |
| 5 | Pollution Control (P) | It means the control of emissions and effluents into air, water or soil. | Handfield at al. (2002)<br>Humphreys et al. (2003)<br>Lee (2009) |
| 6 | Environmental Management System (E) | Environmental Management is the set of general management function aspects for an organization, including planning needed to develop and maintain the policy and the organization's environmental objectives. | Sarkis (1998)<br>Humphreys et al. (2003) |
| 7 | Green Competencies (G) | The factors that show the competencies of supplier in improving green production. It includes the checking of a supplier's ability to reduce pollution effects, implement clean technology and use of environmental friendly materials. | Humphreys et al. (2003) Lee (2009) |
| 8 | Green Image (I) | Green image refers to market share changes as a result of adopting environmentally friendly products and the relationship with stakeholders /due to the change of the company's image after implementing 'green' programs. | Humphreys et al. (2003)<br>Lee (2009)<br>Chiou et al. (2008) |
| 9 | Procurement Management (M) | Defining the overall intended procurement strategies. | Hsu and Hu (2009)<br>Handfield at al. (2002) |
| 10 | Process Management (B) | It represents the activities of planning and monitoring the performance of a process. | Handfield at al. (2002)<br>Lee (2009)<br>Tuzkaya et al. (2009) |
| 11 | Risk Factor (R) | It refers to the performance and past history of the suppliers, the political status of the supplier's country, rules and regulations of the government and managing both business and environmental issues effectively. | Chiou et al. (2008)<br>Min (1994) |

Source: Adapted from Sivaprakasam et al. (2015).

## 3. METHODOLOGICAL PROCEDURES

For the research development, it was considered an applied research according to Gerhardt and Silveira (2009) that aim to generate knowledge for practical application, directed to the solution of specific problems involving local truths and interests.

The research method was defined in four steps: (i) search for articles on green suppliers and the AHP method; (ii) analyze the criteria for selection of green suppliers presented in the literature and the definition of the criteria for this article; (iii) submit the criteria for the selection of green suppliers to specialists in the foundry sector to define the criteria to be used in this study; (iv) apply the AHP method for selection of green suppliers in the foundry sector.

For the development of step (ii), it was considered the opinion of eight experts to define criteria for the selection of green suppliers.

Applying the AHP method demonstrated in step four of this article, equations are used to verify the quality of the input data, evaluating the consistency ratio that is calculated according to the following steps:

- Calculate the relative weights and *l*max for each matrix of order *n;*
- Calculate the consistency index (CI) for each matrix of order *n* by the equation:

$$CI = (l\max - n)/(n - 1) \quad (1)$$

- Calculate the consistency ratio (CR) by the equation:

$$CR = CI/RI \quad (2)$$

For the development of the AHP method, the Microsoft Excel tool was used to create the hierarchy structure of the criteria and sub-criteria, elaboration of all matrices and tables, applying the formulas and analyzes of the methodology.

## 4. RESULTS AND DISCUSSIONS

The results and discussions will be presented in the steps defined in the methodology of the research development.

### i. Search for articles on green suppliers and the AHP method

For the search and selection of articles, a research protocol was developed and applied in order to define the inclusion and exclusion criteria of the texts to be used in the literature review. The search for articles was finalized on Jun. 06th, 2018. Table 2 presents the research protocol used.

**Table 2**: Research protocol.

| **Criteria** | **Description** |
|---|---|
| Database | *Scopus, Web of Science e Science Direct* |
| Keywords | *("green supply chain" OR "supplier selection" OR "AHP method") AND ("green supply chain" AND "supplier selection" AND "AHP method")* |
| Contains keywords | Title, Summary, keywords |
| Period | 2008–2018 |
| Area | Engineering |
| Language | English |

Source: The authors.

From the search of the articles using the inclusion and exclusion criteria defined in the research protocol, seven articles related to the theme of the article were selected that were used as basis for this work.

### ii. Analyze the criteria for selection of green suppliers presented in the literature and the definition of the criteria for this article

The eleven criteria are presented in the Table 1. The evaluation of the criteria was carried out by eight specialists from the foundry area in order to define the criteria to be adopted for this study the opinions of each specialist were checked individually and each one could suggest new criteria. From the consolidation of the analysis of the specialists, forty two criteria were obtained that had their relevance verified in step (iii) of the research.

**iii. Submit the criteria for the selection of green suppliers to experts in the field in the foundry sector to define the criteria to be used in this study**

In this stage of the research, a form containing the forty two criteria obtained in step (ii) was elaborated that was then sent to the eight specialists so that the most relevant criteria were selected considering the general opinion.

In order to be considered as a selection criterion for this study, the evaluated criteria should have relevance greater than 60%, that is, it should have been pointed out by at least five specialists.

It is noted that for some experts the declassified criteria such as: industrial installation, ISO 14001 and OHSAS 18001 certifications and others, which represent 40% of the studied criteria are also important in the foundry sector. During the analysis of the questionnaires, some of the specialists described that the certification process requires investments in integrated management consultancy, administrative structure, training of employees, fees and expenses with external and internal audits. In this context, the specialists considered that the certification processes require foundries to make financial investments that may affect their profit margins and sales.

After receiving the eight forms answered by the specialists, the criteria were tabulated in order of relevance, as shown in Table 3.

**Table 3**: Research with foundry industry specialists.

| Criteria | Specialist | | | | | | | | Relevance (%) |
|---|---|---|---|---|---|---|---|---|---|
| | **E1** | **E2** | **E3** | **E4** | **E5** | **E6** | **E7** | **E8** | |
| Model inspection | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 100.00% |
| Final part inspection | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 100.00% |
| First aid | 1 | 1 | 1 | 1 | | 1 | 1 | 1 | 87.50% |
| Outpatient service | 1 | 1 | 1 | 1 | 1 | 1 | 1 | | 87.50% |
| Pollution control | 1 | 1 | | 1 | 1 | 1 | 1 | 1 | 87.50% |
| Sand recycling | 1 | | 1 | 1 | 1 | 1 | 1 | 1 | 87.50% |
| Energy saving | 1 | 1 | 1 | 1 | 1 | | 1 | 1 | 87.50% |
| Financial health | 1 | 1 | | 1 | 1 | 1 | | 1 | 75.00% |
| Supply management | 1 | 1 | 1 | 1 | | | 1 | 1 | 75.00% |
| Planning and Production Control (PCP) | | 1 | 1 | 1 | 1 | 1 | | 1 | 75.00% |
| Traceability | 1 | | | 1 | 1 | 1 | 1 | 1 | 75.00% |
| Nonconformance | 1 | 1 | 1 | 1 | | | 1 | 1 | 75.00% |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Security policy | 1 | | 1 | 1 | 1 | | 1 | 1 | 75.00% |
| Personal protective equipment (PPE) | 1 | 1 | 1 | 1 | | | 1 | 1 | 75.00% |
| Collective protective equipment (EPC) | | 1 | 1 | 1 | 1 | 1 | 1 | | 75.00% |
| Employee training and recycling | 1 | 1 | 1 | | | 1 | 1 | 1 | 75.00% |
| Canteen | | 1 | 1 | 1 | 1 | | 1 | 1 | 75.00% |
| Ambulance | 1 | 1 | | 1 | 1 | | 1 | 1 | 75.00% |
| Periodical exams | | 1 | | 1 | 1 | 1 | 1 | 1 | 75.00% |
| Occupational gymnastics | 1 | 1 | 1 | 1 | 1 | | | 1 | 75.00% |
| Recycling packaging materials | 1 | 1 | 1 | 1 | | 1 | | 1 | 75.00% |
| Production capacity | 1 | | 1 | 1 | | 1 | 1 | | 62.50% |
| Cost | | 1 | 1 | | 1 | | 1 | 1 | 62.50% |
| Universal language (English) | | 1 | | 1 | | 1 | 1 | 1 | 62.50% |
| Sales | 1 | 1 | | | 1 | 1 | 1 | | 62.50% |
| Metal-liquid capacity | 1 | | 1 | | | 1 | 1 | 1 | 62.50% |
| Machinery and equipment | | 1 | | 1 | 1 | 1 | 1 | | 62.50% |
| Warehousing, packaging and boarding | 1 | 1 | | 1 | 1 | | 1 | | 62.50% |
| Documentation control | | 1 | 1 | 1 | 1 | 1 | | | 62.50% |
| **Criteria** | **Specialist** | | | | | | | | **Relevance (%)** |
| | **E1** | **E2** | **E3** | **E4** | **E5** | **E6** | **E7** | **E8** | |
| Wood preservation models | 1 | | | 1 | 1 | 1 | | 1 | 62.50% |
| Industrial installation | | | 1 | | 1 | | | 1 | 37.50% |
| Budgets | | 1 | 1 | | | | | | 25.00% |
| Proposals feedback | 1 | | 1 | | | | | | 25.00% |
| Manufacture of models | | | | | | 1 | 1 | | 25.00% |
| Expediting and inspection | 1 | | | | | | | 1 | 25.00% |
| Total quality | | 1 | | 1 | | | | | 25.00% |
| OSHAS 18000 | | | | | 1 | 1 | | | 25.00% |
| Security dialog | | | | | 1 | 1 | | | 25.00% |
| ISO 14000 certification | 1 | | | | | | | | 12.50% |
| Documents according to legislation | | | | | | | | 1 | 12.50% |
| Corporate health plan | | | | | | | | | 0.00% |
| Ergonomics | | | | | | | | | 0.00% |

