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Multicriteria Approach for Supplier Selection: Evidence from a Case Study in the Fashion Industry

Giuseppe Caristi [1], Raffaele Boffardi [2], Cristina Ciliberto [1,*], Roberta Arbolino [2] and Giuseppe Ioppolo [1]

[1] Department of Economics, University of Messina, Via dei Verdi 75, 98122 Messina, Italy; giuseppe.caristi@unime.it (G.C.); giuseppe.ioppolo@unime.it (G.I.)

[2] Department of Social and Human Science, University of Naples "L'Orientale", Largo San Giovanni Maggiore 30, 80134 Naples, Italy; rboffardi@unior.it (R.B.); rarbolino@unior.it (R.A.)

* Correspondence: cristina.ciliberto@unime.it

Abstract: Worldwide manufactures are redesigning supply chains, often outsourcing with the aim of maintaining a competitive advantage and gaining market share. When selecting and purchasing fabrics, firms should actively cooperate with suppliers, to meet customers' needs. In this view, the supplier selection process plays a key role in keeping a competitive edge in global markets. Therefore, this study proposes a multicriteria decision-making model (MCDM) to ease supplier evaluation and selection. Supply chain operation reference metrics (SCOR metrics) and fuzzy technique for order of preference by similarity to ideal solution (FTOPSIS) are combined to build a model for supplier selection. The former allows us to conduct a very thorough fact-based analysis of all features in the supply chain, while the combination of fuzzy theory and SCOR model allows us to deal with uncertainty. The main novelty of this method is that it incorporates a consolidated supply chain management criteria within the framework of fuzzy set theory and multicriteria decision-making model (MCDM) facilitating their application into practice. The proposed approach is tested by considering the case of a manufacturing firm in the fashion industry willing to designate the most appropriate supplier within a set of three potential ones.

Keywords: supplier selection; supply chain management; sustainable manufacturing; textile industry

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1. Introduction

Supplier selection in the manufacturing sector is considered one of the most critical activities within a decision support system (DSS), which contributes to the success of purchasing management in the supply chain [1]. Manufacturing industries are striving to achieve cleaner production and sustainable processes and operations [2,3], viable when suppliers provide non-hazardous raw materials, ruled by environmental legislation and pursued by society [4]. In the apparel industry, the issue of environmental pollution in terms of waste regarding manpower, materials, machinery and especially energy consumption is tackled [5,6]. To reduce operating costs, increase profits, improve service quality and increase customer satisfaction, enterprises should develop a decision-making model that meets their goals [7]. In recent years, the selection of suppliers on behalf of firms must cope with the trade-off between the qualitative and quantitative criteria [8]. They provide a supply of materials, raw materials and commodities in order to satisfy company's requests in a flexible way. In this sense, they also contribute to the reduction in production costs and delivery time, help to improve product quality and fulfil customer requirements. In this scenario, supplier selection in sustainable supply chains, which are circular production systems with a zero-waste perspective, is a challenging problem [9] which must be overcome to accomplish the Sustainable Development Goals (SDGs) of the 2030 Agenda [10].

Consumers' attention to the environmental issues will push producers to shift toward more sustainable production systems, so that natural resources will be protected and handed down to the next generations [11]. The more the environmental awareness increases, the more companies become conscious of their environmental duties. Thus, it is important to leave a sustainable world for future generations. In this context, both the regulations and the responsiveness to the environment resulted in a more responsible supplier selection. This viewpoint is expressed as Green Purchase (GP). In the European Commission's statement on Public Procurement for a Better Environment it is defined as, "*among the goods, services, and works that have the same basic function, they have less environmental impact than their counterparts throughout their life cycle*". In other words, green purchase is the choice of materials to be bought from recyclable, reusable or recycled materials [12].

Therefore, the choice of the best supplier not only regards costs, but also a large set of selection criteria [13]. Supplier selection also helps the implementation of a sustainable supply chain [14] and quality programs in organizations such as just-in-time (JIT) and TQM [15]. The achievement of JIT implementation in any organization depends on different variables such as delivery time after order placed, reliability of supplier, capacity of supplier and quick response by supplier. A reliable supplier helps reduce the inventory cost of manufacturing, improving quality, which is the reason why supplier selection for manufacturing is a matter of greatest importance [16].

Starting from [17], who identified 23 criteria to be considered fundamental in supplier selection problems on behalf of purchasing managers, literature has extensively reviewed supplier selection criteria and techniques [18–21].

Based on evidence provided by the literature, supplier selection cannot be considered a simple decision problem; indeed, it has to be considered a typical multicriteria decision issue [22]. The MCDM method is made up of four components: alternatives, criteria, the weight of each criterion and the calculated performance of each alternative with reference to the criteria [23]. The underlying theory is the multi-criteria decision-making (MCDM), firstly developed by [24]. The authors of [21] claim that the supplier selection process has been modified significantly over the past twenty years due to an increased adoption of emerging technologies, more attention to environmental issues and better-quality policies. Subsequently, literature has developed a multitude of formal approaches aimed at structuring information available to the decision-maker and evaluate potential decisions when facing problems with multiple and conflicting goals [25]. Overall, [26] noted that these techniques (i.e., analytic hierarchy process, analytic network process, technique for order preferences by similarity to an ideal solution, the elimination and choice translating reality method, preference ranking organization methods for enrichment evaluations) are extensively implemented in different company sectors as useful decision-making tools for a final supplier selection. Among these, AHP and TOPSIS present several attributes, advantaging their use in the concerned field. Indeed, both models are easy to be computed and understood since they directly provide definite value to the decision-makers willing to take a final and clear decision [27]. Despite being both suitable to deal with supplier selection problems, comparative studies have shown that TOPSIS (especially if it is combined with fuzzy set theory) better adapts to this kind of problem, due to some intrinsic features (i.e., alternative changing, typology and number of criteria and agility) [28,29]. Recently, extensions of the TOPSIS framework and new approaches have been developed and applied to solve multicriteria dimensional problems, such as DARIA-TOPSIS, SPOTIS and COMET. The DARIA-TOPSIS method has been conceived as an extension of TOPSIS, evaluating the performance of a set of alternatives based on aggregate efficiency scores, in which a dynamic element (changes over time) is considered [30]. Besides providing a time-based evaluation, this technique allows one to identify efficiencies and alternatives rankings in each period investigated [31]. The authors of [32] propose a novel methodology for ordering preferences, i.e., stable preference ordering towards ideal solution method. SPOTIS allows one to establish an ordering of preferences using the scoring matrix of the MCDM problem, by comparing alternatives with respect to the ideal solution. Since it does not require relative comparisons among alternatives, it does not involve rank reversal, thus exempting the methodology from the rank reversal problem [32]. Similarly, the characteristic objects method (COMET) proposes a new approach to deal with the problem of rank reversal [33]. This technique computes characteristic objects from the values of the fuzzy numbers included and the preference values on the basis of a tournament method and the principle of indifference. The ordering is obtained by calculating the distance of each characteristic object from the nearest ones [34].

Based on these premises, the present paper aims to develop a framework for a sustainable supplier selection through the adoption of a multicriteria decision-making model (MCDM). To do so, the supply chain operations reference model (SCOR) and fuzzy technique for order of preference by similarity to ideal solution (FTOPSIS) are combined. The proposed approach is tested on a real-life case study. Defining the decision problem has been the starting point of this analysis: the case company—a firm belonging to the textile and apparel industry—is willing to select the "best" supplier of raw materials from a set of three suppliers. More specifically, the research aims to (i) identify the key selection criteria for suppliers in the textile and apparel industry and those which can be developed from both literature and experts within the case company; (ii) assess how the three suppliers perform on these criteria; and (iii) select a potential supplier for the case company which performs the best on the criteria.

