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Article

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Operations Research Perspectives

Provided in Cooperation with:

Elsevier

Suggested Citation: da Cunha, Richard Alex; Rangel, Luís Alberto Duncan; Rudolf, Christian-Alexander; dos Santos, Luiza (2022) : A decision support approach employing the PROMETHEE method and risk factors for critical supply assessment in large-scale projects, Operations Research Perspectives, ISSN 2214-7160, Elsevier, Amsterdam, Vol. 9, pp. 1-14, <https://doi.org/10.1016/j.orp.2022.100238>

This Version is available at:

<https://hdl.handle.net/10419/325731>

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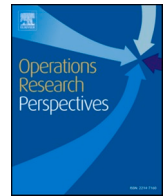
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A decision support approach employing the PROMETHEE method and risk factors for critical supply assessment in large-scale projects[☆]

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ARTICLE INFO

Keywords:

Management Science
Project Management
Construction Industry
FIDIC
MCDA
Modeling

ABSTRACT

The purpose of this article is twofold: to identify the critical risk factors (RFs) that impact supply chains (SC) in the engineering, procurement, and construction of large-scale projects (EPC-LSP) of the oil and gas industry (OGI) and to apply these RFs in a mathematical model developed, based on multiple-criteria decision-making (MCDM) methods in an expert group. The mathematical model was developed in MATLAB and was based on the Preference Ranking Organization Method for Enrichment Evaluations (PROMÉTHÉE) II and (PROMÉTHÉE GDSS) Group Decision Support System methods. The model's criteria were defined with the RF mapping identified using 33 years of literature and the application of questionnaires to specialists. The evaluation process of the alternatives concerning the defined criteria was conducted through questionnaires to specialists. Finally, the functionality and results of the model were validated by the specialists in the field through interviews. As a contribution, managers, companies, and industry could adopt this solution as a practical and dynamic tool to support decision-making. This fact especially holds true in possible critical supply scenarios, where it is necessary to direct resources to minimize risks and other impacts to EPC-LSP SC. Another novelty refers to the critical risk factors identified, originating from an extensive literature mapping covering the three pillars of sustainability. Moreover, this research was to fill the literature gap, given the lack of studies that propose clear, practical, and specific tools for SCRM in EPC-LSP.

1. Introduction

The term “risk” is derived from the Italian word *risicare*, which means to dare [13]. Over time, other meanings were incorporated, such as probability, the dimension of a consequence, danger, and threat [97]. Risks can occur from decision-making (DMG), conditions associated with the environment, or exposure to unforeseen situations [29]. Thus, establishing risk management (RM) strategies [140] is necessary to minimize losses and to increase competitive advantages and new business opportunities.

In the global supply chain (SC) scenario, RM has started to receive more attention from academics and professionals in the last decades. This increase in attention is attributed to several events that significantly affected SC, such as (1) the terrorist attacks of September 11, 2001, the economic crisis of 2008, and the earthquake and tsunami in Japan in 2011 [105]; (2) the decision undertaken by the UK in 2016 to withdraw from the European Union [89]; (3) the KFC chicken supply crisis in early 2018 [140]; and (4) the worldwide COVID-19 pandemic in 2020 [67]. Further, the application of management actions, such as outsourcing, inventory reduction, just-in-time concepts, increased cooperation

[☆] SC: Supply chain; RF: Risk factors; RM: Risk management; SCRM: Supply chain risk management; MCDM: multiple-criteria decision-making; SCM: Supply chain management; EPC-LSP: Engineering, procurement, and construction of large-scale projects; CI: Construction industry; OGI: Oil and gas industry; PROMÉTHÉE: Preference Ranking Organization Method for Enrichment Evaluations; GDSS: Group Decision Support System; PB: Probabilities of occurrence; IC: Intensity of impact; DMG: Decision-making; DM: Decision maker; GDP: Gross domestic product.

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<https://doi.org/10.1016/j.orp.2022.100238>

Received 1 December 2021; Received in revised form 28 April 2022; Accepted 29 April 2022

Available online 5 May 2022

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between companies [73], and higher levels of agility and cyber incidents [14] have contributed to increased risk exposure [5].

This situation is still evident in the SC of engineering, procurement, and construction of large-scale projects (EPC-LSP), characteristic delivery model of the global construction industry (CI). CI is inserted in other industries, such as Oil and Gas (O&G), Mining, Energy, Aerospace, Defense, and others. This industry applies EPC-LSP to constructing land and sea O&G units, submarines, ports, airports, electrical and telecommunications systems, buildings, and others [51,104]. Despite having significant effects on society, researchers [9,71] claim that the CI suffers from poor performance and efficiency compared to other industries due to the high degree of risk and uncertainty presented by its SC.

Some studies such as Rudolf and Spinler [114] state that this high degree of risk in CI is due to: (1) external risk factors (RFs) influencing the internal context of SC; (2) internal RFs linked to the SC's internal management; (3) lack of experience, knowledge, operational flexibility, and manufacturing capacity of suppliers and sub-suppliers; and (4) the behavior and cooperation among the members of the SC. Further, the procurement phase of EPC-LSP is considered to be highly critical for: (1) answering for 80% of the project term [64]; (2) representing 80% of the cost of the project [27], 45% of which is attributed to critical supplies [91]; and (3) being responsible for the quality of the equipment and services provided, which can impact the delivery of the project [90].

Given this scenario, it is essential to develop strategies to increase the EPC-LSP's success rate. For this purpose, there is a need to make the supply chain risk management (SCRM) process a fundamental practice in every EPC-LSP implementation [76,114].

Among the global industries that use EPC-LSP as the primary means of delivering products and services, the oil and gas industry (OGI) stands out [3,51]. This industry applies EPC-LSP to develop and improve its upstream, midstream, and downstream areas. Brazil's OGI stands out globally as the seventh-largest producer and seventh-largest consumer of oil and gas products [44]. This industry has raised a considerable volume of foreign direct investment [65] in the last decade, mainly from countries such as the US, China, England, France, and Norway [79]. This achievement is due to Law No. 12,351, enacted on December 22, 2010, which established the country's production sharing regime [79]. Due to these investments, this sector has expanded its capacity using EPC-LSP as the preferred model for expansion.

However, both the global and Brazil's OGIs have a poor track record in implementing the EPC-LSP [68,117,124]. This situation is mainly due to the problems related to a failure in the RM of the supply phase, where the prioritization of critical supplies is often wrongly defined. Factors such as time, cost, and complexity are considered [137], while the RF belonging to the activity and the relevant industry are disregarded. The failure to define and prioritize critical supplies can result in the unavailability of equipment and services on site and the consequent loss of term, cost, and productivity ([42]/2015; [72]). The worsening of the industry's image and low financial performance is a further consequence [133].

Numerous works have already been proposed to improve the project effectiveness through a more robust RM [130] or improve SC performance by implementing a sound SCRM methodology [121]. Consequently, many processes were generated to address the need for more an effective RM [107] or SCRM [14]. However, the proposals are too generic for the CI and fail to address the EPC-LSP's specific requirements, such as its complex configuration, contractual structure, and frequent changes, compared to other SC of regular industries. Therefore, there is a need to contextualize and adapt the various SCRM components to this particular project environment.

To better understand the critical supply prioritization problem, two questions are asked. (1) Which RF should be considered to establish the criticality of supplies in an EPC-LSP from OGI? (2) How can critical supplies in an EPC-LSP be determined? In order to answer these questions, two objectives were developed: (1) define the critical RFs that impact OGI's EPC-LSP SC and (2) develop a methodology and a

mathematical model that combines the SCRM components and multiple-criteria decision-making methods (MCDM).

