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Combining SCOR® model and fuzzy TOPSIS for supplier evaluation and management

Francisco Rodrigues Lima-Junior, Luiz Cesar Ribeiro Carpinetti *

Production Engineering Department, School of Engineering of São Carlos – University of São Paulo, Av. Trabalhador Sancarlense 400, 13566-590 São Carlos, SP, Brazil

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ABSTRACT

Evaluating suppliers and supporting their continuous improvement have become critical for supply chain (SC) performance management. Since the performance of an organization in a SC depends on the performance of its suppliers, it is desirable that the evaluation of a supplier can be integrated to the evaluation of the SC. Few studies propose decision making models to aid the supplier evaluation for development. However, these studies adopt criteria similar to ones used in supplier selection, which can lead to a mismatch between supplier and SC performance evaluations. Therefore, to overcome this lack of alignment, this article presents a new approach that uses the performance metrics of the SCOR® (Supply Chain Operations Reference) model to evaluate the suppliers in the dimensions cost and delivery performance. It combines two fuzzy TOPSIS models for evaluating and categorizing the suppliers in four groups depending on their performance evaluation. According to their categorization, directives for action plans are proposed. An illustrative application was developed based on a manufacturing context. The combination between the SCOR® and fuzzy TOPSIS brings several benefits when compared with other approaches, such as: it facilitates the integration of the processes of performance evaluation of the suppliers and the SC; it enables benchmarking against other SCs; the fuzzy TOPSIS requires few judgments to parameterization, which contributes to the agility of the decision process; it does not limit the number of alternatives simultaneously evaluated; it does not cause the ranking reversal problem when a new supplier is included in the evaluation process.

1. Introduction

Presently, manufacturing companies rely heavily on suppliers for providing materials and components used in finished products. Some authors have stated that approximately 50% to 70% of the production costs are spent on purchased materials and components (Lee and Drake, 2010). Thus, managing the performance of suppliers and supporting their continuous improvement have become critical for supply chain management (Prajogo et al., 2012; Schoenherr et al., 2012). The evaluation of a supplier's performance happens at least in two distinct moments in the supplier management process. First, the evaluation is conducted during the supplier selection phase. In this case, the final goal is to define an order of preference among the alternatives for the selection of those preferred ones (De Boer et al., 2001, Wu and Barnes, 2011, Chai et al., 2013). In the second moment, the supplier development phase, the supplier evaluation is conducted so that some management practices can be planned and implemented aiming at improving the performance and capabilities of the supplier so as to better fulfill the supply needs (Osiro et al., 2014). Many supplier development practices, as certification systems, incentives, knowledge and resource transfer related to organizational management can be used (Bai and Sarkis, 2011). The choice of a course of action to deploy a particular supplier depends on the supplier's evaluation.

Many authors have proposed the use of fuzzy set theory combined with multicriteria decision making (MCDM) methods to support supplier selection (De Boer et al., 2001; Wu and Barnes; 2011; Chai et al., 2013), since it provides a suitable language to handle qualitative and quantitative factors (Osiro et al., 2014; Mardani et al., 2015). On the other hand, there are few studies that propose MCDM models to aid the supplier evaluation for development purpose. In general, these studies propose the adoption of criteria similar to ones used in supplier selection, such as quality, delivery, price, among others (Sarkar and Mohapatra, 2006; Aksoy and Öztürk, 2011; Rezaei and Ortt, 2013). However, since the

* Corresponding author. Tel.: +55 16 3373 9421.
E-mail addresses: eng.franciscojunior@gmail.com (F.R. Lima-Junior), carpinet@sc.usp.br (L.C.R. Carpinetti).

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Table 1
Dimensions and criteria for supplier evaluation

Author(s)	Evaluation dimension(s)	Criteria
Sarkar and Mohapatra (2006)	Short-term performance	Price, quality, ability to meet delivery promise, consistent delivery, attitude, after sales support and positive attitudes towards complaints
	Long-term capability	Quality philosophy, financial capability, technological capability, reputation for integrity, existence of it standards, performance history, bidding procedural compliance, profitability of suppliers, breadth of product line, supplier's proximity, management and organization, contribution to productivity, conflict resolution, production facilities and capacity, communication openness, labor problems at the supplier's place and business volume
Araz and Ozkarahan (2007)	Strategic partnership	Support in product structural design, support in process design and engineering, design revision time, prototyping time, level of technology, quality performance, financial strength, cost reduction performance, delivery performance and ease of communication
Aksoy and Öztürk (2011)	–	Quality, JIT delivery performance, location for transport, price
Zeydan et al. (2011)	–	New project management, supplier management, quality and environmental management, production process management, test and inspection management, corrective and preventive actions management
Ho et al. (2012)	–	Price, delivery reliability, delivery, speed, quality conformance, demand increases, product range, design, distribution, design leadership, being an existing supplier, marketing and sales, brand name, technical liaison and support, after-sales support
Omurca (2013)	–	Quality management practices and systems, self-audit, manufacturing capability, management of the firm, design and development capabilities, cost reduction capability, quality performance, price performance, delivery performance and cost reduction performance
Rezaei and Ortt (2013)	Capabilities	Price, delivery, quality, reserve capacity, geographical location, financial position
	Willingness	Commitment to quality, communication openness, reciprocal arrangement, willingness to share information, supplier's effort in promoting JIT principles, long term relationship
Akman (2014)	Environmental	Green design, pollution prevention, green image, green capability, environmental system
	Performance	Delivery, quality, cost, service
Liou et al. (2014)	Compatibility	Information sharing, relationship, flexibility
	Cost	Cost saving, flexibility in billing
	Quality	Knowledge and skills, customers' satisfaction, on-time rate
	Risk	Loss of management control, labor union, information security
Osiro et al. (2014)	Potential for partnership	Commitment to improvement and cost reduction, ease of communication, financial capability, technical capability
	Delivery performance	Delivery reliability, price performance, quality of conformance, problem resolution
Sahu et al. (2014)	Enterprise ability	Volume flexibility, scale of production, information level
	Service level	Price rate, delivery time, delivery-check qualified rate
	Cooperation degree	On-time delivery rate, average order completion ratio
	Environmental factors	Content of hazardous substances, energy consumption, harmless rate

performance of a focal organization in a supply chain is dependent upon the performance of its suppliers, it is desirable that the evaluation of performance of a supplier for the purpose of development be aligned with the performance evaluation of the supply chain. This would require the use of similar metrics to evaluate the performance of the suppliers and the supply chain. One approach widely adopted by the practitioner community to supply chain performance evaluation is the Supply Chain Operations Reference (SCOR®) model. This model, developed by the Supply Chain Council (SCC), proposes a hierarchy of performance measurement metrics that evaluates five dimensions of performance: reliability, responsiveness, agility, cost, and asset management (SCC, 2012). However, none of the studies found in the literature proposes a supplier evaluation multicriteria model that considers the performance metrics proposed by the SCOR® model.

Another limitation of the existing multicriteria models for supplier evaluation for development concerns the technique (s) adopted. Most of the studies are based on techniques that require comparative judgments from decision makers, such as Analytic Hierarchy Process-AHP (Park et al., 2010), Analytic Network Process-ANP (Dou et al., 2014; Hsu et al., 2014; Liou et al., 2014), fuzzy AHP (Zeydan et al., 2011; Rezaei and Ortt, 2013) and Decision Making Trial and Evaluation Laboratory-DEMATEL (Ho et al., 2012). Although these techniques are adequate to deal with qualitative and imprecise factors, they limit the numbers of criteria and suppliers that can be evaluated simultaneously. Moreover, another drawback that affects the models based on AHP, ANP and fuzzy AHP is the ranking reversal problem, when the overall ordering of the initial set of suppliers is swapped when additional criteria or alternative suppliers are included in the evaluation (Lima Junior et al., 2014).