The novelty of the proposed methodology is that it integrates consolidated supply chain management criteria within the framework of fuzzy set theory and multicriteria decision-making model (MCDM), thus easing their application into practice. With this purpose, the supply chain operation references model is considered. It was initially proposed by the Supply Chain Council (SCC), a non-profit professional forum founded in 1996. The SCOR model has been adopted in different industries on the emerging issues of supply chain management, merging the methodology and the analytical techniques and recognizing benchmarks as standards to improve supply chain processes. According to this methodology, supply chain management was codified into combined processes including different steps such as plan, source, make, deliver, return from the suppliers' supplier to the customers' customer, and aligned with a company's strategy [35]. In this way, the SCOR model allows firms to conduct a very thorough fact-based analysis of all features in their supply chain [36]. The combination of fuzzy theory and SCOR model has allowed scholars to address the issues of uncertainty, which strongly characterizes supplier selection problems [1,37]. At present, literature has applied case studies to the SCOR model to investigate the problems in different areas, such as in environmental considerations [38], delivery processes [39], inventory management [40], gas and oil [41] and footwear industry [42]. This decision-making method is an effective tool and enables companies to choose suppliers respecting precise criteria in an organized structure [20].

The paper is organized as follows: Section 2 reviews the main literature on supplier selection. Section 3 presents the methodology used through the research. Section 4 presents the main results, which are discussed in Section 5, where conclusions and future perspectives are presented.

2. Literature Review

By tradition, purchasing means buying the amount and quality of materials when needed and at a convenient price. To accomplish this, it implies specification of purchasing needs, choice of a supplier, achievement of a suitable price, definition of terms and conditions, issuance of a contract and follow up with the supplier for delivery and payment [43].

Supplier selection constitutes one of the six steps in purchasing processes [43]. Despite the overall importance of all actions [44], claimed that supplier selection is fundamental. They highlighted that, in the purchasing process, supplier selection is a topic under the magnifying glass of scholars, entrepreneurs and managers as it plays a key role in achieving higher levels of quality in organizations [43]. The importance of performing a conscious selection of suppliers is also recognized by [43] in the consideration of the potential negative effects deriving from bankruptcy and incapacity to satisfy significant requirements. For these reasons, companies should appraise their suppliers recurrently.

The main aim in a supplier selection process is reducing risks associated with long lasting relationships between buyers and suppliers. Furthermore, a choice of an accurate methodology could maximize the value of the purchaser. On the other hand, when conflicting factors affect an MCDM problem, trade-offs between them are to be examined by a purchasing manager [45]. Therefore, performances of each supplier over time, their financial positions and costs of supplying materials are to be evaluated by organizations in search for suppliers. In this sense, the supplier selection process represents a multiple criteria decision-making (MDCM) issue [46]. It constitutes a crucial area in the operational decision of a company.

Ref. [47] reviewed literature systematically from 1977 to 2022 on the applications of MCDM. Findings revealed that AHP, followed by TOPSIS, VIKOR, PROMETHEE and ANP, are the most adopted multicriteria decision-making methods.

The authors of [21] claimed that the supplier selection process has been modified significantly thanks to the introduction of new technologies and environmental policies. They further highlighted that academic literature and purchasing practitioners have been examining criteria for supplier selection and methods for assessing performance suppliers since the 1960s. Conventionally, selection supplier criteria adopted internal logistic measures, such as price, on time performance, lead-time, responsiveness and damage. Thus, cost, quality, delivery time and service were identified as main groupings in supplier selection [48]. The authors of [49] provided novel evidence on the role played by store brand introduction in shaping manufacturer-led supply chain through a game-theoretic model. They showed that, in a context of competitive interactions and contractual agreements, the timing of decision making about branding strongly impacts a firm's profits and supply chain [49].

Ref. [50] assumed that requirements such as the number of employees, the turnover's financial status and a quality management system can help companies reject suppliers that are entirely lacking them.

In the literature, the difficulty in ranking the criteria of cost, delivery and quality is also accounted for, which is highly considered in just-in-time environments [51]. The trade-off between delivery time and cost is often pointed out, as referred to below, but the correlation between them is hard to defeat. Ref. [43] stated that interrelation among criteria is an inevitable conclusion and the probability of changing one criterion depends on the importance attributed to it by a company. In fact, increasing sustainability along the supply chain is fundamental for improving firms' green development behavior, as stated by [52], who identified several factors affecting it: corporate tangible resource, intangible resources and size, region and industry of enterprise. The relevance of inefficiencies along the supply chain as a source of unsustainable development paths is also recognized by [53], developing a Bayesian equilibrium solution for the construction sector. Ref. [54] provided a reflective backward analysis exploiting the data envelopment analysis (DEA). They evaluated the operational performance and eco-efficiency of two industrial districts in the ceramic sector [54]. SMEs are increasingly pushed to adopt a more sustainable production supply chain. The implementation of a life cycle assessment (LCA) can help them overcome the obstacles present in the utilization of environmental actions [55].

In this respect [56], proposed an analytical hierarchy process (AHP)-based model to assess the value of different environmental factors. They estimated suppliers adopting these criteria. In their study, scholars presented different case studies to illustrate advantages and drawbacks of this method. Findings revealed that AHP can be implemented as a sustainable methodology in an environmentally friendly purchasing (ECP) system. In the context of green supplier selection [57], adopted, in the electronic industry, an AHP method, applying material, energy, solid, liquid, gas residue and technology indicators as environmental criteria. In addition [58], examined the interplay of criteria adopted to identify the green suppliers who consider environmental performance using interpretive structural modeling (ISM) and the AHP model.

To support the selection of the most appropriate green supplier [59], carried out a systematic methodology based on a two-stage survey approach and the AHP–Entropy/TOPSIS methodology. Managers involved in the study positioned traditional criteria higher than environmental alternatives. However [60], used the fuzzy TOPSIS method to choose green suppliers to reduce carbon emissions in the paper industry. Furthermore [61], proposed a hands-on hybrid fuzzy multicriteria decision-making approach based on fuzzy DEMATEL (the decision-making trial and evaluation laboratory), fuzzy ANP and fuzzy TOPSIS methods to assess the green performance of four enterprises. Ref. [62] develop a novel integrated framework for supporting firms' decision making in the selection of Industry 4.0 technologies and FinTech for sustainable supply chain. To do so, they propose a hesitant fuzzy-based Industry 4.0 technology selection model. Similarly, to face difficulties along the vaccine supply chain, hampered by the huge demand for vaccines over the last few years [63], propose a novel fuzzy decision framework based on importance performance analysis (IPA), AHP and TOPSIS.