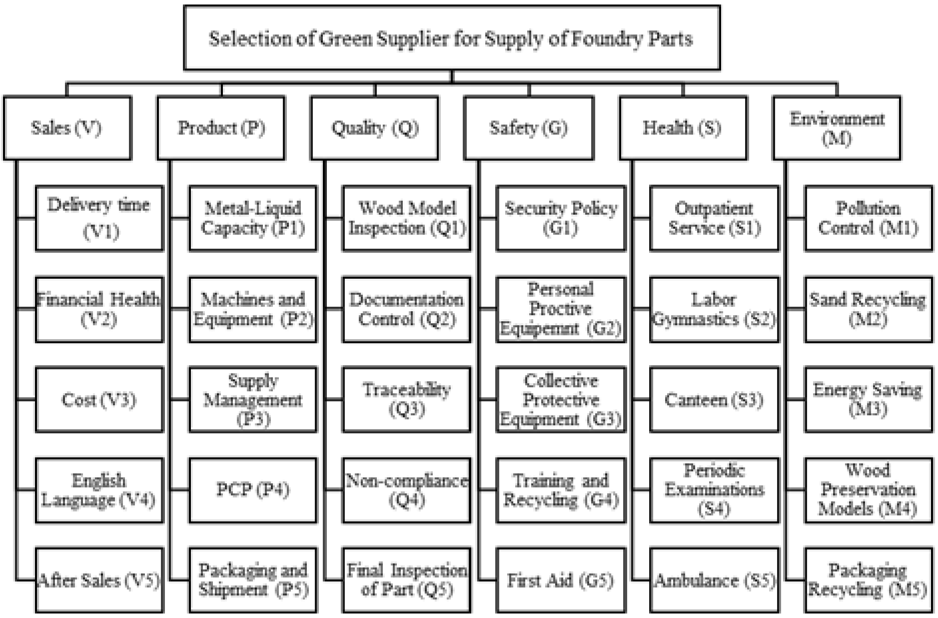
Source: The authors.

As presented below in the Figure 1, thirty criteria were considered relevant to be used in step (iv) for the selection of green suppliers in the foundry sector.

**iv. Apply the AHP method for selection of green suppliers in the foundry sector**

The criteria selected in step (iii) were organized hierarchically into six second level criteria with five sub-criteria each. The created hierarchy structure is shown in Figure 1.

**Figure 1**: Hierarchy for the selection of suppliers of cast parts




Source: The authors.

Then, the comparison matrix of the second level criteria was elaborated where the peer-to-peer comparison of the alternatives was performed by the scale defined by Saaty (1980) that ranges from 1 to 9 and it is determined from the fundamental scale. Table 4 shows the description of each weight.

**Table 4**: Basic scale of Saaty.

| Intensity of importance | Definition | Explanation |
|---|---|---|
| 1 | Equal importance | Two activities contribute equally to the objective |
| 3 | Small importance of one over the other | Experience and judgment slightly favor one activity over another |
| 5 | Essential or strong importance | Experience and judgment strongly favor one activity over another |
| 7 | Very large or demonstrated importance | An activity is strongly favored, and its dominance demonstrated in practice |

| | | |
|---|---|---|
| 9 | Absolute importance | The evidence favoring one activity over another is of the highest possible order of affirmation |
| 2,4,6,8 | Intermediate values | When compromise is needed |

Source: Adapted from Saaty (1980).

Table 5 shows the comparison matrix of the second-level criteria.

**Table 5**: Matrix of comparison of the criteria.

| Criteria | V | P | Q | G | S | M |
|---|---|---|---|---|---|---|
| **V** | 1 | 1/2 | 1/3 | 1/9 | 1/8 | 1/8 |
| **P** | 2 | 1 | 1/7 | 1/7 | 1/8 | 1/8 |
| **Q** | 3 | 7 | 1 | 1/5 | 1/5 | 1/7 |
| **G** | 9 | 7 | 5 | 1 | 1 | 1/3 |
| **S** | 8 | 8 | 5 | 1 | 1 | 1 |
| **M** | 8 | 8 | 7 | 3 | 1 | 1 |
| **Sum** | 31.0000 | 31.5000 | 18.4762 | 5.4540 | 3.4500 | 2.7262 |

Source: The authors.

After pair-to-pair comparison, the normalization of the matrix was done that is the division of each element of the matrix by the sum of the column to which it belongs. The weights obtained for each criteria were found through normalization as shown in Table 6.

**Table 6**: Standardization of criteria and weights.

| Criteria | V | P | Q | G | S | M | Weight |
|---|---|---|---|---|---|---|---|
| **V** | 0.0323 | 0.0159 | 0.0180 | 0.0204 | 0.0362 | 0.0459 | 2.81% |
| **P** | 0.0645 | 0.0317 | 0.0077 | 0.0262 | 0.0362 | 0.0459 | 3.54% |
| **Q** | 0.0968 | 0.2222 | 0.0541 | 0.0367 | 0.0580 | 0.0524 | 8.67% |
| **G** | 0.2903 | 0.2222 | 0.2706 | 0.1834 | 0.2899 | 0.1223 | 22.98% |
| **S** | 0.2581 | 0.2540 | 0.2706 | 0.1834 | 0.2899 | 0.3668 | 27.04% |
| **M** | 0.2581 | 0.2540 | 0.3789 | 0.5501 | 0.2899 | 0.3668 | 34.96% |
| **Sum** | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 |

Source: The authors.