In order to overcome the limitations pointed in the previous paragraphs, this study proposes a new approach that uses some of the performance metrics of the SCOR® model as the criteria to evaluate the suppliers in a classification procedure based on the fuzzy TOPSIS (Technique for Order of Preference by Similarity to Ideal Solution) technique. The aim is that the classification of the evaluated suppliers can guide further development of the supplier base. Fuzzy TOPSIS enables the use of linguistic judgments for the evaluation of the supplier performance and at the same time neither brings limitations on the number of criteria and alternative suppliers nor the problem of ranking reversal. The proposed approach was implemented by using the software *Microsoft Excel*. An illustrative application case was developed based on a manufacturing context. The remainder of this paper is organized as follows: Sections 2, 3 and 4 focus on the theoretical background about supplier evaluation, fuzzy TOPSIS method and SCOR® model. Section 5 presents the proposed approach for supplier evaluation and its application in an illustrative case. It also presents some sensitivity tests of the proposed method. Finally, conclusions and suggestions for future research are presented in Section 6.

2. Supplier evaluation

Different decision making techniques are proposed in the literature to deal with the process of supplier evaluation, especially in supplier selection (De Boer et al., 2001; Wu and Barnes, 2011; Chai et al., 2013). Evaluation for the purpose of supplier development differs from the case of supplier selection, in the sense that the latter seeks to define an order of preference among potential suppliers while the former aims to categorize suppliers (De Boer et al., 2001; Omurca, 2013; Osiro et al., 2014). Several studies presented in the literature propose dimensions of evaluation for categorization of suppliers. The dimensions of evaluation are usually based on a group of criteria, as presented in Table 1.

Sarkar and Mohapatra (2006) propose a two-dimensional model in which suppliers are segmented into motivated and de-motivated categories based on evaluating short-term performance and long-term capability. Short-term performance criteria are price, quality, delivery, lead time and attitude. As for long-term capability the authors consider quality system, financial capability, production facilities, management and organization, technological capability and reputation, among others. Araz and Ozkarahan (2007) propose a one-dimensional model to evaluate and classify suppliers according to their co-design ability and overall performance. Based on ten criteria, suppliers are categorized as pruning, competitive, promising or strategic. Omurca (2013) also propose a one-dimensional model to group suppliers in clusters based on a set of eleven criteria. Rezaei and Ortt (2013) propose a two-dimensional model to evaluate and classify suppliers based on the dimensions willingness and capability. However, their understanding of capability differs from what is proposed by Sarkar and Mohapatra (2006) as they consider criteria such as price, delivery, quality, etc. On the other hand, criteria such as commitment to quality, communication openness, relationship among others which are associated to capability are considered by them under the dimension willingness. Akman (2014) proposes a method in which suppliers are evaluated in two dimensions. First, the suppliers are grouped according to their performance on operations related criteria (named performance dimension). The best performers are then evaluated according to the environmental dimension so as to identify the suppliers to be included in a green development program. Liou et al. (2014) also propose a method to evaluate and improve suppliers' performance based on the interdependence of four dimensions: compatibility, cost, quality and risk. Osiro et al. (2014) propose a method to categorize supplier performance according to the item category so as to indicate strengths and weaknesses of current suppliers, which are evaluated according to the dimensions short-term delivery performance and long-term potential for partnership. Finally, Sahu et al. (2014) propose a hierarchical procedure to evaluate environmental performance of suppliers based on four dimensions of evaluation: enterprise ability, service level, cooperation degree and environmental factors.

Multicriteria decision making methods, statistical and artificial intelligence techniques have been explored to support supplier evaluation for development (Sarkar and Mohapatra, 2006; Araz and Ozkarahan, 2007; Park et al., 2010; Aksoy and Öztürk, 2011; Bai and Sarkis, 2011; Ho et al., 2012; Omurca, 2013; Rezaei and Ortt, 2013; Akman, 2014; Dou et al., 2014; Liou et al., 2014; Osiro et al., 2014; Sahu et al., 2014). The use of appropriate techniques can bring effectiveness and efficiency to the supplier evaluation process (De Boer et al., 2001). Table 2 presents a summarized review of decision making approaches for evaluating suppliers for development purposes, grouped into single or combined methods. Combined methods propose the hybridization of two or more techniques or the sequential application of several techniques.

An important requirement of these techniques for supplier evaluation is that they should allow for inclusion or exclusion of criteria and suppliers without affecting the consistency of the results (Lima Junior et al., 2014). A drawback that affects the models based on AHP, ANP and fuzzy AHP is the ranking reversal problem, a change in the overall ordering of the initial set of suppliers, which can happen when additional criteria or alternative suppliers are included. Another important characteristic of the techniques for evaluation of suppliers' performance is that they should be able to handle uncertainty, which may refer to the lack of precision of the ratings of the alternatives as well as the relative importance of different criteria. This imprecision may be caused by the difficulty of assessing intangible aspects of supplier performance or by subjective judgments of the decision makers. An approach to deal with qualitative criteria and subjective judgements is the use of comparative techniques such as AHP (Park et al., 2010), ANP (Dou et al., 2014; Hsu et al., 2014; Liou et al., 2014), fuzzy AHP (Zeydan et al., 2011; Rezaei and Ortt, 2013) and DEMATEL (Ho et al., 2012). However, these techniques limit the numbers of criteria and suppliers that can be evaluated simultaneously. Saaty (1990) suggests that the number criteria or alternatives to be evaluated using pair-wise comparisons be limited to nine so as not to compromise human judgment and its consistency.

Table 2
Summarized review of decision making models for supplier evaluation.

Approach	Proposed by	Technique(s)	Scope
Single method	Sarkar and Mohapatra (2006)	Comparison of fuzzy numbers	Evaluation of supplier capability and performance
	Araz and Ozkarahan (2007)	PROMETHEE (Preference Ranking Organization Method for Enrichment Evaluations)	Supplier evaluation and management system for strategic sourcing
	Park et al. (2010)	AHP (Analytic Hierarchy Process)	Supplier relationship management
	Bai and Sarkis (2011)	Rough set theory	Evaluation of green supplier development programs
	Aksoy and Öztürk (2011)	Artificial neural networks	Supplier selection and performance evaluation in just-in-time production environments
	Sahu et al. (2014)	Based on trapezoidal fuzzy numbers	Green supplier appraisement in fuzzy environment
	Osiro et al. (2014)	Fuzzy inference	Evaluation of supplier performance according to the type of item purchased
Combined method	Akman (2014)	Fuzzy c-means and VIKOR (Vise Kriterijumska Optimizacija I Kompromisno Resenje)	Evaluation of suppliers to include green supplier development programs
	Dou et al. (2014)	Grey-Analytical Network Process (ANP)	Evaluation of green development programs
	Ho et al. (2012)	Multiple regression analysis and DEMATEL	Supplier quality performance assessment
	Hsu et al. (2014)	ANP and VIKOR	Carbon performance evaluation of supplier in the electronics industry
	Liou et al. (2014)	Fuzzy integral-based model and ANP based on DEMATEL (Making Trial and Evaluation Laboratory)	Supplier evaluation and improvement considering the interdependence among the criteria
	Omurca (2013)	Fuzzy c-means combined with rough set theory	Supplier evaluation, selection and development
	Rezaei and Ortt (2013)	Fuzzy AHP	Supplier segmentation based on multicriteria
	Zeydan et al. (2011)	Fuzzy AHP, Fuzzy TOPSIS and DEA (Data Envelopment Analysis)	A combined methodology for supplier selection and performance evaluation

Another approach commonly used to deal with qualitative criteria and subjective judgments is the adoption of linguistic variables quantified by fuzzy numbers, such as fuzzy TOPSIS, fuzzy QFD (Quality Function Deployment), fuzzy AHP, fuzzy ANP among others (Mardani et al., 2015). In these techniques, the fuzzy number morphology is the main resource for quantifying imprecision, since the parameters of the membership functions can be chosen so as to better represent the linguistic terms used by each decision maker to evaluate the alternatives regarding different decision criteria (Lima Junior et al., 2014). Among the techniques based on fuzzy set theory, fuzzy TOPSIS is usually preferred in the context of supplier evaluation since: it does not limit the number of criteria and suppliers; it does not cause the ranking reversal problem and null weights as in fuzzy AHP; and in relation to comparative approaches, it requires a lower number of judgments by decision makers (Lima Junior et al., 2014). Despite these benefits and the large number of applications of fuzzy TOPSIS to supplier selection, the only application of this technique in a decision model for supplier evaluation is proposed by Zeydan et al. (2011). However, in this decision model presented by Zeydan et al. (2011), fuzzy TOPSIS is used only for supplier performance evaluation since fuzzy AHP is used in the phase of criteria weighting. Thus, besides limiting the number of criteria to be used in the decision process, the model proposed by these authors does not include directives for supplier development based on the evaluation results.