There are different methods in supplier selection literature adopted to carry out an elimination process for the final selection of suppliers [64]. However [65], highlighted that this portion of the supplier selection process concerns pre-qualification, which is more similar to a sorting process than a ranking one. Therefore, proposed methodologies for pre-qualification are categorical and concern data envelopment analysis, cluster analysis and case-based-reasoning systems. As a matter of fact, supplier selection is considered a typical multicriteria decision problem [22]. The authors of [65] assumed the outranking model as an efficient procedure to adopt in MCDM with qualitative and quantitative characteristics to apply in case of a little or quite finite number of suppliers because not all the traditional decision-making techniques can work appropriately under this condition. Based on these considerations, the MCDM method has to be viewed as a critical system for selecting suppliers. In this regard [66], claimed the leading role of an MCDM process in supplier selection for sellers and buyers. In addition [67], asserted that an MCDM process facilitates companies in decision making, production cost and in improving competitiveness. This method, supported by mathematical techniques, was also adopted in agile environments as it helps to recognize the main factors affecting supplier selection. With reference to the healthcare supply chain management during the COVID-19 pandemic [68], develop a novel technique for supplier selection combining both measuring attractiveness through a categorical-based evaluation technique (MACBETH) and a distance-based assessment method. The pandemic is recognized as a fundamental source of uncertainty and, therefore, fuzzy set theory is applied to the study.

Thus, an MCDM application aims to build a structure for solving decision-making processes with more than one condition. Furthermore, the implementation of hybrid methodologies resulted in the development of innovative MCDM methods suited for specific companies and leading to better results [69].

In conclusion, a decision-making process in supplier selection is a procedure that reflects values and principles of companies [70].

As it can be noticed from the previous literature review, in spite of the presence of several different techniques dealing with it, the selection of a supplier is configured as a multicriteria problem. For this, decision problems dealing with it must be addressed through multicriteria techniques, which scholars have largely exploited (TOPSIS, AHP, ANP, etc.).

Among others, together with AHP, the TOPSIS model is largely used in the literature [66]. In comparison with other techniques, it is referable, due to a large set of advantages it provides, such as the simple theoretical and mathematical framework, the high levels of efficiency in the computation process and the comprehensibility of the results it provides. Furthermore, its integration with fuzzy set theory techniques allows us to deal with uncertainty.

Finally, to the best of our knowledge and considering the literature review presented (Table 1), the application of MCDM techniques for the selection of suppliers in the textile manufacturing industry of Vietnam has not been carried out; thus, there is an opportunity to fill this research gap.

Table 1. Summary of the reviewed literature.

Author(s)	Technique	Application	Contribution
Petroni and Braglia (2000)	Multivariate statistical methods—PCA	Medium-sized manufacturer of bottling machinery and complete packaging lines	Innovative model allowing one to objectively determine the relative importance of each vendor and (ii) involve individual judgments and measures in the analysis
Farzad et al. (2008)	Review of several techniques (AHP)	-	Discusses advantages and disadvantages of the most-used techniques
Basilio-Pereira et al. (2022)	Review of different techniques—AHP, TOSIS, VIKOR, PROMETHEE, ANP	-	Discusses advantages and disadvantages of the most-used techniques
Weber et al. (1991)	Supplier selection criteria analysis	Healthcare industry	Overview of the issue of multicriteria techniques over more than 40 years
Karray and Martin-Herran (2022)	Game-theoretic model	Manufacturing sector	Sheds light on competitive interactions and contractual agreements in the manufacturing industry and the impact of store branding
O'Brien (2009)	Strategic category management	-	Provides a large review of best practices in purchasing category management, together with a wide review of the literature
Narasimhan et al. (2001)	Data envelopment analysis	Telecommunications company	Overcomes several shortcomings from other econometric and multicriterial techniques, allowing cost-effective and swift collection and organization of data
Li et al. (2022)	Meta-analysis	Enterprises	Identifies a set of moderators affecting green development behavior of firms (mainly tangible and intangible resources; size; region)
Zheng et al. (2022)	Bayesian equilibrium solution	Construction and demolition industry	New evidence on the role of information sharing in the recycling sector
Appolloni et al. (2022)	Data envelopment analysis	Two Spanish ceramic industrial sectors	An innovative integration of the reflective management approach with DEA-based backward analysis
Testa et al. (2017)	Life cycle assessment-based product environmental footprint	Recycled wool industry	Shows how SMEs can cooperate with their major stakeholders to respond to external financial pressure and that cooperation facilitates the adoption of LCA in clusters
Handfield et al. (2002)	Analytical hierarchy process (AHP)	A group of companies considering including environmental decisions into the supplier selection process	Integration of environmental criteria in AHP for supporting managerial decision making about supplying
Lu et al. (2007)	Analytical hierarchy process (AHP)	Electronic industry	Innovative method using simple and efficient procedures to evaluate the effectiveness, by using a multi-objective decision-making tool for GSC management (GSCM)
Govindan et al. (2008)	Interpretive structural modeling (ISM) and AHP model	Automobile company	Incorporating criteria for green supplier selection into interpretative structural modeling and analytic hierarchy process

Table 1. *Cont.*

Author(s)	Technique	Application	Contribution
Freeman and Chen (2015)	AHP–Entropy–TOPSIS framework	Electronic machinery manufacturer	Expanding potential application of AHP–Entropy/TOPSIS methodology to real-life SCM cases
Govindan and Sivakumar (2015)	Fuzzy TOPSIS	Low-carbon paper industry	New approach for creating a heterogeneous group decision-making model for selecting suppliers, evaluating them based on green criteria and allocating orders
Uygun and Dede (2016)	Fuzzy DEMATEL, fuzzy ANP and fuzzy TOPSIS	Machine manufacturing	Identifies GSCM dimensions and related criteria through a new model based on the integration of different selection techniques for evaluating GSCM performance of companies
Soni et al. (2022)	Hesitant fuzzy-based Industry 4.0 technology selection model	A group of SMEs	Develops a new framework to support SMEs in decision making for FinTech integration in their in their supply chains
Yadav and Kumar (2022)	A fuzzy decision framework of importance performance analysis (IPA)– AHP–TOPSIS	Vaccine supply chain	Novel methods for including lean-agile-green practices in vaccine supply chains
Jankowski et al. (2019)	Multi-objective optimization	Organic Rankine cycle power plant	Develops a novel approach which allows economic and environmental evaluation separately in the determination of the optimal pinch point temperature
De Boer et al. (2001)	Review of different techniques	-	-
Yildiz and Yayla (2015)	Review of different techniques	Different industries: electrical–electronics, automotive and others	Provides a novel guide for literature on the use of techniques in decision making
Dubey et al. (2015)	MICMAC analysis	Firms from 16 industries	Proposes a mixed-methods technique for the management of green supply chain at firm level
Pamucar et al. (2022)	Categorical-based evaluation technique (MACBETH) and a distance-based assessment method	Healthcare supply chain management	Proposes a novel methodology to face supplier selection problems, combining MACBETH and CODAS methods
Beikkhakhian et al. (2015)	ISM, Fuzzy TOPSIS, AHP	Industrial organizations which manufacture polyethylene products and couplings	Develops of a model which allows firms to identify the most suitable supplier and a set of variables derived from the interpretive structural model which increases efficiency and agility on behalf of the supplier

3. Materials and Methods

The present research relies on an innovative combination of two techniques—i.e., MCDM model with SCOR metrics—implemented to support textile industries in the process of supplier evaluation and selection. The proposed approach is constructed following three main phases (Figure 1):

- Establishing goals and criteria: SCOR metrics and literature reviews were used to develop robust criteria for assessing and selecting suppliers.
- Including all potentially efficient suppliers, through a model which determines the weight of all criteria and sub-criteria.
- By applying a fuzzy TOPSIS model, the set of probable suppliers is ranked and, based on PIS and NIS, the optimum supplier is proposed.

