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A supply chain risk management maturity model and a multi-criteria classification approach

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Abstract

Purpose – The purpose of this paper is to propose a supply chain risk management (SCRM) maturity model combined with a fuzzy TOPSIS classification method to evaluate and sort an organization into a pre-defined maturity level.

Design/methodology/approach – An axiomatic and prescriptive research method guided this study. Therefore, it proposes a prescriptive approach of maturity classification based on a theoretical SCRM maturity model combined with a multi-criteria decision technique.

Findings – The results of a pilot application indicated a consistent classification and the value of the model for diagnosing flaws and pointing directions for improving operational and disruption risk management. Its comprehensiveness allows applying it to supply chains of several industry sectors.

Research limitations/implications – The proposed model does not include all possible risks and could be revised in further developments. Also, adjustment of the maturity profiles of the multi-criteria decision-making (MCDM) model requires a learning process from practical applications.

Practical implications – The adoption of the risk management maturity grid by practitioners may bring the benefit of a more objective and comprehensive evaluation of risk management processes in the supply chain context.

Social implications – An immediate social implication derives from the improvement actions that may result from the diagnosis of risk management vulnerabilities identified in the pilot application. In general, the proposed model has the potential to reduce risks, improve results and contribute to economic sustainability.

Originality/value – The maturity grid and decision model integrate overall aspects of risk management, bringing together managerial concepts to deal with a variety of supply chain operational risks. The combined multi-criteria classification procedure to sort the maturity level of an organization is also a novelty.

Keywords Supply chain management, Risk management, Maturity model, Multi-criteria decision-making, Sorting, FTOPSIS-Class

Paper type Research paper

1. Introduction

A supply chain is constantly affected by the influence of unexpected macro and/or micro level events or conditions, the so-called supply chain risks (SCR), that impact and may harm its performance by causing operational, tactical or strategic level failures or irregularities (Ho *et al.*, 2015). Related literature generally classifies the SCR as operational risks, associated to uncertainties inherent to business processes, e.g. demand or supplier uncertainties and disruption risks which refers to ruptures caused by natural disasters or human action, that are unpredictable and frequently of high impact, such as earthquakes, floods and terrorist attacks (Sodhi and Tang, 2012; Tang, 2006a). Other authors also propose similar

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classifications (Wagner and Bode, 2008; Tang and Nurmaya Musa, 2011; Tummala and Schoenherr, 2011).

The supply chain risk management (SCRM) is an inter-organizational collaborative effort to identify, evaluate, mitigate and monitor the SCR, whose effects may diminish the supply chain performance (Ho *et al.*, 2015). The SCRM, in general, is part of the supply chain management (SCM) and therefore requires principles and techniques of world-class operations management theories and practices. More specifically, it requires the principles and techniques of continuous improvement management. As the fundamental continuously improvement technique, the enterprise risk management (ERM) literature proposes the main steps of risk identification, risk assessment and risk mitigation and response (Sodhi *et al.*, 2011; Sodhi and Tang, 2012). Principles such as the requirements of risk management and quality management system standards (ISO 9001 and 31000) exemplify the organizational capabilities that companies have to acquire.

Despite of the risk management relevance as a mean of support and improve supply chain performance, few studies discuss the concept of maturity on the SCRM topic (Boyson, 2014; Oliva, 2016; Zhao *et al.*, 2013, 2014). According to Bititci *et al.* (2014), the application of maturity models (MM) may promote greater levels of organizational learning by making management more critical about their practices. Based on this context, the research question that this study aims to answer is how to comprehensively assess the SCRM maturity of organizations and how to classify it into maturity levels, so as to enable a clear diagnosis as a mean of guiding further improvements.

In a related literature, MM have been proposed as a way to foster improvements by means of a maturity grid that aims to elucidate the capability levels on management principles and techniques of a particular organization and to provide guidance to improvement. They are presented on a diversity of subjects such as circular economy business models evaluation, healthcare supply chain reliability and structuring of supply chain trust for collaborative innovation (Sehnem *et al.*, 2019; Fawcett *et al.*, 2012; Böhme *et al.*, 2015).

The studies that have brought the concept of maturity within the SCRM context presented a maturity model focused in cybersecurity, proposition of maturity stages by an empirical study and use of multivariate statistical analyses and the proposition of a maturity index (Boyson, 2014; Oliva, 2016; Zhao *et al.*, 2013, 2014). However, they do not propose a more comprehensive enterprise SCRM maturity model that can be used by an organization as a guidance to the development of risk management capabilities. Also, none of the studies identified on maturity evaluation proposes, the use of multi-criteria decision-aiding (MCDA) techniques to classify the maturity level of organizations.

That said, aiming to improve the SCRM maturity evaluation, this work proposes a supply chain risk maturity model combined with the FTOPSIS-Class (Ferreira *et al.*, 2018), a MCDA classification method which enables the assessment of risk management level in organizations and their sorting into pre-defined maturity levels. The SCRM maturity model presented here proposes levels of maturity based on a series of criteria related to the types of risks that the organization systematically manages as well on the capability to apply the principles and techniques of ERM and operations management.

The use of MCDA methods to assess maturity and classify it brings objectivity and consistency to the decision-making process. Furthermore, the use of fuzzy set theory allows the imprecision and subjectivity implicit in qualitative evaluations to be mathematically modelled and properly considered in the maturity classification process. The FTOPSIS-Class method (Ferreira *et al.*, 2018) was chosen for this purpose since it's adequate to the sorting problem and stands out for its clearly comprehensible logic and use of linguistic variables and fuzzy numbers, making it possible to grasp the inaccuracies of human judgment in the evaluation of criteria and alternatives.

The proposed decision model follows an axiomatic prescriptive research approach since it is guided by a conceptualized logical structure for decision making, that is, the proposed set of criteria and sub-criteria that characterize maturity levels (De Almeida *et al.*, 2015). The paper is organized in seven sections: section 2 presents a review on SCRM and maturity models on supply chains; sections 3 and 4, respectively, introduces fuzzy theory and the fuzzy TOPSIS-Class method and section 5 details the proposed SCRM maturity model. Finally, section 6 presents a pilot application of the model proposed in an industrial cluster and section 7 brings the main conclusions and some suggestions for further research.

2. Supply chain risk management and maturity models

The effectiveness of coordinating and integrating financial, material and information flows through the supply network may be threaten by risk factors to which supply chains are constantly exposed (Sodhi and Tang, 2012; Stadtler, 2015). The complexity and instability of global supply chains, besides practices such as single sourcing and lean manufacturing, increase the risk factors, whose consequences may affect organizational performance (Kilubi, 2016; Tarei *et al.*, 2020).