3. Fuzzy set theory

Fuzzy set theory (Zadeh, 1965) has been used to support the decision making processes based on imprecise and uncertain information. A fuzzy set $\tilde{A}$ in X is defined by:

$$\tilde{A} = \{\chi, \mu_A(\chi)\}, \chi \in X \tag{1}$$

in which $\mu_A(\chi): X \to [0,1]$ is the membership function of $\tilde{A}$ and $\mu_A(\chi)$ is the degree of pertinence of x in $\tilde{A}$. If $\mu_A(x)$ equals zero, x does not belong to the fuzzy set $\tilde{A}$. If $\mu_A(x)$ equals 1, x completely belongs to the fuzzy set $\tilde{A}$. However, unlike the classical set theory, if $\mu_A(x)$ has a value between zero and 1, x partially belongs to the fuzzy set $\tilde{A}$. That is, the pertinence of x is true with degree of membership given by $\mu_A(x)$ (Zadeh, 1965; Pedrycz and Gomide, 2007). In the fuzzy set theory, the values of the variables are expressed qualitatively by linguistic terms and quantitatively by fuzzy sets in the universe of discourse and respective membership functions. A fuzzy number is a fuzzy set in which the membership function satisfies the conditions of normality and of convexity. Algebraic operations between fuzzy numbers are well detailed in the literature (Pedrycz and Gomide, 2007; Lima Junior et al., 2014).

3.1. The fuzzy TOPSIS method

The fuzzy TOPSIS method was proposed by Chen (2000) aiming at to deal with group decision making problems in uncertain environment. Implicit in the fuzzy TOPSIS technique is the compensatory property, by which decision is based on the assumption that a bad performance of a supplier on a particular criterion can be partially compensated by high ratings on other criteria and its overall evaluation of performance and its rank will reflect that. This method has been largely applied to support decision making problems related to operations management, such as selection of plant location (Kurt, 2014), supplier selection (Lima Junior et al., 2014), selection of optimal robots in manufacturing (Liu et al., 2014), assessment of ergonomic compatibility (Maldonado-Macias et al., 2014), among others. Linguistic variables are used by the decision makers, D_r ($r = 1,\ldots, k$), to evaluate the weights of the criteria and the ratings of the alternatives. The variable $\tilde{w}_j^r$ describes the weight of the jth criterion, C_j ($j=1,\ldots,m$), given by the rth decision maker. Similarly, $\tilde{x}_{ij}^r$ describes the rating of the ith alternative, A_i ($i = 1,\ldots,n$), with respect to criterion j, given by the rth decision maker (Chen, 2000; Lima Junior et al., 2014). This method comprises the following steps:

i. Aggregate the weights of criteria and ratings of alternatives given by k decision makers, as presented in Eqs. (2) and (3) respectively

$$\tilde{w}_j = \frac{1}{K}[\tilde{w}_j^1 + \tilde{w}_j^2 + \ldots + \tilde{w}_j^k] \tag{2}$$

$$\tilde{x}_{ij} = \frac{1}{K}[\tilde{x}_{ij}^1 + \tilde{x}_{ij}^r + \ldots + \tilde{x}_{ij}^k] \tag{3}$$

ii. Assembly the fuzzy decision matrix of the alternatives ($\tilde{D}$) and the criteria ($\tilde{W}$), according to Eqs. (4) and (5)

$$\tilde{D} = \begin{array}{c} \\ A_1 \\ A_i \\ A_n \end{array} \begin{array}{c} \begin{array}{cccc} C_1 & C_2 & C_j & C_m \end{array} \\ \begin{bmatrix} \tilde{x}_{11} & \tilde{x}_{12} & \tilde{x}_{1j} & \tilde{x}_{1m} \\ \vdots & \vdots & \vdots & \vdots \\ \tilde{x}_{n1} & \tilde{x}_{n2} & \tilde{x}_{nj} & \tilde{x}_{nm} \end{bmatrix} \end{array} \tag{4}$$

$$\tilde{W} = [\tilde{w}_1, \tilde{w}_2, \ldots, \tilde{w}_m] \tag{5}$$

iii. Normalize the fuzzy decision matrix of the alternatives ($\tilde{D}$) using linear scale transformation. The normalized fuzzy decision matrix $\tilde{R}$ is given by

$$\tilde{R} = [\tilde{r}_{ij}]_{mxn} \tag{6}$$

The calculation of the normalized decision matrix depends on the type of the criteria. For benefit criteria, that is when the linguistic terms in the higher part of the scale are used to indicate better ratings, the normalized decision matrix is given by Eq. (7). Otherwise, for cost criteria (the linguistic terms in the lower part of the scale are used to indicate better ratings), the normalized decision matrix is given by Eq. (8).

$$\tilde{r}_{ij} = \left(\frac{l_{ij}}{u_j^+}, \frac{m_{ij}}{u_j^+}, \frac{u_{ij}}{u_j^+}\right) \quad \text{and} \quad u_j^+ = \max_i u_{ij} \quad \text{(benefit criteria)} \tag{7}$$

$$\tilde{r}_{ij} = \left(\frac{l_j^-}{u_{ij}}, \frac{l_j^-}{m_{ij}}, \frac{l_j^-}{l_{ij}}\right) \quad \textit{and} \quad l_j^- = \min_i l_{ij} \quad \text{(costcriteria)} \tag{8}$$

iv. Compute the weighted normalized decision matrix, $\tilde{V}$, by multiplying the weights of the evaluation criteria, $\tilde{w}_j$, by the elements $\tilde{r}_{ij}$ of the normalized fuzzy decision matrix

$$\tilde{V} = [\tilde{v}_{ij}]_{mxn} \tag{9}$$

where $\tilde{v}_{ij}$ is given by Eq. (10).

$$\tilde{v}_{ij} = \tilde{r}_{ij} * \tilde{w}_j \tag{10}$$

v. Define the Fuzzy Positive Ideal Solution (FPIS, A^+) and the Fuzzy Negative Ideal Solution (FNIS, A^-), according to Eqs. (11) and (12).

$$A^+ = \left\{\tilde{v}_1^+, \tilde{v}_j^+, \ldots, \tilde{v}_m^+\right\} \tag{11}$$