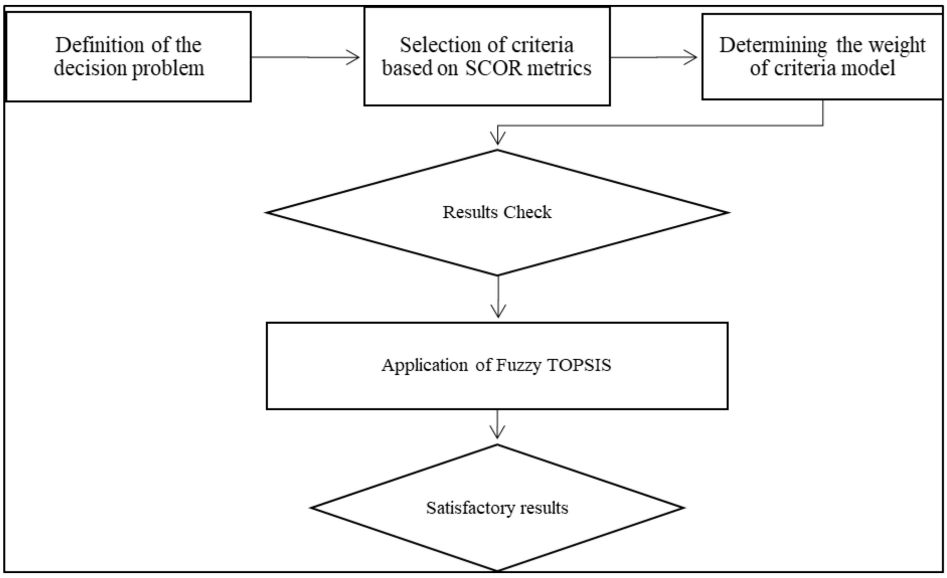

Figure 1. Flow chart of the proposed method for supplier selection.

The final assessments based on the five criteria described in the following paragraph are provided by three managers of a Vietnamese company in the textile industry. They were interviewed on the basis of these criteria to validate the model and understand what requirements a potential supplier should meet.

3.1. Methods for the Selection of Criteria

Criteria to be used in the following analysis are selected based on the performance section of SCOR model, a structure of performance metrics describing five different aspects such as reliability, responsiveness, agility, costs and asset management efficiency. Metrics measure the capacity of a supply chain to reach these goals [71]. In order to identify reliable criteria for supplier selection, literature on SCOR metrics application is reviewed by considering the most recent development on the topic (from 2004 onwards). Ref. [72] was the first author to present SCOR and describe its development and applications. Since then, the SCOR model has been applied to describe the performance of several production sectors. Among others, in the lamp industry [73], the ethanol and petroleum industry [74], geographic information systems [75] and in the service industry [76]. The model has also been linked to other methodologies, thus allowing the expansion of their applications. Integrating the Six Sigma model provides a usable strategic toolset for lean management [77].

The clarification of these metrics and their causal relationship makes the SCOR metric capable of analyzing the performance of a supply chain from different perspectives. The performance attributes of SCOR metrics are described as follows:

3.1.1. Reliability

Reliability requires two kinds of judgements, involving both external factors (i.e., national political conditions and exchange rate) and internal ones (such as trust and warranty policies) [78]. On the side of trust (referring to vendors), frequently used measures involve quality and on time delivery of vendor, while warranty policies implemented by suppliers require standard terms, otherwise a reconsideration of supply chains on the side of buyers should be the most proper action [79]. With reference to external factors, among others, the currency situation needs to be carefully studied by buyers, since higher exchange rates reduce the competitiveness of goods. Therefore, the host country is a fundamental factor which must be assessed when selecting suppliers [78].

3.1.2. Responsiveness

Responsiveness and flexibility of volumes represent a basic need for firms, given the increased relevance of prompt access to products and services and punctual delivery in modern markets [80]. Therefore, actions to increase the response ability, in the short term, organization benefits, while representing a positive determinant of firm performance in the long run [81]. In this framework, order cycle time is defined as the time period that specific flow units spend to go through a process, from entering to leaving [82]. Therefore, the fundamental metric to assess the cycle time "from customer order origination to customer order receipt" is represented by the quantity of time spent, rather than by a quantitative measure of punctual deliveries. The delivery time is counted as the total time required from ordering to producing and shipping [70]. This aspect is negatively influenced by several inefficiencies that might arise along production and transportation processes, as well as the flow of information among the main actors operating in a supply chain [78].

3.1.3. Flexibility Factor

Environmental uncertainties in market dynamics require very high degrees of flexibility, intended as the capability of responding to short-term changes in demand, supply or other external disruptions and adapting in the new environment [79,83]. However, flexibility does not only deal with machinery, but also involves the capability of modifying production patterns and inventory, as well as supplying new jobs when needed, in response to the changeling nature of markets [84]. Therefore, to understand a supplier's flexibility, firms should analyze inventory availability, information sharing, negotiability and customization components [78]. This way, better control over the supply chain is possible, thus allowing a competitive advantage over rival firms [78].

3.1.4. Cost Factor

Considering that the main goal of global sourcing is to abate product prices and thus maximize benefits, cost factors (such as supplier selling cost, internal cost and the charge for invoicing and ordering) are central in determining production flows. Among cost factors, the price of two main inputs is central in supplier's asking price, namely labor and material rate, with the former accounting for almost 50–60% of the final production cost [78]. In this setting, firms located in areas with lower costs of labor and material input report a stronger competitive advantage compared to other subjects [85]. In the sourcing process, internal costs become central role in business profit, with a central role for service costs (such as those related to internal and external communication, promotion activities, payment systems, etc.). This is the reason why a large share of international firms have implemented online financial services, achieving faster, more competent and more profitable management schemes [86].

3.1.5. Asset Management Efficiency

Together with cost factors, asset management attribute is dependent on the internal organization of firms, rather than on costumer behavior (as in the case of the other three groups of attributes). Asset management is often referred to as used/available capacity, and, similarly, SCOR methods rely on measures assessing the ability of boosting plants and equipment capacity with firms [87]. In doing so, these interventions maximize those activities, fostering value added and, simultaneously, reducing time material and orders (including payment for orders) deployed for various processes. Low stock levels, fast transportation options and limited but well-utilized manufacturing facilities are useful aspects allowing one to evaluate operational adjustments and thus managerial abilities. In this vein, at Level 1, assets are operationally defined as total gross product revenue/total net assets.

3.2. Fuzzy Set Theory and Technique for Order Preference by Similarity to Ideal Solution (TOPSIS)

3.2.1. Fuzzy Set Theory

In order to solve rising problems, the vagueness of human thinking has to be represented and treated and thus [88] elaborated the fuzzy set theory.

This theory provides a mathematical representation of both vagueness and uncertainty and is an instrument to cope with decision imprecision. The fundamentals of fuzzy set theory have been elaborated by [88–90] and more recently by [91]. The basic definitions are provided as follows:

Definition 1. *In a universe of discourse X, the belonging or not of an element to a set A is expressed (in numeric terms) by a membership function $\mu A(x)$. It assigns a real number ranging between (0) and (1) to each element x. The grade of membership of x in A defines the value of the membership function* [77].

Definition 2. *A fuzzy set A is convex if and only if X is convex and*

$$\mu A\ (\lambda\ x_1 + (1 - \lambda x_2)\ )\ \geq min\ (\mu A(\ x_1) \cdot\ \mu A(x_2))$$

For X and λ $[0, 1]$, where min represents the minimum operator [92].