The SCRM encompasses approaches, techniques and strategies to manage processes to provide adequate responses to the risks faced by supply chain members (Lavastre *et al.*, 2012). The definitions of SCRM presented on the literature bring that it comprises the collaboration and coordination among supply chain partners in the risk management process (Tang, 2006b; Thun *et al.*, 2011). Accordingly to Sodhi and Tang (2012), the SCRM process incorporates elements from SCM, ERM and crisis management areas.

A general risk management process comprises the steps of risk identification, risk assessment, risk mitigation and risk monitoring (Ho *et al.*, 2015; ISO, 2018). It is important to remark that the ISO31000:2018 also highlights attributes of an advanced risk management, such as leadership and continuous improvement, in a parallel to the requirements of a quality management system brought by ISO 9001:2015.

Table 1 presents different formats and approaches of maturity models focused on SC since the pioneer model proposed by Stevens (1989).

Few studies related to SCRM discuss the maturity concept or present a maturity model (Zhao *et al.*, 2013, 2014; Boyson, 2014; Oliva, 2016). Zhao *et al.* (2013, 2014) propose a fuzzy model to calculate an ERM maturity index based on relevant criteria and best practices in construction firms. A global index is valuable to position a firm according to the criteria defined by the authors, but they do not propose a maturity model as a set of risk management maturity levels in which an organization can be classified. Boyson (2014) proposes a three-stage risk management maturity model focused in cybersecurity and information technology. The proposed maturity stages are based on a set of criteria related to information technology practices and implementation. Oliva (2016) carried out an empirical study involving large Brazilian companies and based on multivariate statistical analyses of results proposed an ordinal scale with five ERM maturity levels in the supply chain.

Therefore, in the few studies identified that relate SCRM and the maturity concept, the authors do not propose a maturity model in which an organization can be classified based on the SCRM process phases and supply chain risk factors. Also, neither of the reviewed studies proposes the application of a MCDA for sorting organizations in maturity levels.

3. Fuzzy set theory

As in other real-word contexts, decision-making in SCM is usually based on subjective evaluation and incomplete information. The use of fuzzy set theory in these situations enables to capture the inaccuracies of the human judgment by assessing subjective or qualitative information in a comprehensible and even intuitive way (Zavadskas *et al.*, 2017;

Authors	Model focus and/or approach	Maturity levels
Stevens (1989)	Development of an integrated supply chain	Four levels – (1) baseline; (2) functional integration; (3) internal integration and (4) External company integration
Ayers and Malmberg (2002)	Supply chain evolution assessment focusing on IT insertion	Four levels – (1) infrastructure; (2) cost reduction; (3) collaboration and (4) strategic contribution
Lockamy III and Mccormack (2004)	Maturity model based on business process orientation (BPO) concepts	Five levels – (1) ad hoc; (2) defined; (3) linked; (4) integrated and (5) extended
Daozhi *et al.* (2006)	Supply chain maturity through three dimensions perspective: environment maturity, resource maturity and management maturity	Four levels for each dimension – from 1 to 4 (low to high)
Lahti *et al.* (2009)	A SCM maturity model which behaves as a maturity assessment tool that could meet the needs of companies' maturity level	Four levels – (1) functional focus; (2) internal integration; (3) external integration and (4) cross-enterprise collaboration
Garcia Reyes and Giachetti (2010)	Supply chain capability maturity model S(CM)2 built through Delphi method (supply chain experts)	Five levels – (1) undefined; (2) defined; (3) manageable; (4) collaborative and (5) leading
Mendes *et al.* (2016)	A general framework for assessing the state of maturity in demand-driven supply chains	Five levels – (1) basic push operation; (2) optimized push; (3) hybrid push-pull; (4) advanced demand-driven (pull) and (5) optimized demand-driven (pull)
Fischer *et al.* (2016)	A framework to measure the maturity of supply chain flexibility	Five levels – (1) no flexibility; (2) intra-firm flexibility; (3) reactive flexibility; (4) proactive flexibility and (5) paradigmatic flexibility
Yatskovskaya *et al.* (2018)	A maturity model that evaluates sustainability in supply network operations management in the context of water scarcity	Five levels – (1) initial; (2) limited; (3) defined/systematic; (4) managed and (5) mastered

Table 1. Supply chain management maturity models

Heidari *et al.*, 2018). It is possible to represent this qualitative decision information through linguistic variables. These are expressed qualitatively by linguistic terms such as "very low", "low", "medium", "high" and quantitatively through a fuzzy set (Lima-Junior *et al.*, 2013).

The fuzzy set theory basic notions are presented next (Zadeh, 1965, 1975; Buckley, 1985):

(1) A *fuzzy* set $\tilde{A}$ in a universe $\mathcal{X}$ is characterized by a *membership function* $\mu_{\tilde{a}}(x)$ which associates each element x on $\mathcal{X}$ to a real number on the range [0,1] (Zadeh, 1965) . The closer to 1 is the value of $\mu_{\tilde{a}}(x)$ the greater the degree of association of x in $\tilde{A}$. A fuzzy set is also called a fuzzy number.

(2) One of the possible formats of fuzzy set membership function is the trapezoidal *fuzzy* number, defined as $\tilde{a} = (a_1, b_2, c_3, d_4)$ (Chen, 2000; Chen *et al.*, 2006; Kauffman and Gupta, 1991). The membership function $\mu_{\tilde{a}}(x)$ for a trapezoidal fuzzy number is defined as follows:

$$\mu_{\tilde{a}}(x) = \begin{cases} f_{\tilde{a}}^{L}(x), & a_1 \leq x \leq a_2 \\ 1, & a_2 \leq x \leq a_3 \\ f_{\tilde{a}}^{R}(x), & a_3 \leq x \leq a_4 \\ 0, & \text{otherwise} \end{cases} \qquad (1)$$

where $f_{\tilde{a}}^{L}(x)$: $[a_1, a_2] \rightarrow [0,1]$ increases monotonically and $f_{\tilde{a}}^{R}(x)$: $[a_3, a_4] \rightarrow [0,1]$ decreases monotonically.

Given two positive fuzzy numbers $\tilde{a} = (a_1, a_2, a_3, a_4)$ e $\tilde{b} = (b_1, b_2, b_3, b_4)$ and a positive real number $r \geq 0$, some of the main algebraic operations with fuzzy sets are:

$$\tilde{a} \oplus \tilde{b} = (a_1 + b_1, a_2 + b_2, a_3 + b_3, a_4 + b_4) \tag{2}$$

$$\tilde{a} \ominus \tilde{b} = (a_1 - b_4, a_2 - b_3, a_3 - b_2, a_4 - b_1) \tag{3}$$

$$\tilde{a} \otimes \tilde{b} = (a_1 \times b_1, a_2 \times b_2, a_3 \times b_3, a_4 \times b_4) \tag{4}$$

$$\tilde{a} \otimes r = (a_1 \times r, a_2 \times r, a_3 \times r, a_4 \times r) \tag{5}$$

The addition and subtraction operations of any two trapezoidal fuzzy numbers result in a trapezoidal fuzzy number. However, the multiplication and of any two trapezoidal fuzzy numbers results only in an approximate trapezoidal fuzzy number (Dubois and Prade, 1994).