The weights obtained for the criteria of safety (22.98%) and health (27.04%) were evaluated with greater importance, while the criterion of environment (34.96%) was of great importance. The remaining criteria were of low importance (below 10%).

In the sequence, to ensure the consistency of the comparisons, the consistency index (CI) and consistency ratio (RC) calculations were performed.

As a rule, a consistency ratio less than 0.10 is considered acceptable, that is, when the CI value is 10% or less than the respective random index. In the case of CR shows unsatisfactory, the comparisons referring to this matrix should be reviewed again. Table 7 shows the data for the consistency analysis of the criteria.

**Table 7**: Criterion consistency analysis.

| lmax | IC | RC | Analyze |
|---|---|---|---|
| 6.5411 | 0.1082 | 0.0966 | Acceptable inconsistency |

Source: The authors.

It is observed in Table 7 that the result obtained is RC < 0.1, so a good level of consistency is guaranteed. Table 8 shows the data for the consistency analysis of the sub-criteria.

**Table 8**: Consistency analysis of sub-criterion.

| Criteria | Sub-criterion | λmax | IC | RC | Analyze |
|---|---|---|---|---|---|
| Sales | V1, V2, V3, V4, V5 | 5.4212 | 0.1053 | 0.0940 | Acceptable inconsistency |
| Product | P1, P2, P3, P4, P5 | 5.4485 | 0.1027 | 0.0917 | Acceptable inconsistency |
| Quality | Q1, Q2, Q3, Q4, Q5 | 5.2066 | 0.0517 | 0.0461 | Acceptable inconsistency |
| Safety | G1, G2, G3, G4, G5 | 5.4377 | 0.1094 | 0.0977 | Acceptable inconsistency |
| Health | S1, S2, S3, S4, S5 | 5.4319 | 0.1080 | 0.0964 | Acceptable inconsistency |
| Environment | M1, M2, M3, M4, M5 | 5.2434 | 0.0609 | 0.0543 | Acceptable inconsistency |

Source: The authors.

As shown in Table 8, all results obtained were RC < 0.1, so a good level of consistency is guaranteed for all sub-criteria.

Subsequently, the comparation matrix of the alternatives was set up according to each sub-criterion and for five suppliers. Suppliers were named sequentially from F1 to F5.

Table 9 shows the analysis performed for the sub-criterion delivery time.

**Table 9**: Comparison of alternatives between suppliers - delivery time.

| Matrix of comparison of the alternatives according to Delivery time | | | | | | Normalization | | | | | Weight |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | F1 | F2 | F3 | F4 | F5 | F1 | F2 | F3 | F4 | F5 | |
| F1 | 1 | 1/4 | 2 | 1/3 | 3 | 0.1132 | 0.0612 | 0.3000 | 0.0625 | 0.2727 | 16.19% |
| F2 | 4 | 1 | 3 | 1/2 | 2 | 0.4528 | 0.2449 | 0.4500 | 0.0938 | 0.1818 | 28.47% |
| F3 | 1/2 | 1/3 | 1 | 3 | 3 | 0.0566 | 0.0816 | 0.1500 | 0.5625 | 0.2727 | 22.47% |
| F4 | 3 | 2 | 1/3 | 1 | 2 | 0.3396 | 0.4898 | 0.0500 | 0.1875 | 0.1818 | 24.97% |
| F5 | 1/3 | 1/2 | 1/3 | 1/2 | 1 | 0.0377 | 0.1224 | 0.0500 | 0.0938 | 0.0909 | 7.90% |
| | 8.8333 | 4.0833 | 6.6667 | 5.3333 | 11.0000 | | | | | | |

Source: The authors.

Table 10 shows the analysis performed for the sub-criterion financial health.

**Table 10**: Comparison of alternatives between suppliers - financial health.

| Matrix of comparison of the alternatives according to Financial Health | | | | | | Normalization | | | | | Weight |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | F1 | F2 | F3 | F4 | F5 | F1 | F2 | F3 | F4 | F5 | |
| F1 | 1 | 2 | 3 | 3 | 1/2 | 0.2400 | 0.2553 | 0.4286 | 0.3243 | 0.0732 | 0.2643 |
| F2 | 1/2 | 1 | 2 | 1/4 | 3 | 0.1200 | 0.1277 | 0.2857 | 0.0270 | 0.4390 | 0.1999 |
| F3 | 1/3 | 1/2 | 1 | 2 | 2 | 0.0800 | 0.0638 | 0.1429 | 0.2162 | 0.2927 | 0.1591 |
| F4 | 1/3 | 4 | 1/2 | 1 | 1/3 | 0.0800 | 0.5106 | 0.0714 | 0.1081 | 0.0488 | 0.1638 |
| F5 | 2 | 1/3 | 1/2 | 3 | 1 | 0.4800 | 0.0426 | 0.0714 | 0.3243 | 0.1463 | 0.2129 |
| | 4 | 8 | 7 | 9 | 7 | | | | | | |

Source: The authors.

Table 11 shows the analysis performed for the sub-criterion cost.

**Table 11**: Comparison of alternatives between suppliers - cost.

| Matrix of comparison of the alternatives according to Cost | | | | | | Normalization | | | | | Weight |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | F1 | F2 | F3 | F4 | F5 | F1 | F2 | F3 | F4 | F5 | |
| F1 | 1 | 4 | 1/4 | 3 | 2 | 0.1644 | 0.3902 | 0.0492 | 0.2927 | 0.2553 | 0.2304 |
| F2 | 1/4 | 1 | 1/3 | 4 | 1/2 | 0.0411 | 0.0976 | 0.0656 | 0.3902 | 0.0638 | 0.1317 |
| F3 | 4 | 3 | 1 | 2 | 1/3 | 0.6575 | 0.2927 | 0.1967 | 0.1951 | 0.0426 | 0.2769 |
| F4 | 1/3 | 1/4 | 1/2 | 1 | 4 | 0.0548 | 0.0244 | 0.0984 | 0.0976 | 0.5106 | 0.1571 |
| F5 | 1/2 | 2 | 3 | 1/4 | 1 | 0.0822 | 0.1951 | 0.5902 | 0.0244 | 0.1277 | 0.2039 |
| | 6 | 10 | 5 | 10 | 8 | | | | | | |

Source: The authors.

Table 12 shows the analysis performed for the sub-criterion English language.

**Table 12**: Comparison of alternatives between suppliers - English language.

| Matrix of comparison of the alternatives according to English Language | | | | | | Normalization | | | | | Weight |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | F1 | F2 | F3 | F4 | F5 | F1 | F2 | F3 | F4 | F5 | |
| F1 | 1 | 1/2 | 2 | 2 | 1/4 | 0.1250 | 0.0822 | 0.2500 | 0.2424 | 0.0380 | 0.1475 |
| F2 | 2 | 1 | 4 | 1/4 | 3 | 0.2500 | 0.1644 | 0.5000 | 0.0303 | 0.4557 | 0.2801 |
| F3 | 1/2 | 1/4 | 1 | 2 | 2 | 0.0625 | 0.0411 | 0.1250 | 0.2424 | 0.3038 | 0.1550 |
| F4 | 1/2 | 4 | 1/2 | 1 | 1/3 | 0.0625 | 0.6575 | 0.0625 | 0.1212 | 0.0506 | 0.1909 |
| F5 | 4 | 1/3 | 1/2 | 3 | 1 | 0.5000 | 0.0548 | 0.0625 | 0.3636 | 0.1519 | 0.2266 |
| | 8 | 6 | 8 | 8 | 7 | | | | | | |

Source: The authors.