Definition 3. *The height of a fuzzy set A on X is the maximum grade of membership reported by each element in the set. A fuzzy set A in the universe of discourse X is defined as normal when:*

$$Alt(A) = 1$$

where Alt(A) represents the height of A [92].

Compared with traditional binary logic (based only on true or false values), fuzzy variables assume values between 0 and 1. In doing so, fuzzy logic is able to handle issues deriving from the concept of partial truth, according to which truth can range from totally true to totally false.

The key idea of fuzzy set theory is that each element belongs to a precise set. Its degree of membership is evaluated through values between 0 and 1. A triangular fuzzy number (TFN) is defined by a triplet (i.e., three points; $l,\ m,\ n$). The membership function of this fuzzy number $\mu_{\tilde{A}}(X) :\ R\ \rightarrow\ [0, 1]$ is given in Equation (1).

$$\mu_{\tilde{A}}(X) = \left\{ \begin{array}{l} 0,\ for\ x < l,\ x > n \\ \frac{x-l}{m-l}\ for\ l \leq x \leq m \\ \frac{x-n}{m-n}\ for\ m \leq x \leq n \end{array} \right\} \quad (1)$$

3.2.2. Fuzzy TOPSIS (FTOPSIS)

The technique for order preference by similarity to ideal solution (TOPSIS) was developed in 1981 by [93]. The idea underlying this technique is that, based on a set of selected criteria, the alternative to be chosen will be the closest to the positive-ideal solution and, simultaneously, the farthest from the negative-ideal one. As a consequence, alternatives ranking will be constructed by considering both closeness and distance from the two ideal solutions, which are artificial and identified as follows [27]:

- Positive-ideal alternative: the alternative achieving the highest score with reference to all the attributes involved in the analysis, or say differently, "all best criteria values attainable". This solution leads to the maximization of all benefits and a minimization of costs.
- Negative-ideal alternative: by reporting the lowest level of the attributes considered, or say differently, "all worst criteria values attainable", this alternative results in benefit minimization and cost maximization [94].

In doing so, TOPSIS might be considered a compensatory method, allowing trade-offs among the set of criteria identified, i.e., weak performance in terms of one or more criteria can be balanced by a strong one in another criterion. This categorization is confirmed by the nature of the best alternative resulting from the model, expressed as that with the shortest distance from the PIS and the opposite for the NIS [95].

Due to the presence of ambiguities, vagueness and uncertainties related to the supplier selection process, the present study employs fuzzy TOPSIS (FTOPSIS) for performance evaluation.

In this context, it is required a specification. According to [96], a temporal supplier evaluation model would imply inserting variability factors over time. In this model, the analysis of variability of decision factors over time and the analysis of the impact of that variability is taken into consideration. Despite the fact that it would be interesting to consider the variability of decision factors over time, in our study we decided to follow the classical MCDM theory, assuming the constancy of both the set of alternatives and the criteria for their evaluation in order to not affect the accuracy of the process.

This combination of techniques allows us to exploit linguistic variables, rather than numerical ones, providing a suitable tool to manage often imprecise criteria dealing with both qualitative and quantitative aspects [28]. As proved by the extensive review provided by [97], fuzzy set theory and multicriteria decision-making techniques, especially TOPSIS, have been extensively used together over the last decade. The application of FTOPSIS comprises the following steps:

Step 1: Generation of alternatives (m), determination of the evaluation criteria (n) and creation of a decision-maker pair (k).

Step 2: Decision about both linguistic terms assessing the importance of weights associated with each criterion ($\widetilde{w}_j = n_{ij}, o_{ij}, p_{ij}$) and linguistic ratings referring to the weights of criteria ($\widetilde{x}_{ij}$).

Step 3: Creation of the aggregated fuzzy weight $\widetilde{w}_j$ of criterion C_i caused by the aggregation of the weight of criteria. Fuzzy rating $\widetilde{x}_{ij}$ of alternative S_i under criterion C_j is provided by experts.

$$\widetilde{x}_{ij} = \frac{1}{k}\left[\widetilde{x}_{ij}^{1} + \widetilde{x}_{ij}^{2} + \cdots + \widetilde{x}_{ij}^{k}\right]; i = 1, 2, \ldots, m; j = 1, 2, \ldots, n \tag{2}$$

$$\widetilde{w}_{ij} = \frac{1}{k}\left[\widetilde{w}_{ij}^{1} + \widetilde{w}_{ij}^{2} + \cdots + \widetilde{w}_{ij}^{k}\right]; j = 1, 2, \ldots, n \tag{3}$$

Step 4: Elaboration of the fuzzy decision matrix.

$$A = \begin{bmatrix} S_1 \\ S_2 \\ S_3 \\ \vdots \\ S_m \end{bmatrix} \begin{bmatrix} C_1 & C_2 & C_3 & \cdots & C_n \\ y_{11} & y_{12} & y_{13} & \cdots & y_{1n} \\ y_{21} & y_{22} & y_{23} & \cdots & y_{2n} \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ y_{m1} & y_{m2} & y_{m3} & \cdots & y_{mn} \end{bmatrix}; \ \widetilde{w} = [\widetilde{w_1}, \widetilde{w_2}, \ldots, \widetilde{w_n}] \tag{4}$$

Step 5: Normalization of the fuzzy decision matrix through a linear scale transformation applied on the raw data, transforming criteria scales into a comparable one. It is denoted by $\widetilde{R}$. In MCDM models, the normalization process serves to homogenize all the variables considered and to be able to compare them with each other [98].

$$\widetilde{R} = \left[\widetilde{r}_{ij}\right]_{mxn}; i = 1,2,\ldots,m\,; j = 1,2,\ldots n \quad (5)$$

$$\widetilde{r}_{ij} = \left(\frac{a_{ij}}{c_j^+}, \frac{b_{ij}}{c_j^+}, \frac{c_{ij}}{c_j^+}\right); \text{ and } c_j^+ = maxc_{ij}(\text{benefit criteria}) \quad (6)$$

$$\widetilde{r}_{ij} = \left(\frac{a_j^-}{c_{ij}}, \frac{a_j^-}{b_{ij}}, \frac{a_j^-}{a_{ij}}\right); \text{ and } a_j^- = mina_{ij}(\cos\text{t criteria}) \quad (7)$$

Step 6: Creation of a weighted normalized matrix $\widetilde{V}$ resulting from the product of the normalized fuzzy decision matrix $\widetilde{r}_{ij}$ and the weight $\widetilde{w}_{ij}$ of the evaluation criteria.

$$\widetilde{V} = \left[\widetilde{v}_{ij}\right]_{mxn};\ i = 1,2,\ldots,m;\ j = 1,2,\ldots,n; \text{where } \widetilde{v}_{ij} = \widetilde{r}_{ij}(.)\widetilde{w}_j \quad (8)$$

Step 7: Identification of the negative-ideal solution (NIS) and the positive-ideal solution (PIS):

$$Z^+ = \left\{\widetilde{v}_1^+, \widetilde{v}_2^+, \ldots, \widetilde{v}_n^+\right\}; \text{ where } \widetilde{v}_j^+ = max\widetilde{v}_{ij3}; i = 1,2,\ldots,m; j = 1,2,\ldots,n \quad (9)$$

$$Z^- = \left\{\widetilde{v}_1^-, \widetilde{v}_2^-, \ldots, \widetilde{v}_n^-\right\}; \text{ where } \widetilde{v}_j^- = min\widetilde{v}_{ij1}; i = 1,2,\ldots,m; j = 1,2,\ldots,n \quad (10)$$

where $d_v(\widetilde{a}, \widetilde{b})$ describes the distance between two fuzzy numbers $\widetilde{a}$ and $\widetilde{b}$.