(3) The distance from the vertex $\delta(\tilde{a}, \tilde{b})$ between two trapezoidal fuzzy numbers is calculated as in equation (3) (Chen, 2000):

$$\delta(\tilde{a}, \tilde{b}) = \sqrt{\frac{1}{4}\left[(a_1 - b_1)^2 + (a_2 - b_2)^2 + (a_3 - b_3)^2 + (a_4 - b_4)^2\right]} \tag{6}$$

(4) Fuzzy matrix: it is said that a matrix M is a fuzzy matrix if at least one of its elements is a fuzzy number (Buckley, 1985).

4. The FTOPSIS-Class method

MCDA methods are largely applied jointly to fuzzy set numbers to improve the quality of decisions in engineering, technology, science and management areas, where they allow approach the decision-making process in a more efficient, rational and explicit way (Mardani *et al.*, 2015). One of the objectives of multi-criteria decision-making is sorting, were each alternative is assigned to exactly one of pre-defined categories. This problematic may deal with nominal classification or ordinal sorting problems. The former refers to categories that are not ordered from best to worst, while the latter brings the idea of order among categories (Araz and Ozkarahan, 2007; Zopounidis and Doumpos, 2002).

Sorting problems are addressed by different MCDA methods such as FlowSort, ELECTRE TRI (*Elimination et Choix Traduisant la Réalité*) and, more recently, the TOPSIS-Sort-B and TOPSIS-Sort-C (de Lima Silva and de Almeida-Filho, 2020), TOPSIS-R (de Farias Aires and Ferreira, 2019) and FTOPSIS-Class (Ferreira *et al.*, 2018). FTOPSIS-Class (Ferreira *et al.*, 2018) is a fuzzy decision method focused on solving ordinal sorting problems developed from the TOPSIS (*Technique for Order of Preference by Similarity to Ideal Solution)* (Hwang and Yoon, 1981) and FTOPSIS methods (Chen, 2000).

The FTOPSIS and TOPSIS are some of the most used multi-criteria methods in the literature with an easy understanding for considering the distance notion from the most desired (positive ideal solution) to the that less desired (negative ideal solution). Therefore, using such a method is suitable in a context where organizations are measuring the distance to the benchmarks, the ideal solution. The FTOPSIS method employs the traditional TOPSIS algorithm in a fuzzy environment, and the FTOPSIS-Class method brings a small modification in the definition of ideal solutions. The closeness coefficient CC_i^p is calculated for each alternative i based on its distance to the fuzzy positive and negative ideal solutions (FPIS and FNIS) of each profile p (Ferreira *et al.*, 2018). It was selected to the application presented here due to its adequacy to the problematic under consideration and to the compensatory rationality and for enabling the use of linguistic variables, later converted into fuzzy numbers.

The application of a fuzzy MCDA classification approach for maturity assessment has not been seen previously in the literature. Developments of risk management maturity evaluation have brought, for instance, a fuzzy model to calculate an *ERM maturity index* ERM maturity index (Zhao *et al.*, 2013, 2014) and empirical study based on multivariate statistical analyses and proposition of an ordinal scale of ERM maturity levels (Oliva, 2016).

The algorithm for the FTOPSIS-Class method (Ferreira *et al.*, 2018) is presented in Appendix. The steps 1 to 4 follow the same procedure as the FTOPSIS method (Chen, 2000).

5. Supply chain risk management maturity model

The SCRM maturity model structuring proposed here considered maturity models in the risk management (Hillson, 1997; Wieczorek-Kosmala, 2014) and the SCM literature (Stevens, 1989; Lockamy and McCormack, 2004; Daozhi *et al.*, 2006; Lahti *et al.*, 2009).

The model is based on the assumption that risk management maturity depends on the following dimensions and criteria (Table 2):

(1) Managed risks: it evaluates the extension that an organization is able to manage different supply chain risk factors. Based on the literature, the most common risk factors are included in the model (Ho *et al.*, 2015; Sodhi and Tang, 2012; Tang, 2006b; Tummala and Schoenherr, 2011). For instance, to manage demand risk, an organization needs to act upon events such as forecast inaccuracies, bullwhip effect and production order non-conformities among others;

(2) Risk management process: this dimension considers the risk management process as proposed by the literature on SCM and ERM and also by ISO 31000:2018. It also considers the techniques for risk management brought by ISO/IEC 31010: 2019-Risk Management, Risk Assessment Techniques (IEC, 2019). This dimension evaluates the degree to which this process is implemented in a given organization.

(3) Organizational support: this last dimension evaluates the presence of organizational aspects fundamental to support a mature risk management process. These aspects were based on the attributes of advanced risk management and the fundamental principles for a quality management system implementation (ISO, 2018; ISO, 2015).

The SCRM maturity model proposed is presented in Table 2. It recommends four levels that conceptualize what would be expected for each maturity stage considering the three dimensions described. Once the theoretical levels of the maturity model for SCRM were defined, a MCDA model for maturity evaluation was structured following the steps proposed by De Almeida *et al.* (2015).

For the MCDA model, the dimensions of maturity were unfolded on criteria and sub-criteria, as presented in Tables 3–5. For the first dimension, in Table 3, the criteria relate to supply chain risk factors. The maturity in managing such risks is assessed indirectly through evaluation of how the organization manages the events described in the last column of Table 3.

For the second dimension, the criteria are related to the risk management process components: identification (C2), assessment (C3), response and mitigation (C4) and monitoring (C5), as presented in Table 4. In turn, criteria C3 and C5 are deployed in sub-criteria (listed in the third column of Table 4). The implementation maturity of these process components is assessed through the utilization degree of the practices and techniques listed on the last column of Table 4. Finally, the criteria for the third dimension, organizational support, as presented in Table 5, assess factors that support a mature risk management, based on elements presented by ISO 31000:2018 e ISO 9001: 2015, such as communication and top management commitment.