This paper is structured as follows. Section 2 presents a brief introduction to the RM of large-scale EPC projects, SC, and a description of the Preference Ranking Organization Method for Enrichment Evaluations (PROMÉTHÉE) methods. Section 3 describes the methods applied, and Section 4 presents the results. Section 5 discusses the implications of the results. Section 6 presents the conclusion by summarizing the results and proposing future research topics.

2. Literature review

2.1. SCRM in large-scale EPC projects

Global CI represents a substantial percentage of the GDP of many countries [71]. According to a World Bank report [66], this industry is considered as the largest consumer of raw materials and constructed objects. Although this industry has significant effects on society, it suffers from poor performance and efficiency [9,71]. It has a narrow profit margin and is subject to several risks and uncertainties in its SC [51,76,114,137]. According to Flyvbjerg [51], the main model for supplying products and services adopted in this industry are EPC-LSP. Since the 1980s, these projects have tended to be increasingly large and complex, involving high investments for their implementation (from millions to billions of US dollars) [114]. They are mainly run under the EPC contractual management, involving a large number and different types of stakeholders. The procurement phase, an EPC's highly critical phase, [28,75], is responsible for the SC of commercial agreements for supplying products and services [28,103]; it involves high long-term investments, and several uncertainties and risks.

Consequently, because of CI's low performance in EPC-LSP implementation, there is a need to effect gradual improvements [9], including adjustments in the applied SCM (supply chain management) methods [1,118]. However, the SCM solutions that are successful in other industries [2,81,83] have not had the same level of effectiveness in CI. They have been implemented or partially established in a fragmented form, focusing on different areas, contexts, and objectives [6]. As per Briscoe and Dainty [24], there is a lack of will in this industry to implement SCM practices and achieve integration in SC. Other studies [47,57,134] show that SCM concepts are based on hypotheses and do not fit this industry's particularities. Some others [7,39,100] confirm that despite the vital contribution of SCM research in the manufacturing industry, it cannot be applied in the CI due to the transitory nature of production in construction projects. The limited use of SCM solutions is because there exists a lack of the models and theoretical concepts studied with regard to this sector [9].

According to the characteristics presented, the EPC-LSP SCM is complex, dynamic, uncertain, and risky. Project managers are challenged during the project life cycle to efficiently identify and manage SCRM with limited resources, aiming for the perfect delivery of the products and services that fulfill the quality, deadline, cost, and contractual scope requirements. Hence, there is a need to develop the SCRM process as a fundamental practice in all EPC-LSP [76,114].

The term "SCRM" originated in the studies Jüttner et al. [70], Finch [49] and Norrman and Jansson [99]. The latter two were published for the field of logistics and SCM [101]. As per Neiger et al. [96], SCRM consists of developing approaches to identify, assess, analyze, and treat the areas of vulnerability and risks in SC. As per Tang [121], SCRM occurs through the coordination and collaboration among SC members to ensure profitability and continuity. SCRM's definitions and objectives align with minimizing or eliminating the impact that affect the SC's overall performance, involving practices related to identifying, assessing, and mitigating risk-triggering events [52,101].

Regarding the benefits that can be achieved through the practice of SCRM, Walters [133] comments:

Operations with less disruption and volatility, improving the

company's image with the client and progress in financial performance; monitoring operations and identifying any problems; identification of crisis-enhancing events; preparation of faster contingency plans in the event of risk realization; Early risk assessment that allows prioritization, planning, and allocation of resources, and others.

Therefore, this topic is relevant to the literature, business, and society, and this research can provide fewer disruptions to SC and increase the success rate of project implementations.

2.2. The PROMÉTHÉE method

The PROMÉTHÉE method [20] belongs to the European school of multi-criteria decision support methods and is based on the notion of outranking relationship [21,112]. This method seeks to solve a $P\gamma$ -type problem in which a priority order is established for a set of selected alternatives. Further, these alternatives are analyzed at par with each criterion, considering the decision-maker's (DM's) degrees of preference until the order is defined [54].

- The PROMÉTHÉE family comprises the following methods:
- PROMÉTHÉE I: the order obtained corresponds to a partial pre-order [20].
- PROMÉTHÉE II: the order obtained establishes a complete pre-order since incomparability is not admitted [20].
- PROMÉTHÉE III: provides an order by intervals for working with variable limits [88].
- PROMÉTHÉE IV: is a generalization of PROMÉTHÉE II, for an infinite set of alternatives [88].
- PROMÉTHÉE V: Extends the PROMÉTHÉE II and is appropriate for the selection of a subset of alternatives [18].
- PROMÉTHÉE VI: assists the decision-maker in determining the weights of the criteria that best express their preference [19].
- PROMÉTHÉE-GAIA: graphical analysis support for the methodology - PROMÉTHÉE [87].
- PROMÉTHÉE GDSS: assists in decision making that involves a group of decision makers [84].

The use of the PROMÉTHÉE GDSS method in this research is justified: 1 - in the decision-making process, the decision-makers considered

the criteria as being non-compensatory, which, a poor performance on one of the criteria cannot be compensated for a good performance on another; 2 - As the EPC-LSP SCs are highly complex and involve many stakeholders, the group decision-making process is the most appropriate; 3 - an important aspect is related to the ease of decision-makers to understand the concepts and parameters inherent to the methods, which simplifies the preference modeling process and, consequently, increases the effectiveness of the application of the multicriteria method. The algorithm of the PROMÉTHÉE method is easier to understand by DM than that of the ELECTRE II method [113]. This aspect represents an advantage of PROMÉTHÉE methods over other outranking methods, such as the ELECTRE II method. 4 - the PROMÉTHÉE GDSS method can be implemented in a computer language. The DM for considering this problem, the criteria as non-compensatory (European school method), it is not possible to employ compensatory methods (American school methods), such as AHP [115]; ANP [116]; MACBETH [8].

2.2.1. The PROMÉTHÉE II method

The PROMÉTHÉE method has six preference functions represented in Fig. 1. They classify an alternative a as preferable to b (aP_b), strictly better than b , or indifferent to b (aI_b), when there are no significant differences between the two alternatives for each criterion. It can be seen in Fig. 1 that q refers to the limit of indifference: if $\delta_{ik} < q$, the alternatives x_i and x_k are indifferent about this criterion. However, p corresponds to the preference limit: if $\delta_{ik} > p$, there is a strict preference for x_i concerning this criterion and logically, there is always $p > q$ [21].

According to extant literature [54,94], the PROMÉTHÉE method can be applied as follows:

Step 1: The DMs are defined and criteria j , alternatives m , and the weights w_j of each criterion are weighted.

Step 2: The preference function to be used is defined as in Fig. 1.

Step 3: The preference function of each criterion j is calculated for each pair of alternatives x_i and x_k . The equation for this is as follows:

$$P_j(x_i, x_k) = P_j(u_j(x_i) - u_j(x_k)) = P_j(\delta_{ik}),$$

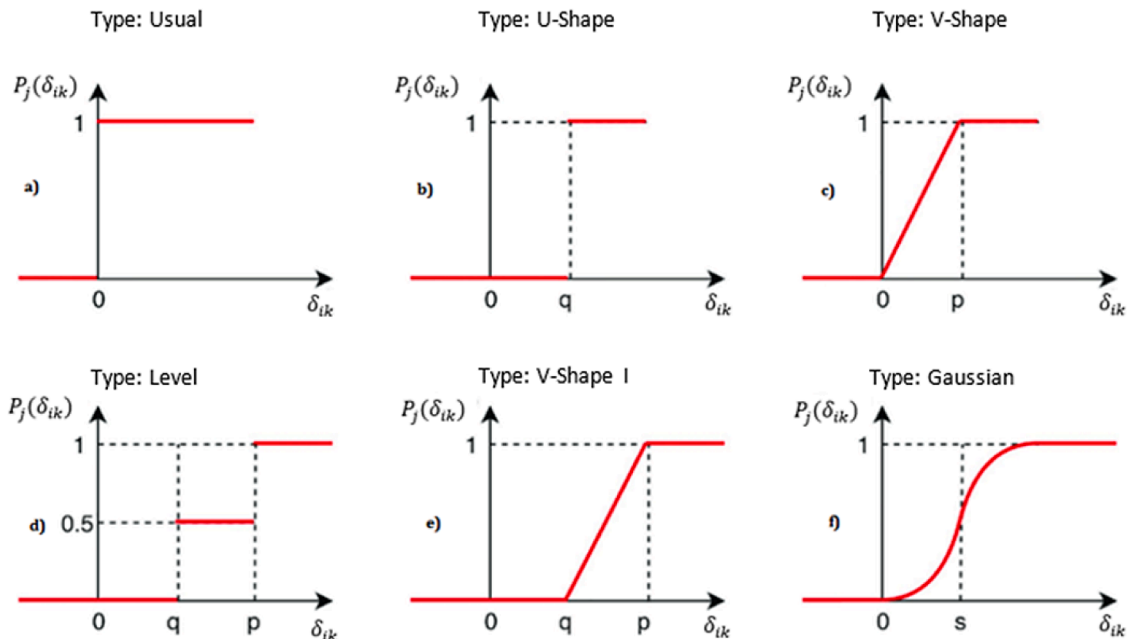


Fig. 1. Preference functions
Source: Adapted from [22].

where P_j represents the preference function chosen to compare the criterion j ; $u_j(x_i) - u_j(x_k)$ correspond to the criterion values j for alternatives i and k ; and δ_{ik} represents the difference in performance of the alternatives x_i and x_k , concerning the criterion j . Further, the equation for it is derived as follows:

$$\delta_{ik} = u_j(x_i) - u_j(x_k).$$

Step 4: The preference index s_{ik} is calculated by comparing alternatives x_i and x_k , that is, the sum of P_j in which x_i is preferable to x_k . This sum is weighted by the weights of each criterion, w_j . The equation is as follows:

$$s_{ik} = \frac{\sum_j w_j P_j(x_i, x_k)}{\sum_j w_j} = \frac{\sum_j w_j P_j(\delta_{ik})}{\sum_j w_j}.$$

Step 5: Positive (ϕ_i^+) and negative (ϕ_i^-) overshoot flows of each alternative x_i are calculated. ϕ_i^+ refers to how x_i surpasses other alternatives, representing the average of all degrees of over-classification of x_i in relation to the other alternatives. The bigger the ϕ_i^+ , the better the alternative. ϕ_i^- refers to how x_i is surpassed by the others; therefore, it represents the average of all degrees of over-classification of the other alternatives on x_i . Through these flows, the partial pre-order of alternatives is obtained (PROMÉTHÉE I), where each relationship must respect one of the conditions mentioned. Relations ϕ_i^+ and ϕ_i^- are described below in Figs. 2, 3, and 4:

Thus, the total flow or net flow for each alternative x_i can be calculated as follows:

$$\varphi_i = \phi_i^+ - \phi_i^-$$

The PROMÉTHÉE II method is used to obtain the pre-orders of the alternatives.

2.2.2. PROMÉTHÉE GDSS

This method can be applied in complex situations of DMG [22]. A finite number of alternatives is evaluated considering conflicting criteria and the participation of n decision-makers with conflicting interests. It allows each DM to express a preference function and integrate their assessments into a group decision. According to Brans and De Smet [21], this method can be divided into three phases as in Fig. 5:

Fig. 5 shows the vectors of total flows ϕ_i and the weights w_i of each of the r DMs involved in the decision-making process. Here, $i = 1, 2, \dots, r$.

Phase 1 - Define the alternatives and criteria: Each DM suggests the possible alternatives and criteria in this phase. A meeting is held to analyze them and decide which ones to exclude, merge, or consider. Phase 2 - Individual assessment: In this phase, each DM conducts their assessments. If any criterion is not of interest to the DM, zero weight is allocated to it. If there is consensus among the decision-making group, some assessments may be made in advance, depending on the criterion. Finally, the individual rankings are generated, and GAIA analysis conducted, if necessary, for each DM [23,84,86,87].

Phase 3 - Global assessment: In this final phase, individual flows are collected and included in the global assessment matrix. The individual results are then aggregated using a weighted average according to the weight attributed to each DM.

$$\begin{aligned} \phi_i^+ &> \phi_k^+ \text{ e } \phi_i^- < \phi_k^- \\ \phi_i^+ &> \phi_k^+ \text{ e } \phi_i^- = \phi_k^- \\ \phi_i^+ &= \phi_k^+ \text{ e } \phi_i^- < \phi_k^- \end{aligned}$$

Fig. 2. - x_i exceeds x_k if.

$$\phi_i^+ = \phi_k^+ \text{ e } \phi_i^- = \phi_k^-$$

Fig. 3. - x_i is indifferent to x_k if.

$$\begin{aligned} \phi_i^+ &> \phi_k^+ \text{ e } \phi_i^- > \phi_k^- \\ \phi_i^+ &> \phi_k^+ \text{ e } \phi_i^- < \phi_k^- \end{aligned}$$

Fig. 4. - x_i is incompatible with x_k if

Source: Adapted from Gomes et al. [54].

The DMG process in group evaluations is characterized by heterogeneous individuals, who did not have a connection or shared goals and tended to act according to their own preferences, values, and aims. This allows for a valuable acquisition of individual information, which often would not be possible in group evaluations with homogeneous-thinking individuals.

3. Method

3.1. Research development

This study conducted an applied research as it aimed to build practical knowledge to solve specific problems [56]. Both the qualitative and quantitative [138] approaches were adopted in which subjectivity and information, convertible into mathematical and objective metrics, were emphasized on. This procedure allowed the verification of the occurrence or non-occurrence of the consequences and acceptance of the hypotheses [37].

In terms of objectives, this research can be classified as exploratory. The study aimed to describe, argue, and alter definitions, and formulate more specific problems for future research [53]. The methods adopted here were bibliographic survey, systematic literature review (SLR), questionnaire application, and case study [138].

The development process of this research followed the steps, as shown in Fig. 6.

3.2. Mathematical model

The model was designed using the MATLAB 2015b software, based on the PROMÉTHÉE II, PROMÉTHÉE GDSS, and sensitivity analysis methods. The PROMÉTHÉE II method establishes individual priorities for each specialist considering their preference, given the differences obtained from comparing the alternatives about each criterion. The PROMÉTHÉE GDSS method aims to group each specialist's priorities and establish a group of DMG. Finally, after obtaining the final prioritization of the alternatives, a sensitivity analysis was performed to present each DM's power of influence in the ordering of the alternatives [21].

For the application of the model, the data were collected using the following process. (1) Identify the model's criteria by reviewing literature and consulting specialists in the area (questionnaire), aiming to select the critical RF that impacts the EPC-LSP SC at Brazil's OGI. (2) Select the alternatives and the information for each supply by extracting the data from an actual EPC-LSP of Brazil's OGI. (3) Finally, evaluate the alternatives for the criteria defined by conducting a questionnaire survey with specialists.

In a decision-making process, decision alternatives are identified/defined by decision-makers. There is no set number of specialists for the group decision-making process, but the greater the number of specialists and the more experienced, the better the decision-making process [54, 110].