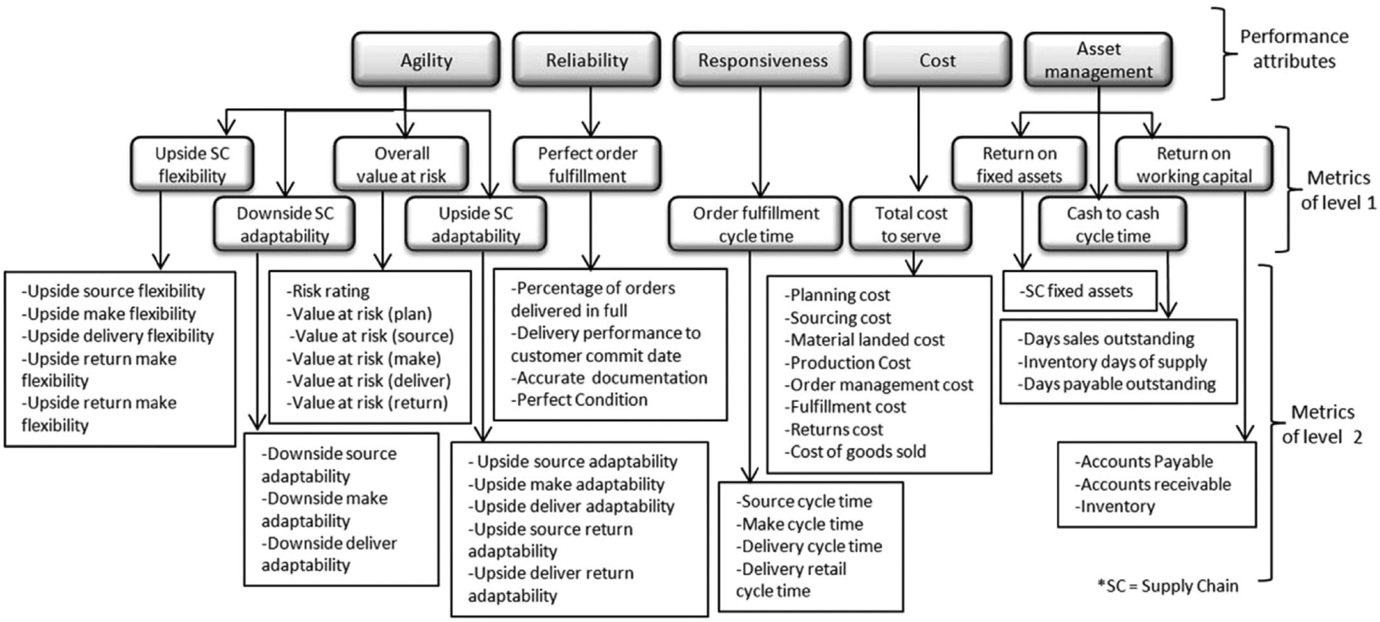

Fig. 1. Performance attributes and metrics of the SCOR model.

$$A^- = \left\{\tilde{v}_1^-, \tilde{v}_j^-, \ldots, \tilde{v}_m^-\right\} \tag{12}$$

where, according to Chen et al. (2006), $\tilde{v}_j^+ = \max_i\left\{u_{v_{ij}}\right\}$ and $\tilde{v}_j^- = \min_i\left\{l_{v_{ij}}\right\}$.

vi. Compute the distances d_i^+ and d_i^- of each alternative from respectively $\tilde{v}_j^+$ and $\tilde{v}_j^-$ according to Eqs. (13) and (14).

$$d_i^+ = \sum_{j=1}^{n} d_v(\tilde{v}_{ij}, \tilde{v}_j^+) \tag{13}$$

$$d_i^- = \sum_{j=1}^{n} d_v(\tilde{v}_{ij}, \tilde{v}_j^-) \tag{14}$$

where $d(.,.)$ represents the distance between two fuzzy numbers according to the vertex method. For triangular fuzzy numbers, this is expressed as in Eq. (15).

$$d(\tilde{x}, \tilde{z}) = \sqrt{\frac{1}{3}\left[(l_x - l_z)^2 + (m_x - m_z)^2 + (u_x - u_z)^2\right]} \tag{15}$$

vii. Compute the closeness coefficient, CC_i, according to Eq. (16).

$$CC_i = \frac{d_i^-}{(d_i^+ + d_i^-)} \tag{16}$$

viii. Define the ranking of the alternatives according to the closeness coefficient, CC_i, in decreasing order. The best alternative is closest to the FPIS and farthest to the FNIS.

4. The SCOR® model

The SCOR® (Supply Chain Operation Reference) model has been developed by the Supply Chain Council (SCC, 2012) to map the business activities related with all phases of fulfilling a customer's demand. The model contains four sections: process, practices, people and performance. The reference model (version 11) is based on six primary management processes: Plan, Source, Make, Deliver, Return and Enable. The performance section of the SCOR® model presents a hierarchical structure of performance metrics related to five attributes. An attribute is used to set strategic direction but cannot be measured. Metrics measure the ability of a supply chain to achieve these strategic attributes.

Top level SCOR® metrics focus on the following performance attributes (SCC, 2012):

- Reliability: the ability to perform tasks as expected. Reliability focuses on the predictability of the outcome of a process. Typical metrics for the reliability attribute include on-time, the right quantity and the right quality;
- Responsiveness: the speed at which tasks are performed. The speed at which a supply chain provides products to the customer. Examples include cycle-time metrics;
- Agility: the ability to respond to external influences, the ability to respond to marketplace changes to gain or maintain competitive advantage. SCOR® agility metrics include flexibility and adaptability;
- Costs: the cost of operating the supply chain processes. This includes labor costs, material costs, management and transportation costs;
- Asset Management Efficiency (Assets): the ability to efficiently utilize assets. Asset management strategies in a supply chain include inventory reduction and in-sourcing vs. outsourcing.

The SCOR® model defines a structure of metrics organized in three levels. Fig. 1 presents the hierarchy of metrics of levels 1 and 2 for the 5 attributes. The Supply Chain Council suggests that scorecards should contain at least one metric for each performance attribute so as to ensure a balanced decision making. The unfolding of these metrics and their cause and effect relationships makes it possible to analyze the performance of a supply chain from different perspectives. Since level-2 metrics serve as diagnostics for level-1 metrics, performance gaps and improvements of level-1 metrics can be explained by analyzing the performance achieved for level-2 metrics (SCC, 2012).

Organizations that use the performance metrics of the SCOR® model can compare their performances levels against of the other organizations in supply chains by using a benchmarking tool named SCORmark. Benchmarking metrics help establishing realistic targets to support decisions related to strategic directions. The database of the SCORmark contains historical data of over 1,000 companies and 2000 supply chains. The benchmarking process using the SCORmark can be conducted by the following steps: (1) define supply chains to be compared; (2) measure internal and external performance; (3) compare performance to relevant industry companies; (4) establish competitive requirements; (5) calculate the opportunity value of improvement (SCC, 2012). To facilitate the comparison, the SCORmark stratifies the process performance according to three positions (Ganga and Carpinetti, 2011):

- *Superior*: is the performance (median value) on a specific indicator attained by 10% of the best classified SC's in relation to the total of the supply chains surveyed;
- *Advantage*: is the performance (median value) among the top 10 companies and the median of all the supply chains studied;
- *Parity*: is the performance (median value) of all the supply chains studied.

The SCOR® model suggests the development of new tools by the combination of the performance metrics with modeling and simulation techniques to support management activities such as supply chain performance measurement, risk assessment, supplier evaluation and benchmarking (SCC, 2012). However, the SCOR®-based applications found in the literature are focused only on supply chain performance measurement (Ganga and Carpinetti, 2011, Agami et al, 2014).

5. The proposed approach for supplier evaluation for development

The proposed approach to support the supplier performance evaluation for development is presented in Fig. 2. It follows other studies based on a two-dimensional model that evaluate and categorize suppliers for identification of needs of further development and opportunities to improve relationship (Olsen and Ellram, 1997; Aksoy and Öztürk, 2011; Rezaei and Ortt, 2013; Osiro et al., 2014). The application of this proposal should involve the participation of one or more decision makers from different functional areas involved with the process of supplier evaluation and development, such as quality, logistics, product development and acquisition. As shown in Fig. 2, the proposal is divided into tree steps. In the steps 1 and 2, evaluation of suppliers according to criteria related to cost and delivery performance is made according to the judgments of the decision makers. In the step 3, the results of the previous steps are used to classify the suppliers into different groups so as to indicate directives for supplier development.