Dimensions	Criteria	Level 1	Level 2
(1) Managed risks	Demand risk Production risk Supply risk Financial risk Information risk Transportation risk Disruption risk (macrorisks)	There is no action to manage any type of operational risk (or micro risks): demand, production, supply, financial, information or transportation risks	Action to manage and minimize operational risks: demand, production, supply, financial, information or transportation risks
(2) Risk Management Process	Identification	Little perception of the risks to which an organization is subject. No use of risk identification techniques nor tools or use of simple tools only	Organization is more aware of the risks to which it is subject. Simple techniques/tools are applied to identify these risks, but the organization may already experience the use of more complex techniques/tools
	Assessment	No assessment is made concerning the probability of occurrence and magnitude of the risk impact	Techniques/tools are used to assess risks in relation to their probability of occurrence and magnitude of impact. However, an organization does not yet effectively apply its results to manage risks
	Response and mitigation	No strategy or practice is used to respond or mitigate risks	The organization begins to use strategies and practices to respond or mitigate risks
	Monitoring	There are no records, reports or any control regarding risks occurrences or preparation for future risks	There are no records, reports or any control regarding risks occurrences or preparation for future risks
(3) Organizational support	Communication Top management commitment Culture Resources Continuous improvement Integration	There is no communication or exchange of information between departments about risk management processes and their performance. There is a lack of senior management commitment, and the organization members do not know their roles and responsibilities in risk management	There is a growing concern about perceived risks management, but commitment of senior management and accountability of the organization's members in the risk management process is still lacking. Communication and exchange of information is still inefficient and there is no monitoring of risk management process performance

Dimensions	Criteria	Level 3	Level 4
(1) Managed risks	Demand risk Production risk Supply risk Financial risk Information risk Transportation risk	Action for management and minimization of all operational risks, involving the internal and external chain	Action for management and minimization of all operational risks in the internal and external chain and disruption risks

(*continued*)

Table 2.
SCRM maturity model

Dimensions	Criteria	Level 3	Level 4
	Disruption risk (macrorisks)		
(2) Risk management process	Identification	Organization fully identifies the risks to which it is subject, with the effective use of simple and complex techniques/tools	Organization fully identifies the risks to which it is subject, with the effective use of simple and complex techniques/tools
	Assessment	Identified risks are assessed concerning their probability of occurrence and magnitude of impact, with the effective use of techniques/tools. The management of these risks can be prioritized according to the results of evaluations	Identified risks are assessed concerning their probability of occurrence and magnitude of impact, with the effective use of techniques/tools. The management of these risks can be prioritized according to the results of evaluations
	Response and mitigation	Risk response and mitigation strategies and practices are effectively implemented	Risk response and mitigation strategies and practices are effectively implemented
	Monitoring	Organization begins to structure and produce records/documentation of risk identification and its evaluation. Results of prioritization, if employed, are also documented	Organization maintains records/documentation of risk management processes (identified risks and evaluated risks) and verifies effectiveness of the strategies/risk management practices employed, emergence of new risks
(3) Organizational support	Communication Top management commitment Culture Resources Continuous improvement Integration	The process of risk management begins to be integrated to the routine of the organization now that the risks are fully identified and evaluated. The records of this process help in the communication and exchange of information between organizational areas/departments. Members of the organization are more aware of their roles and responsibilities	Risk management process integrated in the organizational routine, with consistent communication and information exchange between areas/departments. The risk management process performance is monitored for improvement. Senior management and other members of the organization are committed to the process and aware of their roles and responsibilities

Table 2.

6. Pilot application of the SCRM maturity model

According to the last census of 2015, Brazil has 677 clusters responsible for the generation of 3,051,244 direct jobs. The cluster of clothing industry in Pernambuco is one of the most preeminent in the Northeast region of Brazil. It is responsible for most of the state's garment production and attracts consumers from all over the Northeast region and from other regions of the country, mainly North and Center-West.

One of the reasons for choosing this particular cluster is its importance to the economic and social regional development. The geographic proximity of the researchers to that industrial and economic environment was also a motivating factor. As expected in an industrial cluster, the organizations present very similar characteristics as well as managerial limitations alike. Therefore, the effort to transfer academic knowledge to improve the managerial capabilities of the companies is of great importance to the regional development.

Four organizations, from the main cities of the cluster, Caruaru, Santa Cruz do Capibaribe and Toritama, were chosen for the pilot application. Two of them located in the city of Caruaru and the other two in the city of Santa Cruz do Capibaribe. They have between 50 and 200 employees and a minimum of 15 years of experience in the apparel sector.

In order to evaluate the SCRM maturity level of the companies, production managers or owners were asked to assess the management maturity concerning each of the criteria, sub-criteria and aspects described in Tables 3–5. The respondents have at least undergraduate level of education in areas related to management or industrial engineering and have been working in the organizations for a minimum of one year. Each criterion was assessed indirectly through company performance on managing the risk factor or use of practices and techniques presented on the last columns of Tables 3–5. The respondents evaluated management maturity on each criterion using linguistic terms defined on a five-point scale, as shown on Table 6, along with the respective trapezoidal fuzzy numbers.

The linguistic terms from Table 6 were also used to define the profiles that correspond to the maturity levels, which are presented on Table 7. The linguistic evaluations for each criterion together constitute the maturity profile of the level, which also defines the fuzzy positive and negative ideal solutions of each class or maturity level so as to apply the FTOPSIS-Class method, as presented in section 3.4.

6.1 Application results

Based on the answers given by the respondents, a fuzzy decision matrix was obtained and can be seen in Table 8. The organizations maturity was assessed in relation to the criteria presented in Tables 3–5 using the linguistic terms and corresponding fuzzy numbers given in

Dimension	Criteria	Aspects to be managed
1. Managed risks	Demand risk (C1.1)	Inaccurate forecasts; information distortion or bullwhip effect; order fulfilment errors; uncertain demand; demand variability (seasonality); market changes; changing in technology or customer preference
	Production risk (C1.2)	Lack of experience or training; work conditions; poor maintenance; low production capacity; inadequate production flexibility; quality/manufacturing defects; inventory excess; process inefficiency; design changes and technology changes
	Supply risk (C1.3)	Failure to meet delivery deadlines; supply disruptions; lack of volume flexibility; failure to meet quality requirements; unexpected changes in costs; small or limited supplier base (monopoly); dependence on suppliers and lack of integration with suppliers
	Financial risk (C1.4)	Variations in production costs; fluctuations in raw material prices; low profit margin; exchange rate; contract loss; partners financial strength and market size/growth
	Information risk (C1.5)	Inefficient system integration; information delay; lack of transparent information between entities; insecure information system and incompatibility of information exchange between supply chain partners
	Transportation risk (C1.6)	High costs of transportation; dependency on transportation modal; over-handling; damage during transport and failure to meet delivery deadlines
	Disruption risk (macrorisks) (C1.7)	Natural disasters; fires; political instability; economic crisis; labor strikes; government regulations; regional instability and social and cultural issues