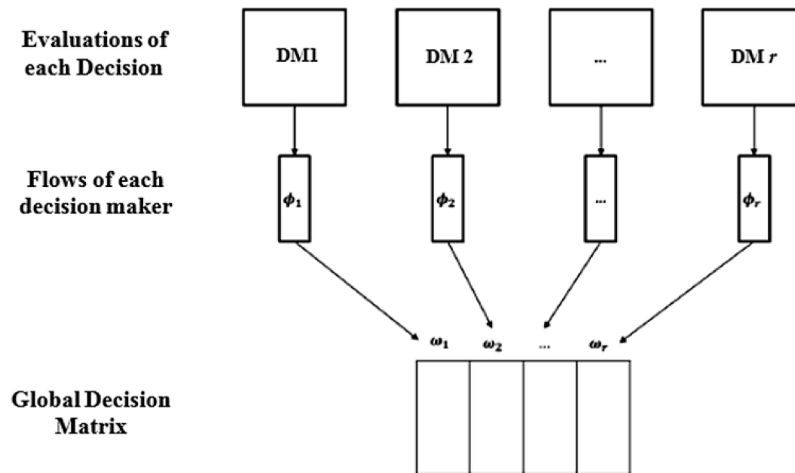


Fig. 5. PROMÉTHÉE GDSS implementation process
Source: Adapted from Macharis et al. [84].

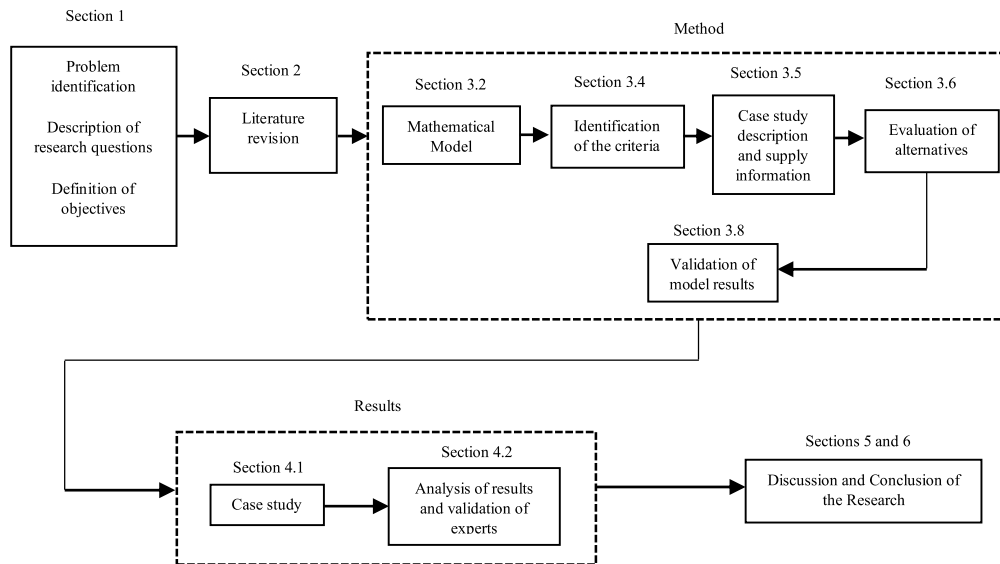


Fig. 6. Research development cycle.

3.3. Literature review

We aim to understand (1) the current research status on SCRM, (2) SCRM in the EPC-LSP of global (3) SCRM in the EPC-LSP of global's and Brazil's OGI, (4) the PROMÉTHÉE methods, and (5) the critical RF that affects the EPC-LSP SC. For this purpose, keywords were defined using the brainstorming process, after referring to the literature and consulting with the professionals in the field. This process represents the baseline for understanding the concepts involved, necessary for constructing the theory [138].

The following keywords were used: "supply chain," "disruptions," "risk sources," "risk factors," "risk taxonomy," "equipment procurement," "construction materials," "criticality materials," "construction project," "EPC project," "large-scale project," "ETO," "oil and gas," "construction industry," "megaproject," "major projects," "IBP," "EIA," "TCU," "critical equipment," "PROMÉTHÉE," and "MCDM."

These keywords were combined, using simple operators and Boolean logic, to form a series of strings to be applied to a publication database. These combinations were built to avoid very generic and broad results. In addition, these search strings were brainstormed, tested, and refined until a reasonable list of terms was deemed sufficient, resulting in ten

relevant search strings.

For identifying the relevant documents, some inclusion and exclusion criteria were defined [98]: (1) prioritize peer-reviewed journal articles; (2) search for documents in English, Portuguese, or German; (3) research RFs that have affected the EPC-LSP SC in publications in the last 33 years (the period from 1987 to 2020); and (4) build a theoretical framework prioritizing publications from the last five years.

The literature review was carried out in the Scopus and Web of Science databases. The rationale for choosing both is that they are the largest database of abstracts and citations in the peer-reviewed literature. They provide broad coverage of scientific, technical, and social science literature. Thus, with the restriction of searches in peer-reviewed journals, higher-quality papers are guaranteed due to the more rigorous analysis and review process [98].

Initially, 722 potentially relevant documents were identified with keywords in their title or abstract. After examining the abstracts and their adherence to the theme, 177 documents were selected. After reading the section's introduction, method, and results, 129 documents were chosen for constructing theoretical frameworks and identifying the RF [15]. A systematic literature review (SLR) was performed based on these results. The SLR is a solid, reliable, and easy-to-apply

methodology. It can be used in a wide field of research to select relevant contributions [32,85].

3.4. Identification of the mathematical model criteria

The model criteria were defined based on the work of Cunha [36], who mapped 33 years of literature and 162 RFs that impacted the global EPC-LSP SC (as in Table 1). This mapping considered SCRM practices, such as identification, analysis, categorization, classification, and validation of RF [52,101]. After this step, RF was included in two questionnaires and evaluated specialists in EPC-LSP from Brazil's OGI. This approach is considered adequate to assess risks in EPC-LSP [114,136], as

Table 1
Categorization and classification of RFs identified in the literature.

Risk Category (RCT)	Risk Class (RCL)	Risk Factor (RF)
1-ENVIRONMENT	1.1-Economical	1.1.1-to-1.1.7
	1.2-Environmental, Health & Safety	1.2.1-to-1.2.3
	1.3-Law & Regulations	1.3.1-to-1.3.4
	1.4-Natural Events	1.4.1-to-1.4.3
	1.5-Political & Governmental	1.5.1
	1.6-Social Environment	1.6.1-to-1.6.7
	1.7-Sociocultural	1.7.1
	1.8-Standards & Codes	1.8.1
	2.1-Standards & Codes	2.1.1-to-2.1.3
	2.2-Communication	2.2.1-to-2.2.2
	2.3-Corporate Social Responsibility	2.3.1-to-2.3.2
	2.4-Demand & Scope Changes	2.4.1-to-2.4.7
	2.5-Inventory	2.5.1-to-2.5.2
	2.6-Logistics	2.6.1-2.6.4
	2.7-Supply Chain Configuration	2.7.1-to-2.7.10
	2.8-Management of the Supply Chain	2.8.1-to-2.8.17
2-SUPPLY CHAIN COORDINATION & MANAGEMENT	2.9-Planning & Forecasting	2.9.1-to-2.9.4
	2.10-Scope & Baseline Specification	2.10.1-to-2.10.7
	3.1-Contractual Terms & Conditions	3.1.1-to-3.1.7
	3.2-Experience & Expertise	3.2.1-to-3.2.8
	3.3-Financial Stability	3.3.1-to-3.3.5
	3.4-Infrastructure & Resources	3.4.1-to-3.4.8
	3.5-Performance & Operations	3.5.1-to-3.5.19
	3.6-Sub-Suppliers	3.6.1-to-3.6.11
	3.7-Supplier Environment & Market	3.7.1-to-3.7.5
	4.1-Collaboration & Teaming	4.1.1-to-4.1.5
	4.2-Misfit of Corporate Cultures	4.2.1
	4.3-Mutual Commitment to Project Success	4.3.1-to-4.3.5
	4.4-No Mindset of "Pain/Gain sharing"	4.4.1-to-4.1.2
	4.5-Trust Issues	4.5.1-to-4.5.2
3-SUPPLIER		
4-BEHAVIOR & COOPERATION		

Source: Cunha [[36], p. 62–72].

it allows the research to be concluded efficiently in terms of time, limiting the number of RFs that need to be evaluated and offering a method for evaluation. In addition, we sought to avoid bias [16], driven by a very comprehensive list of risk classes that must be evaluated in detail [63,77].