The set of criteria suggested for supplier evaluation is formed by the metrics of level 2 of the SCOR® model related to supplier management (SCC, 2012). Table 3 details the metrics adopted as criteria for supplier evaluation and their codification and units of measurement according to the SCOR® model. In the proposed model, the criteria associated to the delivery performance dimension are the metrics of the SCOR® model related to the attributes of reliability

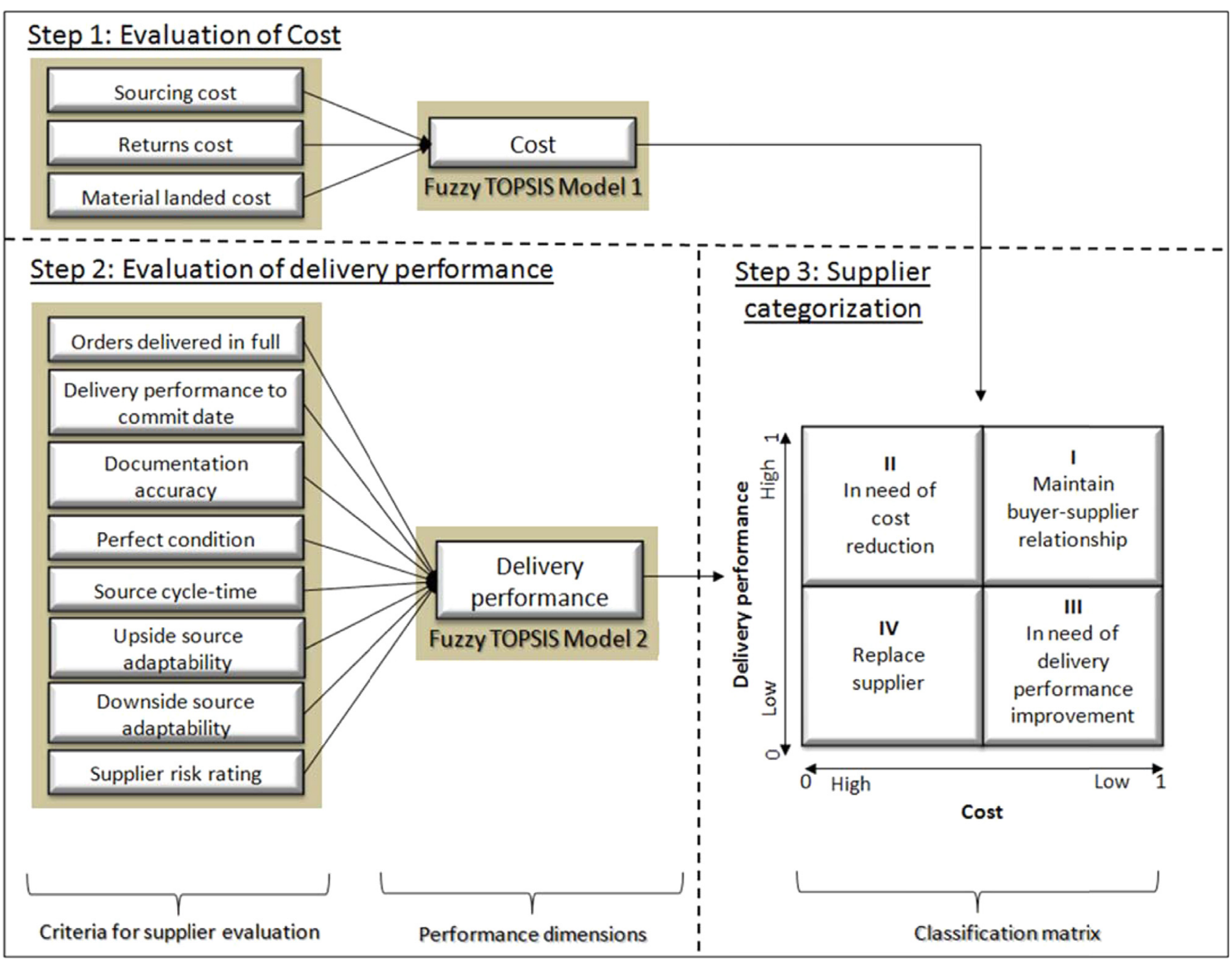

Fig. 2. The proposed approach for supplier performance evaluation for development.

Table 3
Criteria used in the proposed model for supplier evaluation.

Performance dimension	List of criteria	Codification in the SCOR model	Description	Unit
Cost	Sourcing cost (C_1)	CO.2.002	The total cost associated with managing the ordering, receiving, inspection and warehousing of materials, products, merchandise and services. These costs include labor costs for managing material acquisition, managing supplier performance, purchase order management, material handling, inspection and storage and sourcing overhead such as automation, facilities, indirect materials.	Monetary units
	Material landed cost (C_2)	CO.2.003	The total cost associated with buying and making purchased materials, products or merchandize available to the location of use. These costs include the purchase price, freight and insurance and other cost such as import / export duties, tariffs and other taxes-associated with sourcing and delivery product to the location of use.	Monetary units
	Returns cost (C_3)	CO.2.007	The total cost of disposition of materials returned due to planning errors, supplier quality, production, management order and delivery errors.	Monetary units
Delivery performance	Orders delivered in full (C_4)	RL.2.1	Percentage of orders which all of the items are received by customer in the quantities committed. The number of orders that are received by the customer in the quantities committed divided by the total orders.	Percentage
	Delivery performance to commit date (C_5)	RL.2.2	The percentage of orders that are fulfilled on the customer's originally committed date. An order is considered delivered to the customer commitment date if: 1. The order is received on time as defined by the customer; 2. The delivery is made to the correct location and Customer entity.	Percentage
	Documentation accuracy (C_6)	RL.2.3	Percentage of orders with on time and accurate documentation supporting the order, including packing slips, bills of lading, invoices etc. An order is considered to have accurate documentation when the following are accepted by the customer: shipping documentation, payment documentation, compliance documentation and other required documentation.	Percentage
	Perfect condition (C_7)	RL.2.4	Percentage of orders delivered in an undamaged state that meet specification, have the correct configuration, are faultlessly installed (as applicable) and accepted by the customer. An order is considered to be delivered in perfect condition if all items meet the following criteria: undamaged, meet specification and has correct configuration (as applicable), faultlessly installed (as applicable) and accepted by the customer and not returned for repair or replacement (within the warranty period).	Percentage
	Source cycle-time (C_8)	RS.2.1	The average time associated with source process. It includes the schedule product deliveries cycle time, receive product cycle time, verify product cycle time, transfer product cycle time and authorize supplier payment cycle time.	Days
	Upside source adaptability (C_9)	AG.2.6	The maximum sustainable percentage increase in raw material quantities that can be acquired/received in 30 days.	Percentage
	Downside source adaptability (C_{10})	AG.2.11	The raw material quantity reduction sustainable at 30 days prior to delivery with no inventory or cost penalties.	Percentage
	Supplier risk rating (C_{11})	AG.2.14	The sum of the probability of risk events times the monetary impact of the events which can impact any core supply chain functions.	Monetary units

(RL), responsiveness (RS) and agility (AG). The criteria associated to cost dimension are the metrics of the SCOR® model related to the cost (CO) attribute. It is important to mention that only the SCOR® metrics related to supplier performance are considered in the model. Other SCOR® metrics, for instance metrics related to asset management efficiency, are related to the buyers' performance only and therefore should not be considered in the proposed model. It is also worth to note that several of the SCOR® metrics presented in Table 3 concerns the evaluation of activities that involves flow of material. Therefore the proposed model is intended for applications in manufacturing supply chains.

The decision makers should quantify the level of relative importance of these criteria considering the competitive strategy adopted by the buyer company for supply chain management. For instance, if the company adopts a lean strategy, the criteria related to cost and reliability should be considered as the most important ones. In contrast, in the case of using an agile strategy, criteria related to responsiveness and agility should be prioritized (Gattorna, 2010).