Step 8: Calculate the distance of PIS (d_i^+) and NIS (d_i^-) using:

$$d_i^+ = \left\{\sum_{j=1}^n \left(v_{ij} - v_j^+\right)^2\right\}^{\frac{1}{2}}, i = 1,2,\ldots,m \quad (11)$$

$$d_i^- = \left\{\sum_{j=1}^n \left(v_{ij} - v_j^-\right)^2\right\}^{\frac{1}{2}}, i = 1,2,\ldots,m \quad (12)$$

where d_i^+ and d_i^- measure the distances of the worst and best conditions from the target alternative.

Step 9: Determination of the CC_i value:

$$CC_i = \frac{d_i^-}{d_i^+ + d_i^-} \quad (13)$$

Step 10: Ranking of the set of alternatives (suppliers), according to a decreasing order of (CC_i).

4. Results

By exploiting the criteria discussed in the previous sections, three experts were interviewed to test the proposed model. Through the interviews, a set of criteria to be included in the model and the potential supplier requirements were defined according to the SCOR metrics (Table 2).

Two project managers and a purchasing manager—decision-maker 1 (DM-1), decision-maker 2 (DM-2) and decision-maker 3 (DM-3)—were consulted to obtain information about purchasing decisions. They were required to select the preferred supplier(s) from a list of three potential suppliers: supplier 1 (S1), supplier 2 (S2) and supplier 3 (S3).

The decision-making process proceeds as follows. Table 3 describes the linguistic values and fuzzy numbers, while the calculated weights are reported in Table A1 (Appendix A).

Table 2. SCOR metrics, criteria and sub-criteria.

Main Criteria	Sub-Criteria
Reliability (A)	On time delivery A1 Geographic location a2 Delivered the right quantity A3
Responsiveness (B)	Order fulfilment cycle time B1 Processing time of returns B2
Flexibility(C)	Order fulfilment lead time C1 Continuous quality improvement programs C2 Certification C3
Cost (D)	Freight cost D1 Processing cost of returns D2 Cost of materials D3
Assets (E)	Cash-to-cash cycle time E1 Asset turns E2 Inventory value E3

Table 3. Linguistic values and fuzzy numbers.

Linguistic Values	Fuzzy Number
Very low (VL)	(0.1, 0.1, 0.3)
Low (L)	(0.1, 0.3, 0.5)
Medium (M)	(0.3, 0.5, 0.7)
High (H)	(0.5, 0.7, 0.9)
Very high (VH)	(0.7, 0.9, 0.9)

After assigning a weight to each criterion, linguistic scale values for each criterion were collected with reference to all supplier alternatives. These values consist of five values: very low (VL), low (L), medium (M), high (H) and very high (VH). Table A2 reports the linguistic fuzzy evaluation matrix for the ranking of suppliers, as provided by the three decision-makers. Following Table 2, linguistic values are converted into fuzzy numbers. Values provided in Table 2 are exploited by most studies dealing with linguistic values and fuzzy numbers. Linguistic values are converted as VL = (0.1; 0.1; 0.3), L = (0.1; 0.3; 0.5), M = (0.3; 0.5; 0.7), H = (0.5; 0.7; 0.9) and VH = (0.7; 0.9; 0.9). Table 4 reports the linguistic fuzzy evaluation matrices for the ranking of alternatives.

Table 4. Fuzzy decision matrices for alternative ranking.

	DM1			DM2			DM3		
Criteria	**S1**	**S2**	**S3**	**S1**	**S2**	**S3**	**S1**	**S2**	**S3**
A1	(0.5, 0.7, 0.9)	(0.3, 0.5, 0.7)	(0.5, 0.7, 0.9)	(0.3, 0.5, 0.7)	(0.1, 0.3, 0.5)	(0.5, 0.7, 0.9)	(0.3, 0.5, 0.7)	(0.3, 0.5, 0.7)	(0.7, 0.9, 0.9)
A2	(0.7, 0.9, 0.9)	(0.1, 0.3, 0.5)	(0.1, 0.1, 0.3)	(0.5, 0.7, 0.9)	(0.3, 0.5, 0.7)	(0.1, 0.1, 0.3)	(0.7, 0.9, 0.9)	(0.1, 0.3, 0.5)	(0.1, 0.3, 0.5)
A3	(0.5, 0.7, 0.9)	(0.3, 0.5, 0.7)	(0.7, 0.9, 0.9)	(0.3, 0.5, 0.7)	(0.1, 0.3, 0.5)	(0.5, 0.7, 0.9)	(0.3, 0.5, 0.7)	(0.3, 0.5, 0.7)	(0.5, 0.7, 0.9)
B1	(0.3, 0.5, 0.7)	(0.5, 0.7, 0.9)	(0.5, 0.7, 0.9)	(0.1, 0.3, 0.5)	(0.3, 0.5, 0.7)	(0.3, 0.5, 0.7)	(0.1, 0.1, 0.3)	(0.3, 0.5, 0.7)	(0.3, 0.5, 0.7)
B2	(0.5, 0.7, 0.9)	(0.1, 0.1, 0.3)	(0.1, 0.3, 0.5)	(0.3, 0.5, 0.7)	(0.1, 0.3, 0.5)	(0.1, 0.3, 0.5)	(0.5, 0.7, 0.9)	(0.5, 0.7, 0.9)	(0.1, 0.1, 0.3)
C1	(0.5, 0.7, 0.9)	(0.5, 0.7, 0.9	(0.3, 0.5, 0.7)	(0.5, 0.7, 0.9)	(0.3, 0.5, 0.7)	(0.3, 0.5, 0.7)	(0.7, 0.9, 0.9)	(0.3, 0.5, 0.7)	(0.3, 0.5, 0.7)
C2	(0.1, 0.3, 0.5)	(0.5, 0.7, 0.9)	(0.7, 0.9, 0.9)	(0.3, 0.5, 0.7)	(0.7, 0.9, 0.9)	(0.7, 0.9, 0.9)	(0.1, 0.3, 0.5)	(0.5, 0.7, 0.9)	(0.5, 0.7, 0.9)
C3	(0.3, 0.5, 0.7)	(0.5, 0.7, 0.9)	(0.7, 0.9, 0.9)	(0.3, 0.5, 0.7)	(0.7, 0.9, 0.9)	(0.7, 0.9, 0.9)	(0.1, 0.3, 0.5)	(0.5, 0.7, 0.9)	(0.7, 0.9, 0.9)
D1	(0.7, 0.9, 0.9)	(0.1, 0.3, 0.5)	(0.1, 0.1, 0.3)	(0.7, 0.9, 0.9)	(0.3, 0.5, 0.7)	(0.1, 0.3, 0.5)	(0.5, 0.7, 0.9)	(0.1, 0.3, 0.5)	(0.1, 0.1, 0.3)
D2	(0.3, 0.5, 0.7)	(0.1, 0.3, 0.5)	(0.1, 0.3, 0.5)	(0.3, 0.5, 0.7)	(0.3, 0.5, 0.7)	(0.1, 0.3, 0.5)	(0.5, 0.7, 0.9)	(0.1, 0.3, 0.5)	(0.1, 0.3, 0.5)
D3	(0.3, 0.5, 0.7)	(0.5, 0.7, 0.9)	(0.1, 0.1, 0.3)	(0.3, 0.5, 0.7)	(0.7, 0.9, 0.9)	(0.1, 0.3, 0.5)	(0.3, 0.5, 0.7)	(0.5, 0.7, 0.9)	(0.1, 0.1, 0.3)
E1	(0.3, 0.5, 0.7)	(0.3, 0.5, 0.7)	(0.7, 0.9, 0.9)	(0.3, 0.5, 0.7)	(0.5, 0.7, 0.9)	(0.5, 0.7, 0.9)	(0.1, 0.3, 0.5)	(0.7, 0.9, 0.9)	(0.7, 0.9, 0.9)
E2	(0.3, 0.5, 0.7)	(0.1, 0.3, 0.5)	(0.5, 0.7, 0.9)	(0.3, 0.5, 0.7)	(0.3, 0.5, 0.7)	(0.7, 0.9, 0.9)	(0.1, 0.3, 0.5)	(0.5, 0.7, 0.9)	(0.7, 0.9, 0.9)
E3	(0.1, 0.3, 0.5)	(0.7, 0.9, 0.9)	(0.3, 0.5, 0.7)	(0.1, 0.3, 0.5)	(0.5, 0.7, 0.9)	(0.5, 0.7, 0.9)	(0.1, 0.1, 0.3)	(0.5, 0.7, 0.9)	(0.5, 0.7, 0.9)