Table 3. Criteria and sub-criteria of dimension 1 for maturity level evaluation

Dimension	Criteria	Sub-criteria	Practices and techniques to be implemented
1. Risk management Process	Identification (C2)		Check-lists; primary hazard analysis; brainstorming; structured or semi-structured interviews; cause-and-effect analysis; SWIFT – structure "What-if"; Delphi method; human reliability analysis; hazard and operability studies (HAZOP); hazard analysis and critical control points (HACCP); scenario analysis; reliability centred maintenance; event tree analysis; failure mode effect analysis (FMEA and FMECA); fault tree analysis and cause-and-effect analysis
	Assessment (C3)	Risks impact and probability evaluation (C3.1)	Consider for each risk category: demand risk; production risk; supply risk; financial risk; information risk; transportation risk and disruption risk (macrorisks)
		Assessment tools (C3.2)	Cause-and-effect analysis; root cause analysis; scenario analysis; business impact analysis; event tree analysis; FMEA; HAZOP; HACCP; human reliability analysis; reliability centred maintenance; Markov analysis; Monte-Carlo analysis and Bayesian analysis
	Response and mitigation (C4)		Response and/or mitigation strategies for management of *Supply risks* – supply network design; supplier relationship; supplier selection process (criteria); supply order allocation and supply contracts *Demand risks* – demand forecasting; define optimal portfolio of demand distribution among suppliers; pricing strategy (price as an incentive); shifting demand across time; shifting demand across markets and shifting demand across products *Production risks* – postponement (make to order and make to stock); process sequencing; product substitution (products with similar attributes); training and use of quality management and control tools
2. Risk management process	Response and mitigation (C4)		*Information risks* – information sharing; collaborative forecasting; replenishment planning and vendor managed inventory (VMI) Transportation risks – flexible transportation (routes and transport modal); multiple suppliers; strategic stock and supplier relationship *Financial risks* – wholesale price contracts; buy-back contracts; revenue

(*continued*)

Table 4.
Criteria and sub-criteria of dimension 2 for maturity level evaluation

Dimension	Criteria	Sub-criteria	Practices and techniques to be implemented
			sharing contracts; multiple suppliers (e.g. from different countries) and partnerships *Disruption risks* – strategic stock; multiple suppliers (e.g. from different countries); flexible transportation (routes and transport modal); revenue sharing contracts; demand postponement; information sharing; collaborative forecasting and vendor managed inventory (VMI)
	Monitoring (C5)	Use of performance attributes/metrics (C5.1)	Reliability (perfect order fulfilment); cost (total cost to serve); responsiveness (order fulfilment cycle time); agility (upside/downside supply chain flexibility and adaptability) and asset management (return on fixed assets and return on working capital)
		Monitoring reports (C5.2)	Content of risk management monitoring reports/registers: causes/sources of risks; impacts/effects; action plans employed; results accomplished; risk assessment techniques are properly applied; risk treatments are effective and assumptions made in the risk assessment remain valid

Table 4.

Table 6. The alternatives A_i in Table 8 are the evaluated organizations. However, apart from the four organizations actually evaluated, four other alternatives were simulated as organizations at different levels of maturity (alternatives A1, A2, A7 and A8). This was done to verify the behavior of the decision model, that is, whether the simulated alternatives were sorted in the expected maturity level. One of the simulated alternatives indicates an incipient maturity in SCRM; another one, a high level of maturity and the other two intermediate maturity levels.

The fuzzy numbers presented in Table 8 resulted from the aggregation of the maturity evaluations, on several aspects, techniques and practices related to the criteria and sub-criteria, as described in Table 9.

Initially, it was assumed that all the criteria have the same degree of importance. Later on, a scenario analysis was carried out to verify the model response to variations on criteria weights. Table 10 presents the linguistic terms and trapezoidal fuzzy numbers used to define the criteria weights. Their definition was done based on specialist's knowledge of SCRM context and experience in fuzzy MCDA applications.

The decision matrix in Table 8 was normalized by applying the benefit criteria procedure as in equation (7), which is presented in the steps of the method, in Appendix. After normalization and weighting of the decision matrix it was used to calculate the distances $\tilde{d}_i^{p*}$ e $\tilde{d}_i^{p-}$ in relation to the FPIS and to the FNIS, respectively. Then the CC_i^p was calculated for each alternative i in relation to each maturity level/category p. The CC_i^p values obtained for each alternative are presented on Table 11.

The highest values of CC_i^p for each organization are highlighted in italics on Table 11, indicating in which level the organization is classified. For instance, organization A1 is at

Dimension	Criteria	Description
3. Organizational support	Communication (C6)	A consistent and wide sharing of risk information through the supply chain organizations, internal and externally. Clear definition of what to communicate, when, how and who should receive the information
	Top management commitment (C7)	Top management shall lead the risk management process by defining risk management policies, aligning strategic objectives and risk management objectives, assuring the adequate structure for managing risks, for instance
	Risk-aware culture (C8)	Risk-aware culture incorporated into the organization culture; staff at all levels are aware of the risks and uncertainties the supply chain is exposed to. There is a climate of trust within the organization and project teams, without a blame culture nor defensive practices
	Resources (C9)	Ensure allocation of adequate resources to risk management, considering what is necessary on each step of the process. Continual investment in the risk management process: techniques, tools and personnel training
	Continuous improvement (C10)	Continual evaluation and improvement of the risk management process, based on monitoring results and critical analysis. Developing performance analysis, review of process and objectives
	Integration (C11)	Risk management is integrated in all organizational activities. It is part of the organizational purpose, governance, leadership, strategy, objectives and operations

Table 5.
Criteria and sub-criteria of dimension 3 for maturity level evaluation

Maturity Evaluation		Trapezoidal Fuzzy Number			
None (*N*)	Does not apply (NA)	0	0	0.1	0.2
Low (*L*)	Little applicable (LA)	0.1	0.2	0.3	0.4
Moderate (*M*)	Moderately applicable (MA)	0.3	0.4	0.5	0.6
High (*H*)	Highly applicable (HA)	0.5	0.6	0.7	0.8
Integral/Total (*I*)	Totally applicable (TA)	0.7	0.8	0.9	1