Table 13 shows the analysis performed for the sub-criterion after sales.

**Table 13**: Comparison of alternatives between suppliers - after sales.

| **Matrix of comparison of the alternatives according to After Sales** | | | | | | **Normalization** | | | | | **Weight** |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | F1 | F2 | F3 | F4 | F5 | F1 | F2 | F3 | F4 | F5 | |
| F1 | 1 | 2 | 1/4 | 3 | 1/3 | 0.1132 | 0.3582 | 0.0588 | 0.2857 | 0.0488 | 0.1729 |
| F2 | 1/2 | 1 | 1/2 | 4 | 3 | 0.0566 | 0.1791 | 0.1176 | 0.3810 | 0.4390 | 0.2347 |
| F3 | 4 | 2 | 1 | 1/2 | 2 | 0.4528 | 0.3582 | 0.2353 | 0.0476 | 0.2927 | 0.2773 |
| F4 | 1/3 | 1/4 | 2 | 1 | 1/2 | 0.0377 | 0.0448 | 0.4706 | 0.0952 | 0.0732 | 0.1443 |
| F5 | 3 | 1/3 | 1/2 | 2 | 1 | 0.3396 | 0.0597 | 0.1176 | 0.1905 | 0.1463 | 0.1708 |
| | 9 | 6 | 4 | 11 | 7 | | | | | | |

Source: The authors.

Table 14 shows the analysis performed for the sub-criterion metal capacity.

**Table 14**: Comparison of alternatives between suppliers - metal liquid.

| **Matrix of comparison of the alternatives according to Metal Liquid** | | | | | | **Normalization** | | | | | **Weight** |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | F1 | F2 | F3 | F4 | F5 | F1 | F2 | F3 | F4 | F5 | |
| F1 | 1 | 2 | 1/2 | 4 | 4 | 0.2500 | 0.5106 | 0.0769 | 0.2857 | 0.3902 | 0.3027 |
| F2 | 1/2 | 1 | 4 | 3 | 3 | 0.1250 | 0.2553 | 0.6154 | 0.2143 | 0.2927 | 0.3005 |
| F3 | 2 | 1/4 | 1 | 2 | 2 | 0.5000 | 0.0638 | 0.1538 | 0.1429 | 0.1951 | 0.2111 |
| F4 | 1/4 | 1/3 | 1/2 | 1 | 1/4 | 0.0625 | 0.0851 | 0.0769 | 0.0714 | 0.0244 | 0.0641 |
| F5 | 1/4 | 1/3 | 1/2 | 4 | 1 | 0.0625 | 0.0851 | 0.0769 | 0.2857 | 0.0976 | 0.1216 |
| | 4 | 4 | 7 | 14 | 10 | | | | | | |

Source: The authors.

Table 15 shows the analysis performed for the sub-criterion machines and equipment.

**Table 15**: Comparison of alternatives between suppliers - machines and equipment.

| **Matrix of comparison of the alternatives according to Machines and Equipment** | | | | | | **Normalization** | | | | | **Weight** |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | F1 | F2 | F3 | F4 | F5 | F1 | F2 | F3 | F4 | F5 | |
| F1 | 1 | 1/2 | 3 | 4 | 3 | 0.2553 | 0.0714 | 0.3830 | 0.5217 | 0.2903 | 0.3044 |
| F2 | 2 | 1 | 1/2 | 2 | 1/3 | 0.5106 | 0.1429 | 0.0638 | 0.2609 | 0.0323 | 0.2021 |
| F3 | 1/3 | 2 | 1 | 1/3 | 3 | 0.0851 | 0.2857 | 0.1277 | 0.0435 | 0.2903 | 0.1665 |
| F4 | 1/4 | 1/2 | 3 | 1 | 3 | 0.0638 | 0.0714 | 0.3830 | 0.1304 | 0.2903 | 0.1878 |
| F5 | 1/3 | 3 | 1/3 | 1/3 | 1 | 0.0851 | 0.4286 | 0.0426 | 0.0435 | 0.0968 | 0.1393 |
| | 4 | 7 | 8 | 8 | 10 | | | | | | |

Source: The authors.

Table 16 shows the analysis performed for the sub-criterion supply management.

**Table 16**: Comparison of alternatives between suppliers - supply management.

| Matrix of comparison of the alternatives according to Supply Management | | | | | | Normalization | | | | | Weight |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | F1 | F2 | F3 | F4 | F5 | F1 | F2 | F3 | F4 | F5 | |
| F1 | 1 | 2 | 1/2 | 2 | 2 | 0.2222 | 0.4211 | 0.0732 | 0.2927 | 0.1935 | 0.2405 |
| F2 | 1/2 | 1 | 2 | 1/2 | 4 | 0.1111 | 0.2105 | 0.2927 | 0.0732 | 0.3871 | 0.2149 |
| F3 | 2 | 1/2 | 1 | 3 | 1/3 | 0.4444 | 0.1053 | 0.1463 | 0.4390 | 0.0323 | 0.2335 |
| F4 | 1/2 | 1 | 1/3 | 1 | 3 | 0.1111 | 0.2105 | 0.0488 | 0.1463 | 0.2903 | 0.1614 |
| F5 | 1/2 | 1/4 | 3 | 1/3 | 1 | 0.1111 | 0.0526 | 0.4390 | 0.0488 | 0.0968 | 0.1497 |
| | 5 | 5 | 7 | 7 | 10 | | | | | | |

Source: The authors.

Table 17 shows the analysis performed for the sub-criterion PCP.

**Table 17**: Comparison of alternatives between suppliers - PCP.

| Matrix of comparison of the alternatives according to PCP | | | | | | Normalization | | | | | Weight |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | F1 | F2 | F3 | F4 | F5 | F1 | F2 | F3 | F4 | F5 | |
| F1 | 1 | 2 | 2 | 3 | 1/3 | 0.1875 | 0.2637 | 0.5000 | 0.2143 | 0.0435 | 0.2418 |
| F2 | 1/2 | 1 | 1/4 | 3 | 4 | 0.0938 | 0.1319 | 0.0625 | 0.2143 | 0.5217 | 0.2048 |
| F3 | 1/2 | 4 | 1 | 4 | 2 | 0.0938 | 0.5275 | 0.2500 | 0.2857 | 0.2609 | 0.2836 |
| F4 | 1/3 | 1/3 | 1/4 | 1 | 1/3 | 0.0625 | 0.0440 | 0.0625 | 0.0714 | 0.0435 | 0.0568 |
| F5 | 3 | 1/4 | 1/2 | 3 | 1 | 0.5625 | 0.0330 | 0.1250 | 0.2143 | 0.1304 | 0.2130 |
| | 5 | 8 | 4 | 14 | 8 | | | | | | |

Source: The authors.

Table 18 shows the analysis performed for the sub-criterion packaging and shipment.