The implementation of the proposed approach requires the construction of two computational models based on the fuzzy TOPSIS technique. As showed in Fig. 2, in the step 1, the fuzzy TOPSIS model 1 calculates the performance for a particular supplier in relation to the cost dimension based on the criteria "sourcing cost" (C_1), "returns cost" (C_2) and "material landed cost" (C_3). In the step 2, the fuzzy TOPSIS model 2 computes the delivery performance dimension considering "orders delivered in full" (C_4), "delivery performance to commit date" (C_5), "documentation accuracy" (C_6), "perfect condition" (C_7), "source cycle time" (C_8), "upside source adaptability" (C_9), "downside source adaptability" (C_{10}) and "supplier risk rating" (C_{11}). The fuzzy TOPSIS models can be implemented as an expert system with the external support of information technology specialists. However, due its simplicity, it could also be implemented on electronic worksheet by a company interested in its application as long as the developers understand the concepts behind fuzzy variables and their algebraic operations. The decision maker(s) can aid the implementation of the fuzzy TOPSIS models by choosing linguistic terms that are adequate for supplier evaluation and weighting the criteria as well as to parameterize the fuzzy numbers corresponding to each linguistic term.

In step 3, the global scores regarding cost and delivery performance calculated by the fuzzy TOPSIS models, represented by CCi, should be normalized as in Eq. (17).

$$CCn_i = \frac{CC_i}{\max(CC_i)} \tag{17}$$

After normalization, CCn_i can assume values in the interval $[\frac{min(CC_i)}{max(CC_i)}, 1.0]$. For both performance dimensions, values lower than 0.5 are classified as "low" and values in the range [0.5, 1.0] are classified as "high". As illustrated in Fig. 2, the combination of these classifications using a two-dimensional grid enables the categorization of suppliers into four different groups. According to the supplier categorization, action plans can be developed for supplier management based on the following directives (Olsen and Ellram, 1997; Park et al., 2010; Rezaei and Ortt, 2013; Osiro et al., 2014):

- *Group I*: Suppliers falling in this group are considered suitable. Once the supplier has satisfied the buyer's expectations in both performance dimensions, efforts should be directed for maintaining the buyer–supplier relationship. In addition, the supplier can be further developed aiming at a partnership in the co-development of critical items;
- *Group II*: The supplier in this group requires cost reductions. The following steps can be adopted: (1) identification of the criteria related to cost in which the supplier exhibits underperformance; (2) identification of the causes of high costs; (3) negotiation of cost reduction targets with the supplier in respect to each criteria; (4) Development, implementation and monitoring of action plans by the supplier aiming at cost reductions in the critical processes;
- *Group III*: Suppliers categorized in this group need improvements in delivery performance. The buyer and the supplier can follow the following steps: (1) identification of the critical criteria for improvement; (2) investigation of the processes that affects these critical criteria and the causes of the supplier underperformance; (3) development and follow-up of continuous improvement programs aiming at enhancing the reliability, responsiveness and agility of these processes;
- *Group IV*: Suppliers in this group should be replaced. Once the supplier has not achieved sufficient performance in any dimension, development programs do not seem a viable decision. In this case, selecting a substitute supplier seems more adequate.

5.1. Application case

An illustrative application of this proposal was developed based on a real context of a second tier manufacturer in the automobile supply chain. The company produces clutches for heavy vehicle and its competitive strategy is based on low cost, high operation performance, high reliability and low risk. In this illustrative case, the aim is to evaluate the performance of 17 suppliers. One decision maker from purchasing area and the other from quality management were interviewed for the definition of the linguistic terms, weights of criteria, and the rates of the evaluated suppliers. The weights of the criteria and rates of the suppliers were evaluated according to the linguistic terms depicted respectively in Tables 4 and 5. Following Chen (2000), triangular fuzzy numbers were used to specify the linguistic values of the weights of the criteria and the rates of the suppliers, as illustrated in Figs. 3 and 4.

From brainstorming and discussion, the decision makers have achieved a consensus about the weights of the criteria and the rates of the suppliers. Table 6 presents the linguistic judgments of the weights of the criteria and the rates of the suppliers. It is worth to note that the ratings of C_1, C_2, C_3, C_8 and C_{11} were modeled as cost criteria. It means that the linguistic terms in the lower part of the scale are used to indicate better ratings.

For the computation of the fuzzy TOPSIS model 1, the rates of the suppliers related to the cost dimension shown in Table 6 are converted into fuzzy triangular numbers. Table 7 shows these fuzzy triangular numbers, which represents the fuzzy decision matrix of the fuzzy TOPSIS model 1. These values were normalized using Eq. (8) and weighted by Eq. (10). The weighted normalized decision matrix is presented in Table 8.

According to Chen et al. (2006), the Fuzzy Positive Ideal Solution (FPIS, A^+) and the Fuzzy Negative Ideal Solution (FNIS, A^-) were defined as

$$A^+ = [(0.75, 0.75, 0.75),\ (1.00, 1.00, 1.00),\ (0.75, 0.75, 0.75)]$$

$$A^- = [(0.003, 0.003, 0.003),\ (0.01, 0.01, 0.01),\ (0.005, 0.005, 0.005)]$$

The distances d_i^+ and d_i^- of the ratings of each alternative from A^+ and A^-, calculated according to Eqs. (13)–(15), are presented in Tables 9 and 10 respectively. The performance of each supplier

Table 4
Linguistic scale to evaluate the weight of the criteria.

Linguistic terms	Fuzzy triangular number
Little importance (LI)	(0.01, 0.01, 0.25)
Moderately important (MI)	(0.01, 0.25, 0.50)
Important (I)	(0.25, 0.50, 0.75)
Very important (VI)	(0.50, 0.75, 1.00)
Absolutely important (AI)	(0.75, 1.00, 1.00)

Table 5
Linguistic scale to evaluate the ratings of the suppliers.

Linguistic terms	Fuzzy triangular number
Very low (VL)	(0.10, 0.10, 2.50)
Low (L)	(0.10, 2.50, 5.00)
Medium (M)	(2.50, 5.00, 7.50)
High (H)	(5.00, 7.50, 10.0)
Very high (VH)	(7.50, 10.0, 10.0)

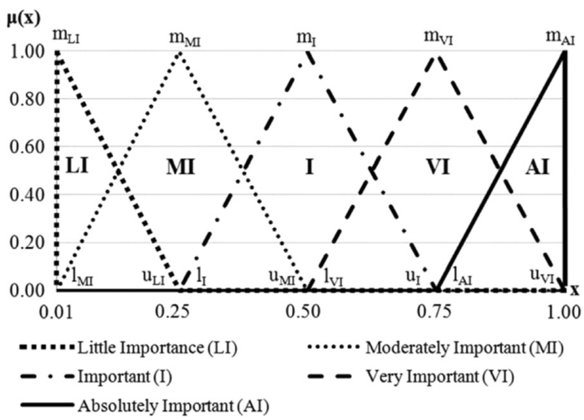

Fig. 3. Triangular fuzzy numbers corresponding to linguistic terms for weighting of the criteria.

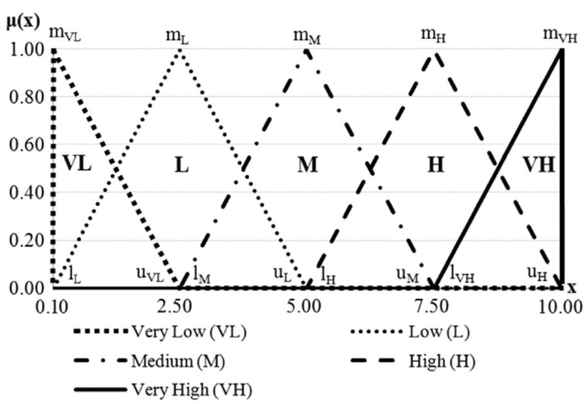

Fig. 4. Triangular fuzzy numbers corresponding to linguistic terms for evaluation of the supplier's performance.

Table 6
Linguistic ratings of the suppliers.