The mapping in Table 1 also considered the three main pillars of sustainability [104]. The economic perspective, in which an economically sustainable company must be able to produce goods at a minimum cost [33]. For example, we can mention risk classes 1.1, 1.3, 1.7, 3.6, and 3.7. The environmental perspective, where an environmentally sustainable company avoids the excessive use of depleting resources or, as an alternative, privileges the use of resources with less depletion potential [129]. For example, we can mention risk classes 1.2, 1.3, 1.8, and 2.3. Moreover, the social perspective, in which a socially sustainable system must guarantee, among other things, fair distribution of opportunities, adequate provision of social services, and gender equity [17]. For example, we can mention risk classes 1.6, 1.7, 1.8, 2.3, 4.1, and 4.2. In this way, Table 1 covers risk factors that cause excessive consumption of resources, pollution generation, production of residues, climate change, and fairer opportunities.

Specialists were selected through social networks (LinkedIn and ResearchGate) and researchers' resume platforms (Lattes platforms) in Brazil, considering the following minimum criteria: (1) a degree in engineering, (2) at least eight years of experience in EPC-LSP at Brazil's OGI, (3) at least a Ph.D. and publications in the area, and (4) select different hierarchical levels to measure the degree of risk exposure in EPC-LSP SC.

Through the platforms and using the selection criteria, 35 specialists were selected among which 16 answered the questionnaire. Of these, 30% had more than 25 years of experience and 70% had between 8 and 18 years of experience in the EPC-LSP at Brazil's OGI. The specialists' hierarchical level was as follows: technician, buyer, engineer, coordinator, manager, director, and researcher.

The experts' evaluation sought to determine the probabilities of occurrence (PB) and intensity of impact (IC) of the 162 identified RFs and to establish a critical RF ranking. The former was evaluated using combinations of standard ordinal terms with numerical range definitions as a scale. Several risk patterns recommend this solution [26,108,109] and so did existing research [29,34,62,114]. Table 2 shows the scale used to evaluate the PB, while Table 3 shows the semi-quantitative ordinal scale used [34,114] to evaluate IC.

Equation 3.4.2 was used to calculate the criticality of each RF (CRF) [34]: $CRF = PB + IC - (PB \cdot IC)$ (3.4.2)

After defining the criticality for each RF in CRF, the RF was assigned according to the following rules [34]: (1) RF with a high BP (grades from 0.8 to 0.9 – Table 2) or a high IC (grades from 0.7 to 0.9 – Char 3) or both is considered critical and (2) an RF with CRF close to zero has low criticality and close to one has high criticality.

Applying equation 3.4.2 and the RF prioritization rules in the experts' evaluations, a relationship was obtained with 22 critical RFs that impact the EPC-LSP SC in Brazil's OGI, as shown in Table 4.

After defining the 22 critical RFs, the first 10 were pre-selected as the mathematical model's criteria. The number of criteria was defined according to the recommendation of MILLER [92]. This author notes that the number of criteria evaluated should not exceed 7 ± 2 , as

Table 2
Evaluation of the probability of occurrence (PB).

Verbal Scale	Value
Rare	0,1
Unlikely	0,3
Possible	0,5
Likely	0,7
Highly probable	0,8
Almost certain	0,9

Source: Adapted from Copper et al. (2005).

Table 3
Assessment intensity of impact (IC).

Verbal Scale	Value
Insignificant	0,1
Low	0,3
Moderate	0,5
Very high	0,7
Catastrophic	0,9

Source: Adapted from Rudolf and Spinler [114] and Copper et al. (2005).

psychometric studies demonstrate the limitations of the human brain to simultaneously compare more than seven attributes.

The next step identified the model's criteria applying a structured questionnaire with multiple-choice questions open to experts. In this questionnaire, the nine pre-selected criteria in Table 4 were inserted. The specialists were asked to evaluate and assign 100 points to the most crucial criterion, and the other criteria were assigned a lower weight, considering their degree of importance relative to the first. Experts suggested excluding the criterion evaluated with zero weight from the analysis. The criteria weights were determined by the direct rating method, and these were normalized for implementation [40,54,55].

Table 5 lists the criteria suggested by the experts and shows correlations between them and the RFs listed in Tables 1 and 4. The criteria (C13 and C20) were disregarded from the alternatives' analysis because they correlate with the criterion (2.7.3) in Table 4. Since the criteria (C19 and C22) were not correlated with the RF listed in Tables 1 and 4, they were considered in the analysis. The other suggested criteria were considered in the analysis due to their correlation with Table 1. Thus, this methodology allows each specialist to establish the set of criteria (from 1 to 22 criteria) they wish to use to analyze supply alternatives.

3.5. Case study description with alternatives and supply information

The alternatives and the information for each supply were extracted from an actual EPC-LSP of Brazil's OGI. This project was implemented in 2015 and consisted of building two natural gas metering stations or Estação de Medição (Portuguese) (EMED 1 and 2), located in the terrestrial storage, processing, and transfer terminal of oil and gas.

The objective of this project was to measure and qualify natural gas, in the transfer of custody between the owner (oil and gas terminal) and distributor (concessionaires in several states of Brazil), via terrestrial gas

pipelines, following fiscal requirements established by regulatory bodies. For each measuring station, other supplies were provided, such as programmable logic controller (PLC), uninterruptible power supply (UPS), electrical panels, battery bank, transformers, and others. The manufacturers of these supplies were distributed globally, as shown in Table 7.

The selection of the four case study alternatives considered their time, cost, and complexity about the other supplies.

This project was contracted under the EPC regime, in which the contracted company (EPCist) assumes responsibility for the following activities:

Table 5
New evaluation criteria.

New Criteria	Correlation with the RFs of Tables 1 and 4	Weights	Decision Makers
C10 Capacity inflexibility	3.5.4	80	4
C11 Subsurface risks at levels 2, 3, and others	3.6.5	98	6
C12 Pain/Gain contractor's mindset	4.4.2	91	6
C13 Customs clearance	2.7.3	75	7
C14 Transport security	2.6.1 and 2.6.3	65	7
C15 Quality management	2.10.3, 3.5.2 and 3.6.3	100	8
C16 Commissioning management	3.2.6	85	8
C17 High turnover of the project team	3.4.6	70	11
C18 Communication failure	2.2.1	89	11
C19 Lack of calibration and repair equipment in the country of application	-	50	12
C20 Customs restrictions	2.7.3	30	12
C21 After sales technical support, installation, monitoring and commissioning	3.2.6	98	14
C22 Spare item supply for departure and for the first year in operation	-	95	14
C23 Qualification of labor	3.5.6	39	16
C24 Company financial health	3.3.1 and 3.3.5	85	16

Source: Data collected from the application of Questionnaire 2.

Table 4
Critical risk factors.