Table 6.
Linguistic terms for maturity evaluation

SCRM	Criteria								
Maturity	C1.1	C1.2	C1.3	C1.4	C1.5	C1.6	C1.7	C2	C3.1	C3.2
Level 1	*N*	*N*	*N*	*N*	*N*	*N*	*N*	*N*	*N*	*N*
Level 2	*M*	*M*	*M*	*L*	*L*	*L*	*L*	*L*	*M*	*L*
Level 3	*M*	*M*	*M*	*M*	*M*	*M*	*L*	*M*	*M*	*M*
Level 4	*H*	*H*	*H*	*M*	*M*	*M*	*M*	*H*	*H*	*H*
	C4	C5.1	C5.2	C6	C7	C8	C9	C10	C11	
Level 1	*N*	*N*	*N*	*N*	*N*	*N*	*N*	*N*	*N*	
Level 2	*L*	*N*	*N*	*L*	*L*	*L*	*L*	*L*	*L*	
Level 3	*M*	*L*	*L*	*M*	*M*	*M*	*M*	*L*	*L*	
Level 4	*H*	*M*	*M*	*H*	*H*	*M*	*M*	*M*	*M*	

Table 7.
Performance evaluation for each criterion for classification on a maturity level

Table 8. Fuzzy decision matrix

	C11				C12				C13				C14				C15			
A1	0.071	0.143	0.243	0.343	0.120	0.200	0.300	0.400	0.063	0.125	0.225	0.325	0.029	0.057	0.157	0.257	0.040	0.080	0.180	0.280
A2	0.700	0.800	0.900	1.000	0.700	0.800	0.900	1.000	0.700	0.800	0.900	1.000	0.671	0.771	0.871	0.971	0.700	0.800	0.900	1.000
A3	0.100	0.171	0.271	0.371	0.270	0.360	0.460	0.560	0.325	0.425	0.525	0.625	0.257	0.343	0.443	0.543	0.260	0.360	0.460	0.560
A4	0.529	0.629	0.729	0.829	0.480	0.580	0.680	0.780	0.275	0.375	0.475	0.575	0.243	0.343	0.443	0.543	0.120	0.200	0.300	0.400
A5	0.271	0.371	0.471	0.571	0.400	0.500	0.600	0.700	0.275	0.375	0.475	0.575	0.443	0.543	0.643	0.743	0.620	0.720	0.820	0.920
A6	0.200	0.286	0.386	0.486	0.420	0.520	0.620	0.720	0.350	0.450	0.550	0.650	0.414	0.514	0.614	0.714	0.420	0.520	0.620	0.720
A7	0.586	0.686	0.786	0.886	0.620	0.720	0.820	0.920	0.650	0.750	0.850	0.950	0.529	0.629	0.729	0.829	0.580	0.680	0.780	0.880
A8	0.329	0.429	0.529	0.629	0.280	0.380	0.480	0.580	0.425	0.525	0.625	0.725	0.157	0.257	0.357	0.457	0.180	0.280	0.380	0.480
	C16				C17				C2				C31				C32			
A1	0.080	0.160	0.260	0.360	0.000	0.000	0.100	0.200	0.038	0.077	0.177	0.277	0.000	0.000	0.100	0.200	0.020	0.040	0.140	0.240
A2	0.700	0.800	0.900	1.000	0.589	0.689	0.789	0.889	0.547	0.647	0.747	0.847	0.700	0.800	0.900	1.000	0.507	0.607	0.707	0.807
A3	0.340	0.440	0.540	0.640	0.311	0.400	0.500	0.600	0.038	0.060	0.160	0.260	0.600	0.686	0.786	0.886	0.087	0.120	0.220	0.320
A4	0.280	0.360	0.460	0.560	0.200	0.289	0.389	0.489	0.083	0.133	0.233	0.333	0.200	0.229	0.329	0.429	0.090	0.127	0.227	0.327
A5	0.380	0.480	0.580	0.680	0.344	0.444	0.544	0.644	0.173	0.253	0.353	0.453	0.700	0.800	0.900	1.000	0.103	0.140	0.240	0.340
A6	0.340	0.440	0.540	0.640	0.211	0.267	0.367	0.467	0.145	0.203	0.303	0.403	0.300	0.343	0.443	0.543	0.080	0.113	0.213	0.313
A7	0.660	0.760	0.860	0.960	0.300	0.400	0.500	0.600	0.520	0.617	0.717	0.817	0.700	0.800	0.900	1.000	0.240	0.287	0.387	0.487
A8	0.340	0.440	0.540	0.640	0.122	0.222	0.322	0.422	0.245	0.303	0.403	0.503	0.600	0.686	0.786	0.886	0.120	0.153	0.253	0.353
	C4				C51				C52				C6				C7			
A1	0.000	0.000	0.100	0.200	0.060	0.120	0.220	0.320	0.000	0.000	0.100	0.200	0.100	0.200	0.300	0.400	0.100	0.200	0.300	0.400
A2	0.574	0.660	0.760	0.860	0.700	0.800	0.900	1.000	0.700	0.800	0.900	1.000	0.700	0.800	0.900	1.000	0.700	0.800	0.900	1.000
A3	0.129	0.183	0.283	0.383	0.000	0.000	0.100	0.200	0.000	0.000	0.100	0.200	0.100	0.200	0.300	0.400	0.100	0.200	0.300	0.400
A4	0.238	0.303	0.403	0.503	0.380	0.480	0.580	0.680	0.600	0.686	0.786	0.886	0.300	0.400	0.500	0.600	0.500	0.600	0.700	0.800
A5	0.359	0.438	0.538	0.638	0.500	0.600	0.700	0.800	0.100	0.114	0.214	0.314	0.300	0.400	0.500	0.600	0.300	0.400	0.500	0.600
A6	0.214	0.286	0.386	0.486	0.420	0.520	0.620	0.720	0.700	0.800	0.900	1.000	0.100	0.200	0.300	0.400	0.300	0.400	0.500	0.600
A7	0.463	0.563	0.663	0.763	0.620	0.720	0.820	0.920	0.700	0.800	0.900	1.000	0.500	0.600	0.700	0.800	0.500	0.600	0.700	0.800
A8	0.163	0.232	0.332	0.432	0.180	0.280	0.380	0.480	0.400	0.457	0.557	0.657	0.500	0.600	0.700	0.800	0.500	0.600	0.700	0.800
	C8				C9				C10				C11							
A1	0.000	0.000	0.100	0.200	0.000	0.000	0.100	0.200	0.000	0.000	0.100	0.200	0.000	0.000	0.100	0.200				
A2	0.700	0.800	0.900	1.000	0.700	0.800	0.900	1.000	0.700	0.800	0.900	1.000	0.700	0.800	0.900	1.000				
A3	0.300	0.400	0.500	0.600	0.500	0.600	0.700	0.800	0.000	0.000	0.100	0.200	0.300	0.400	0.500	0.600				
A4	0.500	0.600	0.700	0.800	0.300	0.400	0.500	0.600	0.100	0.200	0.300	0.400	0.100	0.200	0.300	0.400				
A5	0.300	0.400	0.500	0.600	0.500	0.600	0.700	0.800	0.300	0.400	0.500	0.600	0.100	0.200	0.300	0.400				
A6	0.300	0.400	0.500	0.600	0.300	0.400	0.500	0.600	0.100	0.200	0.300	0.400	0.300	0.400	0.500	0.600				
A7	0.700	0.800	0.900	1.000	0.700	0.800	0.900	1.000	0.500	0.600	0.700	0.800	0.300	0.400	0.500	0.600				
A8	0.300	0.400	0.500	0.600	0.100	0.200	0.300	0.400	0.100	0.200	0.300	0.400	0.300	0.400	0.500	0.600				

maturity level 1; likewise, alternative A2 is at level 4 and so on. The simulated alternatives (A1, A2, A7 and A8) were classified as expected, indicating a consistent behavior of the classification procedure. The four organizations actually evaluated were classified at maturity level 2.