	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}	C_{11}
A_1	VL	VL	VL	VH	VH	VH	H	VL	H	VH	VL
A_2	M	M	L	VH	H	H	M	L	VH	H	M
A_3	VL	L	VL	H	H	VH	VH	VL	H	M	L
A_4	L	VL	VL	VH	H	H	H	VL	M	L	M
A_5	VL	VL	VL	M	M	M	M	M	L	M	H
A_6	VL	M	VL	VH	H	L	L	L	H	H	L
A_7	VL	VL	VL	VH	VH	H	VL	L	L	L	VL
A_8	H	VL	VL	M	H	L	M	L	M	M	L
A_9	M	M	VL	M	M	L	M	M	L	M	H
A_{10}	VL	L	L	H	H	L	VL	L	VL	VL	H
A_{11}	H	VL	VL	H	VH	L	M	VL	H	M	VL
A_{12}	M	M	L	VH	M	VH	VH	M	M	VH	L
A_{13}	VL	VL	VL	H	H	H	H	VL	L	VH	M
A_{14}	VL	L	L	VH	VH	M	VH	L	VL	VH	VL
A_{15}	VL	VL	VL	VH	VH	L	L	VL	M	H	L
A_{16}	L	VL	VL	H	VH	H	VH	L	H	M	VL
A_{17}	VL	L	VL	VH	H	M	M	VL	M	VH	VL
Weights of criteria	I	AI	I	AI	AI	I	VI	I	VI	I	AI

Table 7
Fuzzy numbers of the ratings of the suppliers.

	C_1	C_2	C_3
A_1	(0.10, 0.10, 2.50)	(0.10, 0.10, 2.50)	(0.10, 0.10, 2.50)
A_2	(2.50, 5.00, 7.50)	(2.50, 5.00, 7.50)	(0.10, 2.50, 5.00)
A_3	(0.10, 0.10, 2.50)	(0.10, 2.50, 5.00)	(0.10, 0.10, 2.50)
A_4	(0.10, 2.50, 5.00)	(0.10, 0.10, 2.50)	(0.10, 0.10, 2.50)
A_5	(0.10, 0.10, 2.50)	(0.10, 0.10, 2.50)	(0.10, 0.10, 2.50)
A_6	(0.10, 0.10, 2.50)	(2.50, 5.00, 7.50)	(0.10, 0.10, 2.50)
A_7	(0.10, 0.10, 2.50)	(0.10, 0.10, 2.50)	(0.10, 0.10, 2.50)
A_8	(5.00, 7.50, 10.00)	(0.10, 0.10, 2.50)	(0.10, 0.10, 2.50)
A_9	(2.50, 5.00, 7.50)	(2.50, 5.00, 7.50)	(0.10, 0.10, 2.50)
A_{10}	(0.10, 0.10, 2.50)	(0.10, 2.50, 5.00)	(0.10, 2.50, 5.00)
A_{11}	(5.00, 7.50, 10.00)	(0.10, 0.10, 2.50)	(0.10, 0.10, 2.50)
A_{12}	(2.50, 5.00, 7.50)	(2.50, 5.00, 7.50)	(0.10, 2.50, 5.00)
A_{13}	(0.10, 0.10, 2.50)	(0.10, 0.10, 2.50)	(0.10, 0.10, 2.50)
A_{14}	(0.10, 0.10, 2.50)	(0.10, 2.50, 5.00)	(0.10, 2.50, 5.00)
A_{15}	(0.10, 0.10, 2.50)	(0.10, 0.10, 2.50)	(0.10, 0.10, 2.50)
A_{16}	(0.10, 2.50, 5.00)	(0.10, 0.10, 2.50)	(0.10, 0.10, 2.50)
A_{17}	(0.10, 0.10, 2.50)	(0.10, 2.50, 5.00)	(0.10, 0.10, 2.50)
Weights of criteria	(0.25, 0.50, 0.75)	(0.75, 1.00, 1.00)	(0.25, 0.50, 0.75)

Table 8
Weighted normalized fuzzy decision matrix of the fuzzy TOPSIS model 1.

	C_1	C_2	C_3
A_1	(0.01, 0.50, 0.75)	(0.03, 1.00, 1.00)	(0.01, 0.50, 0.75)
A_2	(0.00, 0.01, 0.03)	(0.01, 0.02, 0.04)	(0.01, 0.02, 0.75)
A_3	(0.01, 0.50, 0.75)	(0.02, 0.04, 1.00)	(0.01, 0.50, 0.75)
A_4	(0.01, 0.02, 0.75)	(0.03, 1.00, 1.00)	(0.01, 0.50, 0.75)
A_5	(0.01, 0.50, 0.75)	(0.03, 1.00, 1.00)	(0.01, 0.50, 0.75)
A_6	(0.01, 0.50, 0.75)	(0.01, 0.02, 0.04)	(0.01, 0.50, 0.75)
A_7	(0.01, 0.50, 0.75)	(0.03, 1.00, 1.00)	(0.01, 0.50, 0.75)
A_8	(0.00, 0.01, 0.02)	(0.03, 1.00, 1.00)	(0.01, 0.50, 0.75)
A_9	(0.00, 0.01, 0.03)	(0.01, 0.02, 0.04)	(0.01, 0.50, 0.75)
A_{10}	(0.01, 0.50, 0.75)	(0.02, 0.04, 1.00)	(0.01, 0.02, 0.75)
A_{11}	(0.00, 0.01, 0.02)	(0.03, 1.00, 1.00)	(0.01, 0.50, 0.75)
A_{12}	(0.00, 0.01, 0.03)	(0.01, 0.02, 0.04)	(0.01, 0.02, 0.75)
A_{13}	(0.01, 0.50, 0.75)	(0.03, 1.00, 1.00)	(0.01, 0.50, 0.75)
A_{14}	(0.01, 0.50, 0.75)	(0.02, 0.04, 1.00)	(0.01, 0.02, 0.75)
A_{15}	(0.01, 0.50, 0.75)	(0.03, 1.00, 1.00)	(0.01, 0.50, 0.75)
A_{16}	(0.01, 0.02, 0.75)	(0.03, 1.00, 1.00)	(0.01, 0.50, 0.75)
A_{17}	(0.01, 0.50, 0.75)	(0.02, 0.04, 1.00)	(0.01, 0.50, 0.75)

in relation to cost is given by the closeness coefficient CC_i presented in Table 11.

Following the same procedure, for the computation of the fuzzy TOPSIS model 2, the rates of the suppliers related to the delivery performance dimension shown in Table 6 are converted into fuzzy triangular numbers. Table 12 shows these fuzzy triangular numbers, which represents the fuzzy decision matrix of the fuzzy TOPSIS model 2. The values of the criteria C_8 and C_{11} (cost criteria) were normalized using Eq. 8. As for the other criteria (benefit criteria), they were normalized using Eq. (7). All the criteria were finally weighted according to Eq. (10). The weighted normalized decision matrix is presented in Table 13.

The Fuzzy Positive Ideal Solution (A^+) and the Fuzzy Negative Ideal Solution (A^-) were defined as

$$A^+ = [(1.00, 1.00, 1.00),\ (1.00, 1.00, 1.00),\ (0.75, 0.75, 0.75), (1.00, 1.00, 1.00),\ (0.75, 0.75, 0.75),\ (1.00, 1.00, 1.00),\ (0.75, 0.75, 0.75),\ (1.00, 1.00, 1.00)]$$

$$A^- = [(0.188,\ 0.188,\ 0.188),\ (0.188,\ 0.188,\ 0.188),\ (0.003,\ 0.003,\ 0.003),\ (0.005,\ 0.005,\ 0.005),\ (0.003,\ 0.003,\ 0.003),\ (0.005, 0.005,\ 0.005),\ (0.003,\ 0.003,\ 0.003), (0.008, 0.008, 0.008)]$$

The distances d_i^+ and d_i^- of the ratings of each alternative from A^+ and A^-, calculated according to Eqs. (13)–(15), are presented in Tables 14 and 15 respectively. The performance of each supplier

Table 9
Distances of the ratings of each alternative from A^+ with respect to each criterion.