**Table 18**: Comparison of alternatives between suppliers - packaging and shipment.

| Matrix of comparison of the alternatives according to Packaging and Shipment | | | | | | Normalization | | | | | Weight |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | F1 | F2 | F3 | F4 | F5 | F1 | F2 | F3 | F4 | F5 | |
| F1 | 1 | 1/4 | 1/3 | 3 | 4 | 0.1165 | 0.0638 | 0.0800 | 0.2500 | 0.4444 | 0.1910 |
| F2 | 4 | 1 | 1/2 | 3 | 3 | 0.4660 | 0.2553 | 0.1200 | 0.2500 | 0.3333 | 0.2849 |
| F3 | 3 | 2 | 1 | 3 | 1/2 | 0.3495 | 0.5106 | 0.2400 | 0.2500 | 0.0556 | 0.2811 |
| F4 | 1/3 | 1/3 | 1/3 | 1 | 1/2 | 0.0388 | 0.0851 | 0.0800 | 0.0833 | 0.0556 | 0.0686 |
| F5 | 1/4 | 1/3 | 2 | 2 | 1 | 0.0291 | 0.0851 | 0.4800 | 0.1667 | 0.1111 | 0.1744 |
| | 9 | 4 | 4 | 12 | 9 | | | | | | |

Source: The authors.

Table 19 shows the analysis performed for the sub-criterion wood model inspection.

**Table 19**: Comparison of alternatives between suppliers - wood model inspection.

| Matrix of comparison of the alternatives according to Wood Model Inspection | | | | | | Normalization | | | | | Weight |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | F1 | F2 | F3 | F4 | F5 | F1 | F2 | F3 | F4 | F5 | |
| F1 | 1 | 1/2 | 3 | 4 | 2 | 0.2449 | 0.0588 | 0.5806 | 0.4528 | 0.2353 | 0.3145 |
| F2 | 2 | 1 | 1/2 | 1/3 | 1/2 | 0.4898 | 0.1176 | 0.0968 | 0.0377 | 0.0588 | 0.1602 |
| F3 | 1/3 | 2 | 1 | 3 | 3 | 0.0816 | 0.2353 | 0.1935 | 0.3396 | 0.3529 | 0.2406 |
| F4 | 1/4 | 3 | 1/3 | 1 | 2 | 0.0612 | 0.3529 | 0.0645 | 0.1132 | 0.2353 | 0.1654 |
| F5 | 1/2 | 2 | 1/3 | 1/2 | 1 | 0.1224 | 0.2353 | 0.0645 | 0.0566 | 0.1176 | 0.1193 |
| | 4 | 9 | 5 | 9 | 9 | | | | | | |

Source: The authors.

Table 20 shows the analysis performed for the sub-criterion documentation control.

**Table 20**: Comparison of alternatives between suppliers - documentation control.

| Matrix of comparison of the alternatives according to Documentation Control | | | | | | Normalization | | | | | Weight |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | F1 | F2 | F3 | F4 | F5 | F1 | F2 | F3 | F4 | F5 | |
| F1 | 1 | 4 | 3 | 2 | 2 | 0.3871 | 0.3200 | 0.3214 | 0.2424 | 0.4800 | 0.3502 |
| F2 | 1/4 | 1 | 2 | 1/4 | 1/3 | 0.0968 | 0.0800 | 0.2143 | 0.0303 | 0.0800 | 0.1003 |
| F3 | 1/3 | 1/2 | 1 | 3 | 1/3 | 0.1290 | 0.0400 | 0.1071 | 0.3636 | 0.0800 | 0.1440 |
| F4 | 1/2 | 4 | 1/3 | 1 | 1/2 | 0.1935 | 0.3200 | 0.0357 | 0.1212 | 0.1200 | 0.1581 |
| F5 | 1/2 | 3 | 3 | 2 | 1 | 0.1935 | 0.2400 | 0.3214 | 0.2424 | 0.2400 | 0.2475 |
| | 3 | 13 | 9 | 8 | 4 | | | | | | |

Source: The authors.

Table 21 shows the analysis performed for the sub-criterion traceability.

**Table 21**: Comparison of alternatives between suppliers - traceability.

| Matrix of comparison of the alternatives according to Traceability | | | | | | Normalization | | | | | Weight |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | F1 | F2 | F3 | F4 | F5 | F1 | F2 | F3 | F4 | F5 | |
| F1 | 1 | 2 | 3 | 3 | 4 | 0.4138 | 0.2667 | 0.2647 | 0.3956 | 0.3243 | 0.3330 |
| F2 | 1/2 | 1 | 4 | 1/4 | 4 | 0.2069 | 0.1333 | 0.3529 | 0.0330 | 0.3243 | 0.2101 |
| F3 | 1/3 | 1/4 | 1 | 1/3 | 3 | 0.1379 | 0.0333 | 0.0882 | 0.0440 | 0.2432 | 0.1093 |
| F4 | 1/3 | 4 | 3 | 1 | 1/3 | 0.1379 | 0.5333 | 0.2647 | 0.1319 | 0.0270 | 0.2190 |
| F5 | 1/4 | 1/4 | 1/3 | 3 | 1 | 0.1034 | 0.0333 | 0.0294 | 0.3956 | 0.0811 | 0.1286 |
| | 2 | 8 | 11 | 8 | 12 | | | | | | |

Source: The authors.

Table 22 shows the analysis performed for the sub-criterion non-compliance.

**Table 22**: Comparison of alternatives between suppliers - non-compliance.

| Matrix of comparison of the alternatives according to Non-compliance | | | | | | Normalization | | | | | Weight |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | F1 | F2 | F3 | F4 | F5 | F1 | F2 | F3 | F4 | F5 | |
| F1 | 1 | 2 | 1/3 | 4 | 5 | 0.2020 | 0.2553 | 0.0800 | 0.3333 | 0.5128 | 0.2767 |
| F2 | 1/2 | 1 | 2 | 3 | 1/4 | 0.1010 | 0.1277 | 0.4800 | 0.2500 | 0.0256 | 0.1969 |
| F3 | 3 | 1/2 | 1 | 2 | 3 | 0.6061 | 0.0638 | 0.2400 | 0.1667 | 0.3077 | 0.2768 |
| F4 | 1/4 | 1/3 | 1/2 | 1 | 1/2 | 0.0505 | 0.0426 | 0.1200 | 0.0833 | 0.0513 | 0.0695 |
| F5 | 1/5 | 4 | 1/3 | 2 | 1 | 0.0404 | 0.5106 | 0.0800 | 0.1667 | 0.1026 | 0.1801 |
| | 5 | 8 | 4 | 12 | 10 | | | | | | |

Source: The authors.

Table 23 shows the analysis performed for the sub-criterion final inspection of part.

**Table 23**: Comparison of alternatives between suppliers - final inspection of part.

| Matrix of comparison of the alternatives according to Final Inspection of Part | | | | | | Normalization | | | | | Weight |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | F1 | F2 | F3 | F4 | F5 | F1 | F2 | F3 | F4 | F5 | |
| F1 | 1 | 1/3 | 2 | 3 | 4 | 0.1967 | 0.0385 | 0.1778 | 0.3495 | 0.4688 | 0.2462 |
| F2 | 3 | 1 | 3 | 1/4 | 1/3 | 0.5902 | 0.1154 | 0.2667 | 0.0291 | 0.0391 | 0.2081 |
| F3 | 1/2 | 1/3 | 1 | 4 | 1/5 | 0.0984 | 0.0385 | 0.0889 | 0.4660 | 0.0234 | 0.1430 |
| F4 | 1/3 | 4 | 1/4 | 1 | 3 | 0.0656 | 0.4615 | 0.0222 | 0.1165 | 0.3516 | 0.2035 |
| F5 | 1/4 | 3 | 5 | 1/3 | 1 | 0.0492 | 0.3462 | 0.4444 | 0.0388 | 0.1172 | 0.1992 |
| | 5 | 9 | 11 | 9 | 9 | | | | | | |

Source: The authors.

Table 24 shows the analysis performed for the sub-criterion security policy.