Order	RCT	RCL	RF	RF Description	Authors	Criticality	Criterion
1°	3	3.5	3.5.8	Delays	[31,95,122]	0,9278	C1
2°	1	1.1	1.1.1	Exchange rate/Currency fluctuations	[4,58,139]	0,9228	C2
3°	2	2.9	2.9.4	Unrealistic contractual schedules	[11]	0,9168	C3
4°	3	3.6	3.6.7	Long delivery time for imported items	[11]	0,9054	C4
5°	2	2.8	2.8.14	Project unavailability on time and delay in approval	[11]	0,9015	C5
6°	2	2.4	2.4.1	Design changes	[12,106]	0,8888	C6
7°	2	2.9	2.9.1	"Black Swans"/Completely unforeseen events	[48,51,60]	0,8844	C7
8°	2	2.4	2.4.4	Scope changes	[93,102,125]	0,8802	C6
9°	2	2.7	2.7.3	International suppliers	[25,69,139]	0,8779	C8
10°	1	1.6	1.6.4	Bribery/Corruption/Comply with rules (Compliance)	[4,35,61]	0,8777	C9
11°	1	1.1	1.1.3	Economic downturn	[4,102,135]	0,8749	-
12°	2	2.4	2.4.2	End-customer investment risk	[38,59,139]	0,8473	-
13°	1	1.4	1.4.1	Rupture/Natural disasters/Force majeure	[2,4,132]	0,8467	-
14°	2	2.7	2.7.8	Lack of detailed analysis in bid Phase	[106]	0,8448	-
15°	2	2.10	2.10.1	Unclear design and specifications/Poor or inconsistent design	[51,120,139]	0,8447	-
16°	2	2.10	2.10.6	Incorrect information sources during project design	[10]	0,8349	-
17°	2	2.4	2.4.6	Owner interference and suspension of work	[11]	0,8315	-
18°	3	3.2	3.2.5	Lack of experience with complex contracts	[106]	0,8315	-
19°	2	2.9	2.9.2	Cost estimation	[43,58,107]	0,8296	-
20°	3	3.1	3.1.1	Insufficient cost coverage	[82,128,131]	0,8296	-
21°	2	2.10	2.10.7	Long-lasting design	[30]	0,8237	-
22°	3	3.1	3.1.7	Reduced plant availability and performance	[74]	0,8003	-

- Engineering: Conducting engineering studies, executing a multidisciplinary executive project (civil, architecture, piping, electrical, instrumentation, automation, safety, and process), and providing technical support for procurement and construction activities.
- Procurement/Supply: supply of equipment, instruments, materials, and services.
- Construction: Implementation of the executive project, commissioning, pre-operation of the plant, delivery, and demobilization.

The value of this contract was BRL 20 million (approximately USD 7 million), of which 80% corresponded to the supply phase. The deadline for project implementation was set at six months, including commissioning, pre-operation and construction decommissioning.

This project was chosen for the following reasons: (1) it is an EPC-LSP by OGI; (2) the SCRM was not carried out throughout the life cycle of the project; (3) the prioritization of critical supplies occurred only at the beginning of the project, considering only the significant aspects of time, cost, and technical complexity; and (4) finally, there were significant delays and excess costs in the delivery of supplies, due to erroneous prioritization, without considering critical RFs belonging to the activities and the industry inserted in the questionnaire.

The scope of the selected alternatives is described in Table 6.

Table 7 presents information on each supply (S1, S2, S3, and S4) collected from the project in 2016.

Table 7 can help assist specialists in the evaluation of each alternative considering the criteria defined in 3.4.

3.6. Evaluation of alternatives

With the help of the specialists, the alternatives were evaluated through a questionnaire, to judge the alternatives based on the criteria defined by them in 3.4.

The Likert scale was used, akin to Table 8, in which the interviewee expressed their degree of agreement or disagreement with each statement, using a five-point grading system [53,80]. Tables 6 and 7 were also considered in this assessment, and the technical specifications of each piece of equipment were inserted in the questionnaire.

3.7. Application of the mathematical model

The model was applied considering a scenario with 16 DMs. For each DM, a weight of 1 was assigned, and they evaluated four supplies (Table 6). The assessment considered the RF criteria pre-selected in the literature (Table 4), as well as new criteria included by the experts (Table 5). The information of each supply is shown in Table 7. Further, we aimed to maximize each criterion and defined the preference of the DM using the Pseudo-criteria function with Linear Preference (Type III). With this information and the problem analyzed, a strict preference (p) equal to 1.99 was used.

Table 6
Definition of alternatives.

Alternatives	Units	Scope 1	Scope 2 (Common to all supplies [S1 to S4])
Supply 1 (S1)	4	- Flow Computer, model similar to the FloBoss 107;	- Engineering project;
Supply 2 (S2)	4	- Ultrasonic Flow Meter 24", model similar to FLOWSiC600;	- Databook (customized);
Supply 3 (S3)	8	- 24" Tripartite Ball Valves Series 600, similar model B5W;	- Operator training;
Supply 4 (S4)	2	- Chromatographs, Similar model to HGC303;	- Technical assistance for commissioning; - Spare parts for 2 years of operation;

3.8. Validation of the result of the mathematical model

To evaluate the ranking, the validation of the model's result was carried out by inviting specialists in the area, who did not participate in the research. The selection considered the minimum criteria defined in 3.4.

In order to apply the developed model, a case study was developed, having as a scenario the oil and gas industry (OGI) in Brazil. The case study is a methodology that uses typically qualitative data, collected from actual events, aiming to explain, explore or describe current phenomena within their context [45,138]. This method is frequently used in several areas and is sometimes highly criticized and poorly understood. One of the main criticisms is the impossibility, from the analysis of one or more cases, to establish generalizations. Another alleged criticism is the lack of scientific rigor, as the researcher is subject to accepting false evidence or biased views that may influence their conclusions [50,126]. Despite criticism, the methodology has been gaining increasing attention. The interest in empirical methods has been increasing due to the need to incorporate real data into research and obtain substantiated results [46]. Furthermore, the case study is beneficial to investigate new concepts and verify how elements of a theory are applied and used in practice [138].

4. Results

4.1. Case Study

With the information described in 3.4, the mathematical model (PROMÉTHÉE GDSS method) was executed, obtaining the following prioritization (as in Table 9) of critical supplies for the EMED project.

The prioritization obtained by the model indicates Alternative 4 (A4) as the most critical supply. The following describes some aspects that make this alternative the most critical, due to the factors observed in Fig. 7, and Tables 6 and 7:

- 1) The individual rankings of DMs (D4/D6/D7/D11/D12/D13) established A4 as the most critical.
- 2) Considering items 2.1/2.2/3.2/2.7/3.1/2.15/3.4/2.6/4.2/4.3 of Table 7, the DMs (D4/D6/D7/D11/D12/D13) assigned high marks (High and Very High) to A4, in all the criteria of Table 4 and some criteria of Table 5.
- 3) Weights between 80 and 100 were observed for (i) D4 for criteria C1/C2/C5/C6/C10; (ii) D6 for all criteria, (iii) D7 for criteria C1/C3/C5/C6, (iv) D11 for criteria C1/C2/C3/C5/C6/C9/C18, (v) D12 for criteria C1/C6, and (vi) D13 for criteria C1/C2/C3/C8.
- 4) For DM (D1/D5/D14/D15/D16), A4 was considered the second-most critical option.

Table 10 and Fig. 8 aims to verify the influence of the DM in obtaining the individual ordinations.

Through Table 10, the stability intervals (SR) of the DMs (D1/D3/D4/D5/D6/D9/D10/D11/D15) are verified as being narrow. This indicates that small variations in the weights of the DMs can alter the final ordering of the alternatives. In fact, this was observed in Fig. 8, where a variation in the weight of D3 can change the position of alternatives A4 and A1. Another highlight is the SR of D2/D13. These SRs do not change, even if the DM's weight changes.

Table 11 shows the prioritization of equipment supply established in 2016 during the implementation of the EMED project.