The classification in level 2 means, according to the maturity model developed here, that these organizations are already looking for ways to act on the risks they are exposed to and already have the application of some tools to identify and evaluate these risks. Strategies and/or practices are used to respond to identified risks, but still at an initial level in most of the cases. There are still no organized records or monitoring procedures regarding the risk occurrence and the effectiveness of what is employed in response to them. Finally, regarding the aspects of organizational support, the maturity level 2 description indicates that the concern and interest of managers in identifying and managing risks is perceived, although the culture of risk management in the organization is mostly in a primary state.

The results of the classification of organizations in maturity level 2 are seen as consistent also when considering the characteristics of the environment in which the organizations are embedded. It is understood that risk management, although decisive to achieve the expected organizational performance, was not among the main concerns of the cluster organizations.

Table 9. Aggregation procedures applied to criteria and sub-criteria evaluation

Criteria/sub-criteria	Evaluation aggregation
C1.1 to C1.7 and C5.1	Arithmetic mean of evaluation of the aspects to be managed (as in Table 3)
C2 and C3.2	Weighted mean of evaluation of the use of practices and techniques listed in Table 4 weighted according to their complexity
C3.1 and C5.2	Arithmetic mean of dichotomic evaluation (yes or no) of practices application, as in Table 4
C4	Arithmetic mean of evaluation of implemented practices combined with a decision rule: if aggregated value is below "Low", it returns "None". Otherwise, it returns the aggregated value
C6 to C11	No aggregation. Direct evaluation of maturity

Table 10. Linguistic terms for criteria weight

Weight	Trapezoidal Fuzzy Number			
Low (*L*)	0	0	0.1	0.2
Moderate (*M*)	0.1	0.2	0.3	0.4
Important (*I*)	0.3	0.4	0.5	0.6
Very important (VI)	0.5	0.6	0.7	0.8
Extremely important (EI)	0.7	0.8	0.9	1

Table 11. Alternatives classification based on the CC_i^p results

	Closeness Coefficient CC_i^p			
	Level 1	Level 2	Level 3	Level 4
A1	*0.9037*	0.7031	0.1358	0.0963
A2	0.2081	0.3184	0.7518	*0.7919*
A3	0.6789	*0.7629*	0.4378	0.3211
A4	0.5800	*0.7108*	0.5437	0.4200
A5	0.5068	*0.6678*	0.6216	0.4932
A6	0.5704	*0.8013*	0.5526	0.4296
A7	0.2905	0.4565	*0.7687*	0.7095
A8	0.5813	*0.7510*	0.5733	0.4187

This is a demand that only recently has been focused by organizations on that region. It happens because of the growing interest in expansion in the domestic market and exportation, which leads to greater concern about quality assurance and efforts to remain competitive in face of new foreigner entrants in the regional markets.

6.2 Scenario analysis

The application results discussed in the previous section were obtained using the same weight for all criteria. The weight "Very Important" was used for each criterion j, $\tilde{w}_j = (0{,}5; 0{,}6; 0{,}7; 0{,}8)$. In order to verify the model response to these parameter variations, a scenario analysis was performed by applying variations in the criteria weight grouped according to the dimensions: managed risks (D_1), risk management process (D_2) and organizational support (D_3). For example, for "Managed Risks", the weights of all the criteria within this dimension were simultaneously varied and the others were kept as initially. The criteria weights were reduced and increased to "Important" and "Extremely Important", respectively. Table 12 presents the results of the applied weight variations. The arrows indicate the direction the alternative has changed, to a higher or lower level and the dashes indicate that there was no change in the classification.

The classification of organizations remains the same only for the third scenario, in which the weight of the organizational support dimension is reduced, keeping the others as "Very Important". This may evidence, therefore, that for this model, the "Organizational Support" dimension is required, but it is not essential as "Managed Risks" and "Risk Management Process". The reduction in the weight of dimensions D_1 and D_2, first and second scenarios, has caused a change of classification for alternative A2. Meanwhile, in the scenarios in which the weight of these dimensions was increased, scenarios four and five, the alternatives A5 and A7 change to the level immediately higher than the originally classified. The scenario six caused that only alternative A5 moved to one level higher. Analyzing all the results in a global way, the model responds to what is intuitively expected, in which "Organizational Support" helps and enhances the outcome of the processes, but it is essential that there is an adequate risk management process.

Observing the results for the closeness coefficients CC_i^{ρ} in Table 11, it is worth noting that the alternatives have changed classification, shown in Table 12, only when they have CC_i^{ρ} values very close to each other when compared to the other alternatives that remained stable. These observations are valid for alternatives A2, A5 and A7, considering their CC_i^{ρ} in relation to levels 3 and 4. From these results, it is possible to infer that the classification of the organizations by the model is consistent and that the results obtained are coherent since there are few changes in the tests of scenarios and they are minimum in relation to changes in

Organizations	Application results	Scenarios analyzed (Weight D_1, Weight D_2, Weight D_3)					
	(VI, VI, VI)	*(I, VI, VI)*	*(VI, I, VI)*	*(VI, VI, I)*	*(EI, VI, VI)*	*(VI, EI, VI*	*(VI, VI, EI)*
A1	Level 1	–	–	–	–	–	–
A2	Level 4	↓	↓	–	–	–	–
A3	Level 2	–	–	–	–	–	–
A4	Level 2	–	–	–	–	–	–
A5	Level 2	–	–	–	↑	↑	↑
A6	Level 2	–	–	–	–	–	–
A7	Level 3	–	–	–	↑	–	-
A8	Level 2	–	–	–	–	–	–

Table 12. Scenario analysis results

maturity levels. They have occurred only for those alternatives that would be at a possible transition threshold between levels.