The subsequent step involves the creation of a weighted normalized fuzzy decision matrix, based on the normalized fuzzy decision matrix (Table 5) and the weights of criteria reported in Table A1 (Appendix A). Weighting criterion in each row is multiplied to the fuzzy value of each row.

Table 5. Normalized fuzzy decision matrix.

Criteria	S1	S2	S3
A1	(0.333, 0.630, 1)	(0.111, 0.481, 0.778)	(0.556, 0.852, 1)
A2	(0.556, 0.923, 1)	(0.111, 0.407, 0.778)	(0.111, 0.185, 0.556)
A3	(0.333, 0.623, 1)	(0.111, 0.481, 0.778)	(0.556, 0.852, 1)
B1	(0.143, 0.333, 1)	(0.111, 0.176, 0.333)	(0.111, 0.177, 0.333)
B2	(0.111, 0.158, 0.333)	(0.111, 0.273, 1)	(0.2, 0.429, 1)
C1	(0.556, 0.852, 1)	(0.333, 0.629, 1)	(0.333, 0.556, 0.778)
C2	(0.111, 0.407, 0.778)	(0.556, 0.852, 1)	(0.556, 0.926, 1)
C3	(0.111, 0.481, 0.778)	(0.556, 0.852, 1)	(0.778, 1, 1)
D1	(0.111, 0.12, 0.2)	(0.143, 0.273, 1)	(0.2, 0.6, 1)
D2	(0.111, 0.176, 0.333)	(0.143, 0.273, 1)	(0.2, 0.333, 1)
D3	(0.143, 0.2, 0.333)	(0.111, 0.130, 0.2)	(0.2, 0.6, 1)
E1	(0.143, 0.231, 1)	(0.111, 0.143, 0.333)	(0.111, 0.12, 0.2)
E2	(0.143, 0.231, 1)	(0.111, 0.2, 1)	(0.111, 0.12, 0.2)
E3	(0.2, 0.429, 1)	(0.111, 0.130, 0.2)	(0.111, 0.158, 0.333)

For constructing the weighted normalized fuzzy evaluation matrix, the same procedures are applied to the other supplier alternatives (Table 6).

Table 6. Weighted normalized fuzzy decision matrix.

Criteria	S1	S2	S3
A1	(0.1667, 0.525, 0.9)	(0.056, 0.401, 0.7)	(0.278, 0.709, 0.9)
A2	(0.2778, 0.709, 0.9)	(0.056, 0.312, 0.7)	(0.056, 0.142, 0.5)
A3	(0.1, 0.399, 0.9)	(0.033, 0.305, 0.7)	(0.167, 0.539, 0.9)
B1	(0.071, 0.278, 0.9)	(0.056, 0.147, 0.3)	(0.056, 0.147, 0.3)
B2	(0.0556, 0.111, 0.3)	(0.056, 0.191, 0.9)	(0.1, 0.3, 0.9)
C1	(0.389, 0.767, 0.9)	(0.233, 0.567, 0.9)	(0.23, 0.5, 0.7)
C2	(0.033, 0.285, 0.7)	(0.167, 0.596, 0.9)	(0.167, 0.648, 0.9)
C3	(0.033, 0.272, 0.7)	(0.167, 0.483, 0.9)	(0.233, 0.567, 0.9)
D1	(0.0333, 0.076, 0.18)	(0.043, 0.173, 0.9)	(0.06, 0.38, 0.9)
D2	(0.033, 0.1, 0.3)	(0.043, 0.155, 0.9)	(0.06, 0.189, 0.9)
D3	(0.071, 0.167, 0.3)	(0.056, 0.109, 0.18)	(0.1, 0.5, 0.9)
E1	(0.071, 0.177, 0.9)	(0.056, 0.109, 0.3)	(0.056, 0.092, 0.18)
E2	(0.0423, 0.161, 0.9)	(0.033, 0.14, 0.9)	(0.033, 0.084, 0.18)
E3	(0.1, 0.329, 0.9)	(0.056, 0.1, 0.18)	(0.056, 0.121, 0.3)

The fuzzy PIS and fuzzy NIS for the given criteria are calculated using Equations (9) and (10) and reported in Table 7. Then, the distance between PIS, NIS and each proposed alternative is computed following Equations (11) and (12) (Tables A3 and A4, Appendix B).

Table 7. Fuzzy PIS and fuzzy NIS.

Criteria	Z_+	Z^-
A1	(0.278, 0.709, 0.9)	(0.056, 0.401, 0.7)
A2	(0.278, 0.709, 0.9)	(0.056, 0.1412, 0.5)
A3	(0.167, 0.539, 0.9)	(0.033, 0.305, 0.7)
B1	(0.071, 0.278, 0.9)	(0.056, 0.147, 0.3)
B2	(0.1, 0.3, 0.9)	(0.056, 0.111, 0.3)
C1	(0.389, 0.767, 0.9)	(0.233, 0.5, 0.7)
C2	(0.167, 0.648, 0.9)	(0.033, 0.285, 0.7)
C3	(0.23, 0.5667, 0.9)	(0.033, 0.273, 0.7)
D1	(0.06, 0.38, 0.9)	(0.033, 0.076, 0.18)
D2	(0.06, 0.189, 0.9)	(0.033, 0.1, 0.3)
D3	(0.1, 0.5, 0.9)	(0.056, 0.109, 0.18)
E1	(0.071, 0.177, 0.9)	(0.056, 0.092, 0.18)
E2	(0.043, 0.162, 0.9)	(0.033, 0.084, 0.18)
E3	(0.1, 0.3289, 0.9)	(0.0556, 0.1, 0.18)

For example, for supplier 1 (S1), the A1 criterion (on time delivery) is computed as (0.5; 0.833; 0.9), while fuzzy values are (0.333; 0.630; 1). Therefore, the corresponding value reported in the fuzzy weighted evaluation matrix is computed as follows: [(0.5 × 0.333), (0.883 × 0.630), (0.9 × 1)] = (0.1667; 0.525; 0.9).