This prioritization (Table 11) was defined in the project planning phase, where A2 and A3 were considered the most critical. The prioritization considered only aspects of the term, cost, complexity, and feeling, and not the activity risks. However, in the project's implementation, A4 became more critical, followed by A1. It caused a delay of 2.5 months in the project delivery. Comparing Table 11 with the results obtained in Table 9, it appears that this methodology helped the

Table 7
Information for each supply (S).

Code	Particularities of Supplies	S1	S2	S3	S4
Deadlines	1.1 Workdays needed	130	130	130	130
	1.2 Delivery (days)	115	117	120	114
	1.3 On-site delivery (days)	122	124	121	121
Supplier	2.1 Size (Small = 1, Medium = 2, Large = 3)	1	3	2	2
	2.2 Location/Manufacturing (USA = 1, Germany = 2, Brazil = 3, Italy = 4)	1	2	3	4
	2.3 Do you provide financial KPIs?	No	Yes	No	Yes
	2.4 Do you provide factory KPIs?	No	Yes	No	Yes
	2.5 Non-compliance (last 24 months)?	No	Yes	No	No
	2.5.1 If so, was it solved?	-	Yes	-	-
	2.6 Does it have a quality management system?	Yes	Yes	Yes	Yes
	2.7 Current percentage of plant occupancy	85%	75%	50%	70%
	2.8 Employee turnover	High	Low	High	Low
	2.9 Senior position turnover (managerial)	Low	Low	Medium	Low
	2.10 Is the salary position of employees unionized?	No	Yes	No	Yes
	2.11 Is there a possibility of extending the workday?	Yes	Yes	Yes	Yes
	2.12 Does this supply have a dedicated team (design, documentation, manufacturing, purchasing)?	No	Yes	No	No
	2.13 Did you previously provide the customer?	No	Yes	No	Yes
	2.14 Is the supply value in line with the competition's values? (Upper = S, Lower = I)	Yes	Yes	No, (I)	Yes
	2.15 Functional currency with Customer	USD	EUR	BRL	EUR
	2.16 Modal-Supplier x Customer (Air = 1, Road = 2)	1	1	2	1
	2.17 Part of the raw material and components in stock at the factory?	No	No	No	No
Sub-suppliers	2.18 Do you have an ERP system in place?	No	Yes	No	Yes
	3.1 Total sub-suppliers	3	5	4	7
	3.2 Location (USA = 1, China = 2, Germany = 3, India = 4, Italy = 5, Japan = 6, South Korea = 7, Brazil = 8)/Number of sub-supplies of raw materials and components	1/2, 2/1	3/2, 2/2, 4/1	8/2, 2/2	5/1, 2/2, 1/1, 6/1, 7/2
	3.3 Modal-Sub-Suppliers x Supplier (Air = 1, Sea = 2)	1	1	2	1
	3.4 Functional currency with under-delivery (USA = USD = 1, China = USD = 2, Germany = EUR = 3, India = INR = 4, Brazil = BRL = 5, Italy = EUR = 6, Japan = JPY = 7, South Korea = KRW = 8)	1,2	3,2,4	5,2	6,2,1,7,8
	3.5 Was there evidence of implementation of a quality management system (QMS)?	Yes	Yes	Yes	No
	3.6 How are subcontractors monitored? (Remote = 1, Face-to-face = 2)	1	1 and 2	1	1 and 2
Client (EPC and Final)	4.1 Will the project and Databook be commented?	Yes	Yes	Yes	Yes
	4.1.1 Did other stakeholders participate in this step?	Yes	Yes	Yes	Yes
	4.2 Will there be due diligence during manufacturing?	Yes	Yes	Yes	Yes
	4.2.1 Type of inquiries (Remote = 1, Face-to-face = 2)	1	2	2	1
	4.3 Will there be an inspection hold point?	No	Yes	Yes	No
	4.4 Were the deadline estimates checked prior to contracting the supplier?	No	Yes	Yes	No
	4.5 Will there be inspection of receipt in the work?	Yes	Yes	Yes	Yes

Table 8
Scale of judgments.

Verbal Scale	Value
Very low	1
Low	2
Medium	3
High	4
Very high	5

Source: Adapted from Likert [80].

Table 9
Prioritization of EMED project supplies.

Ranking	Supplies	Final Total Flow
Alternative 4 (A4)	S4 - Chromatography System	0,09
Alternative 1 (A1)	S1 - Flow Computer	0,04
Alternative 2 (A2)	S2 - Ultrasonic Flowmeter	-0,03
Alternative 3 (A3)	S3 - 24" Ball Valves	-0,09

Source: PROMÉTHÉE GDSS Software Data.

manager define possible scenarios in terms of critical supplies, and direct the necessary resources to minimize any delays and costs.

4.2. Ranking validation obtained in Table 9

Experts with extensive experience in EPC-LSP SC from OGI were invited to evaluate the ranking obtained in Table 9, and the functionality of the model was developed. This analysis considered the criteria of

Tables 4 and 5, the data of Tables 6 and 7, and the application of the model in the EPC-LSP SCM. All recognized the potentiality of the developed model, and its practical application in the EPC-LSP SCM. All experts agreed with the ranking obtained for the following reasons:

- 1) The alternatives A4 and A1 were critical aspects of the supply. However, A4 was more critical because it had many assembly components, a high number of suppliers with various (international) supply locations, many currencies, and a lack of evidence of QMS (quality management system) implementation at their sub-suppliers.
- 2) Alternative A3 was compared with A1, A2, and A4. This alternative was considered the least critical. Since the leading supplier was national, it had a low occupancy rate, the supplied equipment had low complexity, sub-suppliers were mostly of national origin, and a more significant customer presence was expected in the factory, following the supply in person.

Given the experts' feedback, the prioritization of Table 9 and the model developed were validated.

5. Discussion

The SCRM consists of at least three phases: identification, assessment, and mitigation [52]. These phases depend on the coordination and collaboration of the SC partners [121] for the correct DMG. The DMG in SCRM reflects its complexity and involves analyzing information from all parties involved and the actions that affect the entire SC. To this end, researchers in SC employ efforts to develop methods and

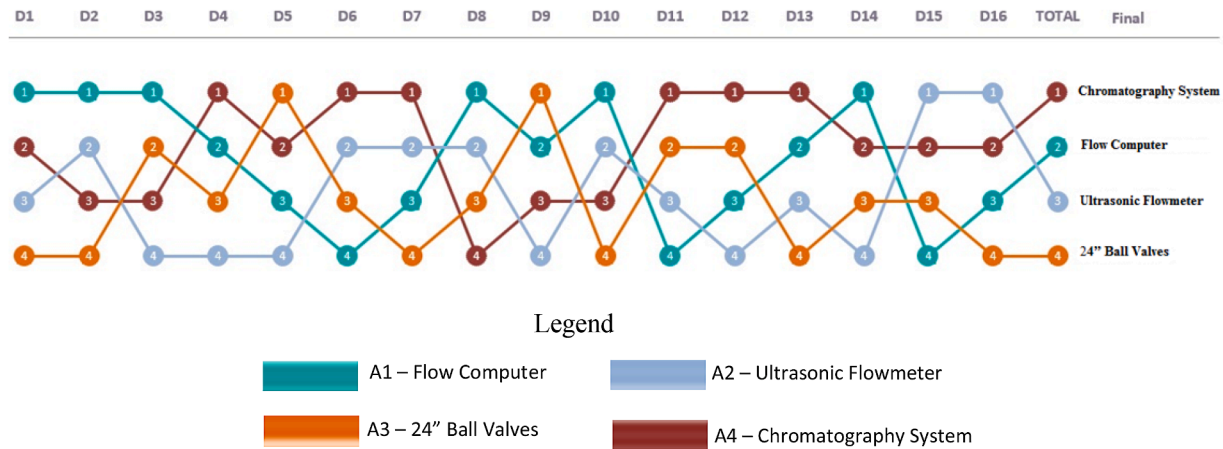


Fig. 7. Individual and final ranking
Source: PROMÉTHÉE GDSS Software Data.