**Table 24:** Comparison of alternatives between suppliers - security policy.

| Matrix of comparison of the alternatives according to Security Policy | | | | | | Normalization | | | | | Weight |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | F1 | F2 | F3 | F4 | F5 | F1 | F2 | F3 | F4 | F5 | |
| F1 | 1 | 3 | 3 | 3 | 3 | 0.4286 | 0.3750 | 0.3000 | 0.4286 | 0.4390 | 0.3942 |
| F2 | 1/3 | 1 | 2 | 2 | 1/3 | 0.1429 | 0.1250 | 0.2000 | 0.2857 | 0.0488 | 0.1605 |
| F3 | 1/3 | 1/2 | 1 | 1/2 | 1/2 | 0.1429 | 0.0625 | 0.1000 | 0.0714 | 0.0732 | 0.0900 |
| F4 | 1/3 | 1/2 | 2 | 1 | 2 | 0.1429 | 0.0625 | 0.2000 | 0.1429 | 0.2927 | 0.1682 |
| F5 | 1/3 | 3 | 2 | 1/2 | 1 | 0.1429 | 0.3750 | 0.2000 | 0.0714 | 0.1463 | 0.1871 |
| | 2 | 8 | 10 | 7 | 7 | | | | | | |

Source: The authors.

Table 25 shows the analysis performed for the sub-criterion for individual safety equipment.

**Table 25**: Comparison of alternatives between suppliers - personal protective equipment.

| Matrix of comparison of the alternatives according to Personal Protective Equipment | | | | | | Normalization | | | | | Weight |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | F1 | F2 | F3 | F4 | F5 | F1 | F2 | F3 | F4 | F5 | |
| F1 | 1 | 3 | 2 | 2 | 2 | 0.3529 | 0.6000 | 0.2857 | 0.2424 | 0.1667 | 0.3295 |
| F2 | 1/3 | 1 | 3 | 3 | 3 | 0.1176 | 0.2000 | 0.4286 | 0.3636 | 0.2500 | 0.2720 |
| F3 | 1/2 | 1/3 | 1 | 2 | 2 | 0.1765 | 0.0667 | 0.1429 | 0.2424 | 0.1667 | 0.1590 |
| F4 | 1/2 | 1/3 | 1/2 | 1 | 4 | 0.1765 | 0.0667 | 0.0714 | 0.1212 | 0.3333 | 0.1538 |
| F5 | 1/2 | 1/3 | 1/2 | 1/4 | 1 | 0.1765 | 0.0667 | 0.0714 | 0.0303 | 0.0833 | 0.0856 |
| | 3 | 5 | 7 | 8 | 12 | | | | | | |

Source: The authors.

Table 26 shows the analysis performed for the sub-criterion collective protection equipment.

**Table 26**: Comparison of alternatives between suppliers - collective protection equipment.

| Matrix of comparison of the alternatives according to Collective Protective Equipment | | | | | | Normalization | | | | | Weight |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | F1 | F2 | F3 | F4 | F5 | F1 | F2 | F3 | F4 | F5 | |
| F1 | 1 | 3 | 3 | 4 | 2 | 0.4138 | 0.5455 | 0.4286 | 0.4286 | 0.2000 | 0.4033 |
| F2 | 1/3 | 1 | 2 | 2 | 2 | 0.1379 | 0.1818 | 0.2857 | 0.2143 | 0.2000 | 0.2039 |
| F3 | 1/3 | 1/2 | 1 | 2 | 2 | 0.1379 | 0.0909 | 0.1429 | 0.2143 | 0.2000 | 0.1572 |
| F4 | 1/4 | 1/2 | 1/2 | 1 | 3 | 0.1034 | 0.0909 | 0.0714 | 0.1071 | 0.3000 | 0.1346 |
| F5 | 1/2 | 1/2 | 1/2 | 1/3 | 1 | 0.2069 | 0.0909 | 0.0714 | 0.0357 | 0.1000 | 0.1010 |
| | 2 | 6 | 7 | 9 | 10 | | | | | | |

Source: The authors.

Table 27 shows the analysis performed for the sub-criterion training and recycling.

**Table 27**: Comparison of alternatives between suppliers - training and recycling.

| Matrix of comparison of the alternatives according to Training and Recycling | | | | | | Normalization | | | | | Weight |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | F1 | F2 | F3 | F4 | F5 | F1 | F2 | F3 | F4 | F5 | |
| F1 | 1 | 3 | 4 | 4 | 2 | 0.4286 | 0.5806 | 0.4706 | 0.3200 | 0.1818 | 0.3963 |
| F2 | 1/3 | 1 | 3 | 3 | 2 | 0.1429 | 0.1935 | 0.3529 | 0.2400 | 0.1818 | 0.2222 |
| F3 | 1/4 | 1/3 | 1 | 4 | 4 | 0.1071 | 0.0645 | 0.1176 | 0.3200 | 0.3636 | 0.1946 |
| F4 | 1/4 | 1/3 | 1/4 | 1 | 2 | 0.1071 | 0.0645 | 0.0294 | 0.0800 | 0.1818 | 0.0926 |
| F5 | 1/2 | 1/2 | 1/4 | 1/2 | 1 | 0.2143 | 0.0968 | 0.0294 | 0.0400 | 0.0909 | 0.0943 |
| | 2 | 5 | 9 | 13 | 11 | | | | | | |

Source: The authors.

Table 28 shows the analysis performed for the sub-criterion first aid.

**Table 28**: Comparison of alternatives between suppliers - first aid.

| Matrix of comparison of the alternatives according to First Aid | | | | | | Normalization | | | | | Weight |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | F1 | F2 | F3 | F4 | F5 | F1 | F2 | F3 | F4 | F5 | |
| F1 | 1 | 1/4 | 1/3 | 1/2 | 2 | 0.0952 | 0.1071 | 0.0800 | 0.0732 | 0.1538 | 0.1019 |
| F2 | 4 | 1 | 2 | 3 | 4 | 0.3810 | 0.4286 | 0.4800 | 0.4390 | 0.3077 | 0.4072 |
| F3 | 3 | 1/2 | 1 | 2 | 3 | 0.2857 | 0.2143 | 0.2400 | 0.2927 | 0.2308 | 0.2527 |
| F4 | 2 | 1/3 | 1/2 | 1 | 3 | 0.1905 | 0.1429 | 0.1200 | 0.1463 | 0.2308 | 0.1661 |
| F5 | 1/2 | 1/4 | 1/3 | 1/3 | 1 | 0.0476 | 0.1071 | 0.0800 | 0.0488 | 0.0769 | 0.0721 |
| | 11 | 2 | 4 | 7 | 13 | | | | | | |

Source: The authors.

Table 29 shows the analysis performed for the sub-criterion outpatient service.

**Table 29**: Comparison of alternatives between suppliers - outpatient service.

| Matrix of comparison of the alternatives according to Outpatient Service | | | | | | Normalization | | | | | Weight |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | F1 | F2 | F3 | F4 | F5 | F1 | F2 | F3 | F4 | F5 | |
| F1 | 1 | 2 | 2 | 1/4 | 1/4 | 0.1000 | 0.1818 | 0.4800 | 0.0612 | 0.0370 | 0.1720 |
| F2 | 1/2 | 1 | 1/3 | 1/3 | 1/2 | 0.0500 | 0.0909 | 0.0800 | 0.0816 | 0.0741 | 0.0753 |
| F3 | 1/2 | 3 | 1 | 2 | 3 | 0.0500 | 0.2727 | 0.2400 | 0.4898 | 0.4444 | 0.2994 |
| F4 | 4 | 3 | 1/2 | 1 | 2 | 0.4000 | 0.2727 | 0.1200 | 0.2449 | 0.2963 | 0.2668 |
| F5 | 4 | 2 | 1/3 | 1/2 | 1 | 0.4000 | 0.1818 | 0.0800 | 0.1224 | 0.1481 | 0.1865 |
| | 10 | 11 | 4 | 4 | 7 | | | | | | |

Source: The authors.