7. Conclusions

The ability to effectively manage the risk factors that may threaten organizational performance is crucial to enhance the achievement of planned goals. Therefore, diagnosing and recognizing the SCRM maturity level is of great value since it enables organizations to identify areas that need to be strengthened or even practices that need to be implemented.

This paper proposed a SCRM maturity model based on four levels that enable assessing the maturity of organizations, considering criteria in the dimensions of risks managed, risk management process and organizational support. It was done by incorporating relevant supply chain and risk management literature, ISO 31000 and ISO 9001 management requirements. The maturity assessment and sorting of organizations in the MM levels was based on the FTOPSIS-Class method. The decision model structuring for sorting the companies required assumptions based on the literature and analysts' knowledge to define the profiles of the maturity levels, as well as the option for equal criteria weights and the procedures of aggregation used in the evaluations of some of these criteria. These assumptions and criteria weight choices may be revised and improved by a learning process which would be possible after some cycles of application and revision of the proposed model.

The proposed MM was tested in a pilot application that included four organizations belonging to an industrial cluster in the apparel sector. The results obtained have demonstrated the model provides relevant information to the organizations regarding their risk management. The pilot application also illustrated the adequacy of the MCDA method in this kind of evaluation. Sensitivity tests were carried out with simulated data which generated consistent classification results.

The theoretical and managerial implications of this study are discussed next as well as suggestions to further developments.

7.1 Theoretical implications

The proposed maturity grid and decision model are theoretical contributions that may be seen as a first attempt to integrate overall aspects of risk management in a maturity assessment process, bringing together other managerial concepts to deal with a variety of supply chain operation risks. However, further improvements are possible and desirable, such as revising and improving:

(1) The criteria and sub-criteria, for instance, risks factors could also include specific aspects that are relevant for different industry sectors;

(2) Other risks such as the ones related to sustainability aspects could also be considered. Especially, those companies that already achieved the highest levels of maturity or those that would be growing in maturity for SCRM and sustainability;

(3) The evaluation method of each criterion in order to better capture the capability level of each aspect considered by the model;

(4) The definitions of each maturity level profile so as to better differentiate the levels and minimize misunderstanding;

In addition, the proposition of a MCDA approach to classify assessed companies in maturity levels was also an important theoretical contribution. The use of fuzzy set theory enabled the mathematical modelling of the imprecision implicit in the qualitative evaluation of maturity capabilities. Regarding this approach, further improvements can be made such as:

(1) Testing new parameterizations such as adjusting the linguistic terms and corresponding fuzzy sets used in the assessment process;

(2) Including a procedure to define the criteria weights used in the evaluation process;

(3) Testing other MCDA techniques such improvements in the FTOPSIS-Class technique.

7.2 Managerial implications

For the companies that engaged in the pilot application, the awareness of their vulnerability to several risk factors is initially the main contribution of this study. This precipitates the need of incorporating risk management initiatives throughout the organization and has the potential to facilitate the identification of areas where improvements are necessary. For the other companies in the same industrial cluster, a supposition is that the pilot application results represent a general diagnosis of risk management vulnerabilities.

A more general contribution of this proposition is that the use of the risk management maturity grid is an approach that helps to build more mature risk management processes. When and if adopted by practitioners, it may bring the benefit of a more comprehensive evaluation of organizational risks and management processes in the supply chain context. Finally, another more general contribution of the proposed evaluation model is that, in the long run, it is expected that companies can benefit of a more efficient and effective supply chain.

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Appendix

FTOPSIS-Class (Ferreira *et al.*, 2018) method steps:

Step 1: Structure the decision model by identifying the decision-maker and the set of criteria and alternatives.

Step 2: Define linguistic variables that will be used to assess the relative importance of criteria and to evaluate the alternatives on those criteria.

Step 3: Construct the normalized decision matrix $\tilde{R} = [\tilde{r}_{ij}]_{m \times n}$ as follows:

$$\tilde{r}_{ij} = \begin{cases} \left(\frac{a_{ij}}{d_j^*}, \frac{b_{ij}}{d_j^*}, \frac{c_{ij}}{d_j^*}, \frac{d_{ij}}{d_j^*}\right) \text{ if } j \in B, \text{where } B \text{ represents benefit criteria, and } d_j^* = \max_i d_{ij} \\ \left(\frac{a_j^-}{d_{ij}}, \frac{a_j^-}{c_{ij}}, \frac{a_j^-}{b_{ij}}, \frac{a_j^-}{a_{ij}}\right) \text{ if } j \in C, \text{where } C \text{ representes cost criteria, and } a_j^- = \min_i a_{ij} \end{cases} \quad (7)$$

Step 4: Construct the weighted normalized fuzzy decision matrix $\tilde{V} = [\tilde{v}_{ij}]_{m \times n}$ from $\tilde{R} = [\tilde{r}_{ij}]$ and $\tilde{W} = [\tilde{w}_j]$, where $\tilde{v}_{ij} = \tilde{r}_{ij} \otimes \tilde{w}_j$.

Step 5: For each class p, determine:

Step 5.1: The fuzzy positive ideal solution of profile p as $\tilde{A}_p^* = [\tilde{v}_{p1}^*, \tilde{v}_{p2}^*, \ldots, \tilde{v}_{pn}^*]$, where $\tilde{v}_{pj}^* = \tilde{q}_{pj}$, is the linguistic evaluation of profile p in the jth criterion.

Step 5.2: The fuzzy negative ideal solution of class p as $\tilde{A}_p^- = [\tilde{v}_{p1}^-, \tilde{v}_{p2}^-, \ldots, \tilde{v}_{pn}^-]$, where $\tilde{v}_{pj}^-$ are the values of the farthest profile p' from p, and the distance to be maximized.

Step 6: Calculate the distances of each alternative i in relation to each class p as follows:

$$\tilde{d}_i^{p*} = \sum_{j=1}^{n} \delta\left(\tilde{v}_{ij}, \tilde{v}_{pj}^*\right), \quad i = 1, 2, \ldots, m \quad (8)$$

$$\tilde{d}_i^{p-} = \sum_{j=1}^{n} \delta\left(\tilde{v}_{ij}, \tilde{v}_{pj}^-\right), \quad i = 1, 2, \ldots, m \quad (9)$$

Step 7: Calculate the closeness coefficient CC_i^p of each alternative i regarding each profile p as:

$$CC_i^p = \frac{\tilde{d}_i^{p-}}{\tilde{d}_i^{p*} + \tilde{d}_i^{p-}} \quad i = 1, 2, \ldots, m. \quad (10)$$

Step 8 (sorting): For each alternative i, determine its class $p_i^* = \text{argmax} p \epsilon P\{CC_i^p\}$, that is, p_i^* is the category with the highest value of CC_i^p for the alternative i.

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