Table 10
Normalized stability intervals.

Decision Makers	Stability Range – SR
1	0,00–0,29
2	0,00–1,00
3	0,00–0,14
4	0,00–0,21
5	0,00–0,18
6	0,00–0,27
7	0,00–0,51
8	0,00–0,51
9	0,00–0,17
10	0,00–0,16
11	0,00–0,16
12	0,00–0,51
13	0,00–1,00
14	0,00–0,37
15	0,00–0,13
16	0,00–0,32

Source: PROMÉTHÉE GDSS Software Data.

techniques to provide DM with the support needed to achieve their goals related to SCRM [140].

Thus, this research presents a methodology and a mathematical model applied to the SCRM of EPC-LSP from the OGI to establish a dynamic and complete prioritization of critical supplies throughout the project's life cycle. This proposal aims to assist the managers' DMG process in defining possible critical supply scenarios. Here, it is necessary to direct resources to minimize delays, excess costs, reduced productivity ([41,72]/ 2013), worsening of image, low financial performance of the industry [133], and disruption of SC [36].

According to Zsidisin and Henke [140], problems of SCRM in EPC-LSP are actual examples of a process that depends on the use of MCDM methods to identify a set of possibilities (alternatives) that are evaluated, considering several conflicting threats (RF/Criteria) by several professionals involved in the SC operation.

The model's criteria (Tables 4 and 5) are defined by identifying RFs through literature and applying questionnaires to specialists in two steps. However, the alternatives are defined based on a supply list of an actual EPC-LSP from Brazil's OGI (Table 6). During the supply assessment process, both the methodology and the model allowed each DM to define the criteria to be used. It also allowed for checking the results of each DM's individual prioritizations and their stability intervals through a sensitivity analysis. It is worth mentioning that the prioritization obtained can be changed, depending on the decision maker's weights, when one wants to simulate prioritizations with DM of various hierarchical levels in the organization. In addition, prioritization can also be

affected depending on the expertise and number of DMs evaluating the RF and problem data (Table 7).

Several studies indicated that the lack of effective RM was the leading cause of the high number of unsuccessful EPC-LSPs in the past [78,139]. This fact is observed in the studied EMED project when comparing the project's priorities with that obtained in the model (in 4.2), considering the supply characteristics at the time (Table 7). This comparison shows that the model's prioritization allowed for the early identification of critical supplies, which could not be identified with the criteria adopted when the project was carried out.

Despite the rich literature on RM and the dizzying increase in publications on SCRM owing to the recent crises and memorable catastrophes, and their impact on global SC [123], there are only a few SCRM research projects applied in the specific context of EPC-LSP [119,127]. It is important to also note the scarcity of (1) research with clear, empirical definitions [123] and (2) studies of practical and specific nature [82] ready to be applied directly in the business environment.

These aspects are mainly due to these projects' specific context, which induces a unique risk exposure with specific risk sources, driven by the complicated technical nature, the lengthy timelines, numerous interfaces, and diverse stakeholders. Existing work in the field concludes that "the lack of predictability of most major projects has become painfully apparent [111]." Therefore, predicting and detecting risks is not easily possible using standard SCRM tools for EPC-LSP. Accordingly, sufficient risk identification and minimization is a significant challenge. Thus, there is a clear need for more robust and useful analytical tools to identify and model SC risk sources for EPC-LSP [32,106].

6. Conclusion and implications for future research

Based on the findings of this study, we can conclude that the research problem was solved, and the questions were answered by applying the solution validated by specialists. As a contribution, managers, companies, and organizations could adopt this solution as a practical and dynamic tool to support decision-making. This fact especially holds true in possible critical supply scenarios, where it is necessary to direct resources to minimize risks and other impacts to EPC-LSP SC. Another novelty refers to the critical risk factors identified, originating from an extensive literature mapping covering the three pillars of sustainability. Moreover, this research fills the literature gap, given the lack of studies that propose clear, practical, and specific tools for SCRM in EPC-LSP.

The limitations of this research are related to scoping. The problem was solved by considering a large-scale EPC project for the oil and gas industry. Non-compensatory criteria, a limited number of alternatives, the definition of weight, and the expertise of the specialists to obtain the ranking using the PROMETHEE GDSS method.

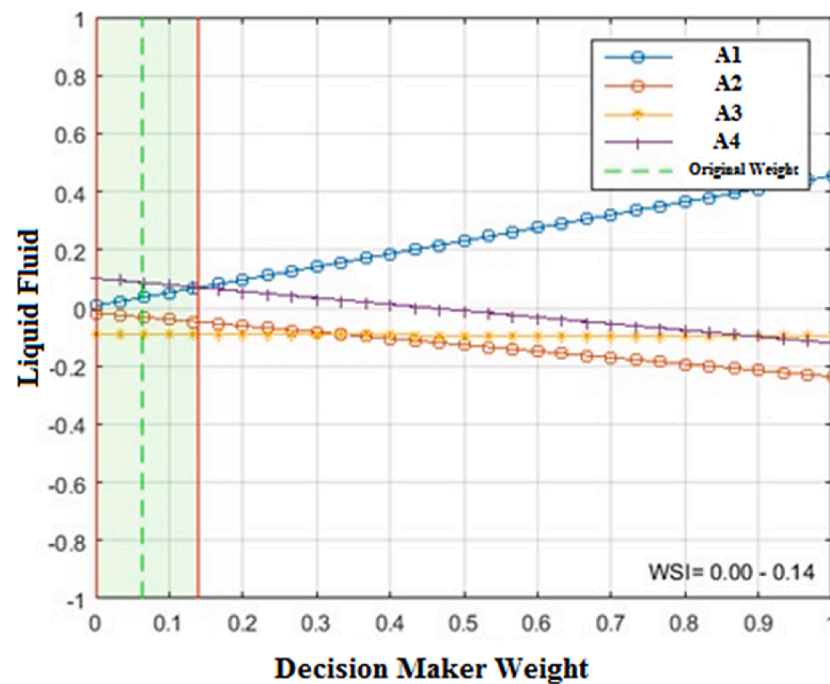


Fig. 8. Sensitivity analysis - Decision 3.

Table 11

Prioritization of EMED project supplies in 2016.

Ranking	Supplies
Alternative 2 – A2	S2 - Ultrasonic Flowmeter
Alternative 3 – A3	S3 - 24" Ball Valves
Alternative 1 – A1	S1 - Flow Computer
Alternative 4 – A4	S4 - Chromatography System

Source: PROMÉTHÉE GDSS Software Data.

Another limitation is related to the application of a case study. Some authors are critical of establishing generalizations from one or more case studies applied to a given problem. However, this methodology has increased interest in the literature, mainly due to the need to aggregate current data to support the results. In addition, according to [138], this method is suitable for investigating new concepts and assessing how the theory is applied and used in practice.

This methodology can be replicated in other industries as long as these industries use large-scale EPC projects as the primary delivery model for products and services. In this way, we understand that the approach was considered adequate, providing an excellent essence of critical RF that impacts OGI's EPC-LSP SCs and a practical application of the model based on the PROMÉTHÉE GDSS method.

These limitations could inspire academics in their future research agendas. It could help validate this proposal in other projects and allow for a better evaluation of its efficiency. Further, validating the present findings in the context of different industries, such as mining, defense, aerospace, energy, and infrastructure, could deliver valuable insights into this field.

Declarations of Competing interest

None.

Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Acknowledgements

We thank the institutions listed below for their support during the development of this research: Federal Fluminense University - UFF

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