Table 30 shows the analysis performed for the sub-criterion labor gymnastics.

**Table 30**: Comparison of alternatives between suppliers - labor gymnastics.

| Matrix of comparison of the alternatives according to Labor Gymnastics | | | | | | Normalization | | | | | Weight |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | F1 | F2 | F3 | F4 | F5 | F1 | F2 | F3 | F4 | F5 | |
| F1 | 1 | 3 | 4 | 4 | 1/3 | 0.2069 | 0.3830 | 0.3810 | 0.4211 | 0.0800 | 0.2944 |
| F2 | 1/3 | 1 | 3 | 2 | 1/3 | 0.0690 | 0.1277 | 0.2857 | 0.2105 | 0.0800 | 0.1546 |
| F3 | 1/4 | 1/3 | 1 | 2 | 1/2 | 0.0517 | 0.0426 | 0.0952 | 0.2105 | 0.1200 | 0.1040 |
| F4 | 1/4 | 1/2 | 1/2 | 1 | 2 | 0.0517 | 0.0638 | 0.0476 | 0.1053 | 0.4800 | 0.1497 |
| F5 | 3 | 3 | 2 | 1/2 | 1 | 0.6207 | 0.3830 | 0.1905 | 0.0526 | 0.2400 | 0.2974 |
| | 5 | 8 | 11 | 10 | 4 | | | | | | |

Source: The authors.

Table 31 shows the analysis performed for the sub-criterion inside restaurants.

**Table 31**: Comparison of alternatives between suppliers - canteen.

| Matrix of comparison of the alternatives according to Canteen | | | | | | Normalization | | | | | Weight |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | F1 | F2 | F3 | F4 | F5 | F1 | F2 | F3 | F4 | F5 | |
| F1 | 1 | 4 | 4 | 2 | 2 | 0.4000 | 0.6154 | 0.5217 | 0.1818 | 0.2400 | 0.3918 |
| F2 | 1/4 | 1 | 2 | 2 | 2 | 0.1000 | 0.1538 | 0.2609 | 0.1818 | 0.2400 | 0.1873 |
| F3 | 1/4 | 1/2 | 1 | 3 | 3 | 0.1000 | 0.0769 | 0.1304 | 0.2727 | 0.3600 | 0.1880 |
| F4 | 1/2 | 1/2 | 1/3 | 1 | 1/3 | 0.2000 | 0.0769 | 0.0435 | 0.0909 | 0.0400 | 0.0903 |
| F5 | 1/2 | 1/2 | 1/3 | 3 | 1 | 0.2000 | 0.0769 | 0.0435 | 0.2727 | 0.1200 | 0.1426 |
| | 3 | 7 | 8 | 11 | 8 | | | | | | |

Source: The authors.

Table 32 shows the analysis performed for the sub-criterion periodic examinations.

**Table 32**: Comparison of alternatives between suppliers - periodic examinations.

| Matrix of comparison of the alternatives according to Periodic Examinations | | | | | | Normalization | | | | | Weight |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | F1 | F2 | F3 | F4 | F5 | F1 | F2 | F3 | F4 | F5 | |
| F1 | 1 | 2 | 2 | 2 | 4 | 0.3636 | 0.4444 | 0.3333 | 0.2727 | 0.3333 | 0.3495 |
| F2 | 1/2 | 1 | 2 | 2 | 2 | 0.1818 | 0.2222 | 0.3333 | 0.2727 | 0.1667 | 0.2354 |
| F3 | 1/2 | 1/2 | 1 | 2 | 2 | 0.1818 | 0.1111 | 0.1667 | 0.2727 | 0.1667 | 0.1798 |
| F4 | 1/2 | 1/2 | 1/2 | 1 | 3 | 0.1818 | 0.1111 | 0.0833 | 0.1364 | 0.2500 | 0.1525 |
| F5 | 1/4 | 1/2 | 1/2 | 1/3 | 1 | 0.0909 | 0.1111 | 0.0833 | 0.0455 | 0.0833 | 0.0828 |
| | 3 | 5 | 6 | 7 | 12 | | | | | | |

Source: The authors.

Table 33 shows the analysis performed for the sub-criterion ambulance.

**Table 33**: Comparison of alternatives between suppliers - ambulance.

| Matrix of comparison of the alternatives according to Ambulance | | | | | | Normalization | | | | | Weight |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | F1 | F2 | F3 | F4 | F5 | F1 | F2 | F3 | F4 | F5 | |
| F1 | 1 | 2 | 2 | 2 | 2 | 0.3333 | 0.4444 | 0.3333 | 0.2667 | 0.2222 | 0.3200 |
| F2 | 1/2 | 1 | 2 | 2 | 2 | 0.1667 | 0.2222 | 0.3333 | 0.2667 | 0.2222 | 0.2422 |
| F3 | 1/2 | 1/2 | 1 | 2 | 2 | 0.1667 | 0.1111 | 0.1667 | 0.2667 | 0.2222 | 0.1867 |
| F4 | 1/2 | 1/2 | 1/2 | 1 | 2 | 0.1667 | 0.1111 | 0.0833 | 0.1333 | 0.2222 | 0.1433 |
| F5 | 1/2 | 1/2 | 1/2 | 1/2 | 1 | 0.1667 | 0.1111 | 0.0833 | 0.0667 | 0.1111 | 0.1078 |
| | 3 | 5 | 6 | 8 | 9 | | | | | | |

Source: The authors.

Table 34 shows the analysis performed for the sub-criterion pollution control.

**Table 34**: Comparison of alternatives between suppliers - pollution control.

| Matrix of comparison of the alternatives according to Pollution Control | | | | | | Normalization | | | | | Weight |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | F1 | F2 | F3 | F4 | F5 | F1 | F2 | F3 | F4 | F5 | |
| F1 | 1 | 3 | 4 | 4 | 4 | 0.4800 | 0.6102 | 0.4660 | 0.3243 | 0.2667 | 0.4294 |
| F2 | 1/3 | 1 | 3 | 4 | 3 | 0.1600 | 0.2034 | 0.3495 | 0.3243 | 0.2000 | 0.2474 |
| F3 | 1/4 | 1/3 | 1 | 3 | 4 | 0.1200 | 0.0678 | 0.1165 | 0.2432 | 0.2667 | 0.1628 |
| F4 | 1/4 | 1/4 | 1/3 | 1 | 3 | 0.1200 | 0.0508 | 0.0388 | 0.0811 | 0.2000 | 0.0982 |
| F5 | 1/4 | 1/3 | 1/4 | 1/3 | 1 | 0.1200 | 0.0678 | 0.0291 | 0.0270 | 0.0667 | 0.0621 |
| | 2 | 5 | 9 | 12 | 15 | | | | | | |

Source: The authors.

Table 35 shows the analysis performed for the sub-criterion sand recycling.