Finally, based on the fundamental rule that, in the TOPSIS model, the best alternative will be the one that minimizes the distance from the PIS, while simultaneously maximizing the distance from the negative-ideal one, the ranking of alternatives is obtained based on the CC_i. CC_i is the closeness index, computed using Equation (13) and given in the following table (Table 8).

Table 8. Fuzzy closeness index and ranking of supplier alternatives.

Supplier	d_i^+	d_i^-	CC_i	Ranking
S1	2.264	2.623	0.536	2
S2	2.805	2.288	0.449	3
S3	2.192	2.639	0.546	1

Based on this evidence, supplier 3 (S3) is selected as the best solution, being the closest to d_i^+ (2.192) and the furthest from d_i^- (2.639), proved by the highest closeness index (0.546) (Figure 2).

Figure 2. Final ranking score.

5. Discussion, Conclusions and Future Perspectives

This research covered two main objectives. A supplier selection model was proposed and implemented into practice through a multiple criteria decision-making method. To achieve the second objective, the determination of supplier selection criteria and a suitable multiple criteria decision-making method were two fundamental concerns. Both were faced in the paper and their importance in helping companies manage product sourcing in order to improve their whole supply chain was shown. Supplier selection model and supplier selection criteria are constantly expanding topics that, over time, are including different combinations of methodologies and this is contributing to the solution of many decision-making problems in various fields.

In the study, a review of the literature comprising sustainable supplier selection models and supplier selection criteria using the SCOR model was carried out to develop an innovative supplier selection model. Second, in-depth interviews and discussions with experts in the field of the research, the fashion industry, were conducted to analyze their current set of supplier selection conditions and methodologies. After that, a supplier selection model, a fuzzy TOPSIS method, and a set of supplier selection criteria were proposed taking into consideration the features of the fashion industry. With regard to the set of selection criteria, it needs to be re-assessed in the specific company sector. Various statistical tests were conducted to validate survey results. The set of supplier selection criteria is composed of fiv5 criteria (reliability, responsiveness, flexibility, cost and assets) and 14 sub-criteria. These 14 sub-criteria are allocated into 5 criteria as follows:

- Reliability: On time delivery, geographic location and delivery of the right quantity.
- Responsiveness: Order fulfilment cycle time and processing time of returns.
- Flexibility: Order fulfilment lead time, continuous quality improvement programs and certification.
- Cost: Freight cost, processing cost of returns and cost of materials.
- Assets: Cash-to-cash cycle time, asset turns and inventory value.

Thus, an effort to apply the set of supplier selection criteria into practice by using the fuzzy TOPSIS method was conducted. Findings reveal that purchasing companies can adopt this model and the set of criteria to evaluate and choose the greenest and most sustainable suppliers. The model is also useful in helping pursue sustainable growth based on the green economy and is strategically competitive in the market. In addition, the model developed through the fuzzy TOPSIS method provides decision-makers with wide-ranging evaluations in respect to the multiple criteria ranging the performance metrics.

In the study, the proposed model was built through three steps listed in Section 4. In the first phase, all criteria affecting raw material suppliers have been specified, based on the SCOR model. In the second phase, criteria have been evaluated on a fuzzy scale with the help of experts. In the final stage, the fuzzy TOPSIS method was applied to enrich selection, rank suppliers and select the most suitable one. As a result, the optimal supplier was determined and it was supplier 3 (S3).

The textile and apparel industry's supplier selection model is to some extent a new research topic and has caught the attention of organizations and academicians, despite the fact that the selection model and selection criteria for suppliers were first analyzed ten years ago.

The theoretical contribution of the proposed methodology is that it integrates classical supply chain management criteria within the framework of fuzzy set theory and multicriteria decision-making model (MCDM). This combination facilitates their application into practice. Furthermore, in the textile industry in Vietnam, there is still limited evidence of selection criteria and selection models.

In conclusion, the adopted model can serve as a precious tool for the examination of company purchasing activity and it can also result in better resource management. The supplier selection model carried out in this work and the comprehensive set of supplier selection conditions provided can support decision-making processes, combining all information in a single pattern.

Further empirical studies on this topic are needed to validate the model. It would also be interesting to make a comparison between this model and other MCDM models applied to the same sector for selecting suppliers.

As a matter of fact, in a nation such as Vietnam, a consistent number of responses from textile industries are needed to generalize the obtained results to all Vietnamese textile manufacturing sectors.

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Appendix A

Table A1. Weights of all criteria.

Criteria	Weights
On time delivery A1	(0.5, 0.833, 0.9)
Geographic location A2	(0.5, 0.767, 0.9)
Delivery the right quantity A3	(0.3, 0.633, 0.9)
Order fulfilment cycle time B1	(0.5, 0.833, 0.9)
Processing time of returns B2	(0.5, 0.7, 0.9)
Order fulfilment lead time C1	(0.7, 0.9, 0.9)
Continuous quality improvement programs C2	(0.3, 0.7, 0.9)
Certification C3	(0.30.567, 0.9)
Freight cost D1	(0.3, 0.633, 0.9)
Processing cost of returns D2	(0.3, 0.567, 0.9)
Cost of materials D3	(0.5, 0.833, 0.9)
Cash-to-cash cycle time E1	(0.5, 0.767, 0.9)
Asset turns E2	(0.3, 0.7, 0.9)
Inventory value E3	(0.5, 0.767, 0.9)

Table A2. Linguistic evaluation matrices for the ranking of alternatives.

Criteria	Decision-Maker 1			Decision-Maker 2			Decision-Maker 3		
	S1	S2	S3	S1	S2	S3	S1	S2	S3
A1	H	A	H	A	L	H	A	A	VH
A2	VH	L	VL	H	A	VL	VH	L	L
A3	H	A	VH	A	L	H	A	A	H
B1	A	H	H	L	A	A	VL	A	A
B2	H	VL	L	A	L	L	H	H	VL
C1	H	H	A	H	A	A	VH	A	A
C2	L	H	VH	A	VH	VH	L	H	H
C3	A	H	VH	A	VH	VH	L	H	VH
D1	VH	L	VL	VH	A	L	H	L	VL
D2	A	L	L	A	A	L	H	L	L
D3	A	H	VL	A	VH	L	A	H	VL
E1	A	A	VH	A	H	H	L	VH	VH
E2	A	L	H	A	A	VH	L	H	VH
E3	L	VH	A	L	H	H	VL	H	H

Appendix B

Table A3. Distance of d_i^+ for alternatives.

Criteria	S1	S2	S3
A1	0.125	0.248	0
A2	0	0.287	0.421
A3	0.090	0.194	0
B1	0	0.355	0.355
B2	0.364	0.068	0
C1	0	0.146	0.212
C2	0.251	0.030	0
C3	0.235	0.062	0
D1	0.451	0.120	0
D2	0.351	0.022	0
D3	0.397	0.474	0
E1	0	0.349	0.418
E2	0	0.014	0.418
E3	0	0.437	0.367
d_i^+	2.264	2.805	2.192

Table A4. Distance of d_i^- for alternatives.

Criteria	S1	S2	S3
A1	0.150	0	0.248
A2	0.421	0.152	0
A3	0.133	0	0.194
B1	0.355	0	0
B2	0	0.350	0.364
C1	0.212	0.121	0
C2	0	0.227	0.251
C3	0	0.184	0.235
D1	0	0.419	0.451
D2	0	0.348	0.350
D3	0.077	0	0.473
E1	0.419	0.070	0
E2	0.418	0.417	0
E3	0.437	0	0.070
d_i^-	2.623	2.288	2.639

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