**Table 35**: Comparison of alternatives between suppliers - sand recycling.

| Matrix of comparison of the alternatives according to Sand Recycling | | | | | | Normalization | | | | | Weight |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | F1 | F2 | F3 | F4 | F5 | F1 | F2 | F3 | F4 | F5 | |
| F1 | 1 | 3 | 3 | 4 | 4 | 0.4615 | 0.6316 | 0.3396 | 0.2857 | 0.3243 | 0.4086 |
| F2 | 1/3 | 1 | 4 | 4 | 4 | 0.1538 | 0.2105 | 0.4528 | 0.2857 | 0.3243 | 0.2854 |
| F3 | 1/3 | 1/4 | 1 | 2 | 3 | 0.1538 | 0.0526 | 0.1132 | 0.1429 | 0.2432 | 0.1412 |
| F4 | 1/4 | 1/4 | 1/2 | 1 | 1/3 | 0.1154 | 0.0526 | 0.0566 | 0.0714 | 0.0270 | 0.0646 |
| F5 | 1/4 | 1/4 | 1/3 | 3 | 1 | 0.1154 | 0.0526 | 0.0377 | 0.2143 | 0.0811 | 0.1002 |
| | 2 | 5 | 9 | 14 | 12 | | | | | | |

Source: The authors.

Table 36 shows the analysis performed for the sub-criterion energy saving.

**Table 36**: Comparison of alternatives between suppliers - energy saving.

| Matrix of comparison of the alternatives according to Energy Saving | | | | | | Normalization | | | | | Weight |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | F1 | F2 | F3 | F4 | F5 | F1 | F2 | F3 | F4 | F5 | |
| F1 | 1 | 1/3 | 3 | 1/2 | 2 | 0.1463 | 0.0500 | 0.3913 | 0.0984 | 0.1905 | 0.1753 |
| F2 | 3 | 1 | 1/3 | 3 | 1/2 | 0.4390 | 0.1500 | 0.0435 | 0.5902 | 0.0476 | 0.2541 |
| F3 | 1/3 | 3 | 1 | 1/3 | 3 | 0.0488 | 0.4500 | 0.1304 | 0.0656 | 0.2857 | 0.1961 |
| F4 | 2 | 1/3 | 3 | 1 | 4 | 0.2927 | 0.0500 | 0.3913 | 0.1967 | 0.3810 | 0.2623 |
| F5 | 1/2 | 2 | 1/3 | 1/4 | 1 | 0.0732 | 0.3000 | 0.0435 | 0.0492 | 0.0952 | 0.1122 |
| | 7 | 7 | 8 | 5 | 11 | | | | | | |

Source: The authors.

Table 37 shows the analysis performed for the sub-criterion wood preservation models.

**Table 37**: Comparison of alternatives between suppliers - wood preservation models.

| Matrix of comparison of the alternatives according to Wood Preservation Models | | | | | | Normalization | | | | | Weight |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | F1 | F2 | F3 | F4 | F5 | F1 | F2 | F3 | F4 | F5 | |
| F1 | 1 | 3 | 3 | 3 | 3 | 0.4286 | 0.6000 | 0.3830 | 0.2857 | 0.2727 | 0.3940 |
| F2 | 1/3 | 1 | 3 | 3 | 3 | 0.1429 | 0.2000 | 0.3830 | 0.2857 | 0.2727 | 0.2569 |
| F3 | 1/3 | 1/3 | 1 | 3 | 2 | 0.1429 | 0.0667 | 0.1277 | 0.2857 | 0.1818 | 0.1609 |
| F4 | 1/3 | 1/3 | 1/3 | 1 | 2 | 0.1429 | 0.0667 | 0.0426 | 0.0952 | 0.1818 | 0.1058 |
| F5 | 1/3 | 1/3 | 1/2 | 1/2 | 1 | 0.1429 | 0.0667 | 0.0638 | 0.0476 | 0.0909 | 0.0824 |
| | 2 | 5 | 8 | 11 | 11 | | | | | | |

Source: The authors.

Table 38 shows the analysis performed for the sub-criterion packaging recycling.

**Table 38**: Comparison of alternatives between suppliers - packaging recycling.

| Matrix of comparison of the alternatives according to Packaging Recycling | | | | | | Normalization | | | | | Weight |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | F1 | F2 | F3 | F4 | F5 | F1 | F2 | F3 | F4 | F5 | |
| F1 | 1 | 2 | 2 | 2 | 4 | 0.3636 | 0.4800 | 0.3529 | 0.2162 | 0.2667 | 0.3359 |
| F2 | 1/2 | 1 | 2 | 3 | 3 | 0.1818 | 0.2400 | 0.3529 | 0.3243 | 0.2000 | 0.2598 |
| F3 | 1/2 | 1/2 | 1 | 3 | 3 | 0.1818 | 0.1200 | 0.1765 | 0.3243 | 0.2000 | 0.2005 |
| F4 | 1/2 | 1/3 | 1/3 | 1 | 4 | 0.1818 | 0.0800 | 0.0588 | 0.1081 | 0.2667 | 0.1391 |
| F5 | 1/4 | 1/3 | 1/3 | 1/4 | 1 | 0.0909 | 0.0800 | 0.0588 | 0.0270 | 0.0667 | 0.0647 |
| | 3 | 4 | 6 | 9 | 15 | | | | | | |

Source: The authors.

Finally, after comparing all the alternatives based on the criteria and sub-criterion, the suppliers were compared and ranked, as shown in Table 39.

**Table 39**: Ranking of Suppliers.

| Supplier | Weight | Ranking |
|---|---|---|
| F1 | 30.46% | 1° |
| F2 | 22.14% | 2° |
| F3 | 18.31% | 3° |
| F4 | 15.98% | 4° |
| F5 | 13.11% | 5° |

Source: The authors.

From the analysis of Table 39, it is observed that the recommended supplier is F1, presenting a weight of 30.46%. It should be noted that this supplier was ranked the first place that was purely coincidental.

Analyzing the results of supplier F1, it is noted that the criteria Environment, Health and Safety are the most important according to the opinion of the specialists consulted in this research, once they have a weight of 85%.

Of all the criteria evaluated in this research, it was found that the environment was considered the most important in the eyes of experts. This is due to the fact that people, in general, are increasingly aware of the need for the economy and the environment to walk together so that there are financial gains, but without the omission with regard to the environmental impacts generated by industrial operations.

Therefore, it is concluded that the criteria studied here have a significant impact on the foundry processes and a green supplier selection process is of paramount importance for the sustainability of the supply chain.

## 5. CONCLUSION

The present research aimed to propose criteria for the selection of green suppliers in the foundry sector and select the best suppliers using AHP method. For this purpose, a literature review was carried out through which eleven criteria that were identified in the implementation of the GSCM. After the analysis of eight specialists, six criteria were selected with five sub-criterion each. Then the criteria and sub-criterion were used to rank top five suppliers using the AHP method in order to recommend a supplier at the end of the selection process.

The analysis of importance order of each criteria showed that in the view of specialists in the foundry area, the environment is considered a factor of great importance presenting a weight of 34.96% followed by health (27.04%) and security (22.98%). The remaining criteria were considered as low importance (below 10%).

The analysis of importance order of each criteria showed that in the view of specialists in the foundry area, the environment is considered a factor of great importance, presenting a weight of 34.96%, followed by health (27.04%) and security (22.98%). The remaining criteria were of low importance (below 10%).

The results obtained of this research are useful for the foundry sector and for the researchers of GSCM as well, because they bring a proposal for adopting new criteria for the selection of green suppliers.

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