	C_1	C_2	C_3	d_i^+
$d(A_1,A^+)$	0.451	0.560	0.451	1.462
$d(A_2,A^+)$	0.736	0.977	0.602	2.315
$d(A_3,A^+)$	0.451	0.794	0.451	1.696
$d(A_4,A^+)$	0.602	0.560	0.451	1.613
$d(A_5,A^+)$	0.451	0.560	0.451	1.462
$d(A_6,A^+)$	0.451	0.977	0.451	1.879
$d(A_7,A^+)$	0.451	0.560	0.451	1.462
$d(A_8,A^+)$	0.742	0.560	0.451	1.753
$d(A_9,A^+)$	0.736	0.977	0.451	2.163
$d(A_{10},A^+)$	0.451	0.794	0.602	1.847
$d(A_{11},A^+)$	0.742	0.560	0.451	1.753
$d(A_{12},A^+)$	0.736	0.977	0.602	2.315
$d(A_{13},A^+)$	0.451	0.560	0.451	1.462
$d(A_{14},A^+)$	0.451	0.794	0.602	1.847
$d(A_{15},A^+)$	0.451	0.560	0.451	1.462
$d(A_{16},A^+)$	0.602	0.560	0.451	1.613
$d(A_{17},A^+)$	0.451	0.794	0.451	1.696

Table 10
Distances of the ratings of each alternative from A^- with respect to each criterion.

	C_1	C_2	C_3	d_i^-
$d(A_1,A^-)$	0.518	0.808	0.516	1.843
$d(A_2,A^-)$	0.016	0.018	0.430	0.465
$d(A_3,A^-)$	0.518	0.572	0.516	1.607
$d(A_4,A^-)$	0.432	0.808	0.516	1.757
$d(A_5,A^-)$	0.518	0.808	0.516	1.843
$d(A_6,A^-)$	0.518	0.018	0.516	1.053
$d(A_7,A^-)$	0.518	0.808	0.516	1.843
$d(A_8,A^-)$	0.008	0.808	0.516	1.332
$d(A_9,A^-)$	0.016	0.018	0.516	0.551
$d(A_{10},A^-)$	0.518	0.572	0.430	1.520
$d(A_{11},A^-)$	0.008	0.808	0.516	1.332
$d(A_{12},A^-)$	0.016	0.018	0.430	0.465
$d(A_{13},A^-)$	0.518	0.808	0.516	1.843
$d(A_{14},A^-)$	0.518	0.572	0.430	1.520
$d(A_{15},A^-)$	0.518	0.808	0.516	1.843
$d(A_{16},A^-)$	0.432	0.808	0.516	1.757
$d(A_{17},A^-)$	0.518	0.572	0.516	1.607

Table 11
Outranking of alternative suppliers according to the fuzzy TOPSIS model 1.

Suppliers	CC_i
A_1	0.558
A_2	0.167
A_3	0.486
A_4	0.521
A_5	0.558
A_6	0.359
A_7	0.558
A_8	0.432
A_9	0.203
A_{10}	0.451
A_{11}	0.432
A_{12}	0.167
A_{13}	0.558
A_{14}	0.451
A_{15}	0.558
A_{16}	0.521
A_{17}	0.486

in relation to delivery is given by the closeness coefficient CC_i presented in Table 16.

Finally, the global scores regarding cost and delivery performance calculated by the fuzzy TOPSIS models are normalized according to Eq. (17). Table 17 presents the evaluation of the suppliers, their categorization and the directives for action plans according to the model depicted in Fig. 2. Fig. 5 also presents the classification of the suppliers according to the categories defined by the proposed decision model. As it can be seen, most of the evaluated suppliers were categorized in group I, which fully comprises the requirements of delivery and cost and therefore the recommendation is to follow up to maintain and improve relationship. Suppliers A_2 and A_{12} were classified in group II, which means that they present a high delivery performance but high costs and therefore actions for cost reduction need to be planned and implemented. In the opposite group are the suppliers A_5 and A_{10}, which were evaluated as having low costs as well as low delivery performance and the recommendation is to carry out plans for improvements in delivery cycle time and conformity. Finally, supplier A_9 was classified in group IV since its performance both in cost and delivery were classified as low. The recommendation in this case is for replacement.

5.2. Sensitivity analysis

Sensitivity analysis of the results of the proposed method was carried out in order to evaluate:

- The effect of variation of the weight of the criteria on the categorization of the alternatives;
- The effect of variation of the ratings of the alternatives on the categorization results;
- The consistency of the results.

The sensitivity analysis was based on four different tests. In the four tests, the ratings of the alternatives were kept the same, as in Table 6. Table 18 presents the weights of the criteria for the four different tests based on the linguistic terms of Table 4. In each test, the set of criteria related to one particular SCOR® attribute was assumed to be absolutely important. For instance, in test 1, the weights of the criteria related to the SCOR® cost attribute were set as "absolutely important" (AI) while for the other attributes the weights of the criteria were set to "moderately important" (MI). In tests 2, 3 and 4 the criteria chosen as absolutely important were related to reliability, responsiveness and agility attributes, respectively.

Table 19 shows the normalized closeness coefficients (CCn_i) for the two fuzzy TOPSIS models for the four sensitivity tests. Table 20 shows the categorization results of the alternatives in the four tests. It also shows the categorization of the alternatives for the application case (as in Table 17). First, it can be seen that for some tests there were changes in the categorization of the alternatives A_5, A_9 and A_{10} when compared with the results of the application case. Although the values of the CCn_i have not changed significantly, the categorization has changed because the CCn_i values of these alternatives were close to the border in the classification grid in Fig. 5.

In tests 1, 2 and 3, for alternatives A_5 and A_{10}, in relation to the application case, the categorization of these alternatives changed from "in need of delivery performance improvement" to "maintain relationship". For tests 2 and 3, the weights of the criteria C_4 to C_8 (related to reliability and responsiveness) were increased and the weights of the criteria C_9 to C_{11} (related to agility) were decreased in relation to the application case. This change in categorization was consistent, since these alternatives have good ratings in the criteria C_4 to C_8 and low performance in the criteria C_9 to C_{11}. In test 1, also for alternatives A_5 and A_{10}, all the criteria related to the dimension of delivery performance had their weights decreased in relation to the application case, which means that the buyer expectation in relation to this dimension has diminished. This led to this change in the categorization, from "in need of delivery

Table 12
Fuzzy numbers of the ratings of the suppliers.

	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}	C_{11}
A_1	(7.50, 10.0, 10.0)	(7.50, 10.0, 10.0)	(7.50, 10.0, 10.0)	(5.00, 7.50, 10.0)	(0.01, 0.01, 2.50)	(5.00, 7.50, 10.0)	(7.50, 10.0, 10.0)	(0.01, 0.01, 2.50)
A_2	(7.50, 10.0, 10.0)	(5.00, 7.50, 10.0)	(5.00, 7.50, 10.0)	(2.50, 5.00, 7.50)	(0.01, 2.50, 5.00)	(7.50, 10.0, 10.0)	(5.00, 7.50, 10.0)	(2.50, 5.00, 7.50)
A_3	(5.00, 7.50, 10.0)	(5.00, 7.50, 10.0)	(7.50, 10.0, 10.0)	(7.50, 10.0, 10.0)	(0.01, 0.01, 2.50)	(5.00, 7.50, 10.0)	(2.50, 5.00, 7.50)	(0.01, 2.50, 5.00)
A_4	(7.50, 10.0, 10.0)	(5.00, 7.50, 10.0)	(5.00, 7.50, 10.0)	(5.00, 7.50, 10.0)	(0.01, 0.01, 2.50)	(2.50, 5.00, 7.50)	(0.01, 2.50, 5.00)	(2.50, 5.00, 7.50)
A_5	(2.50, 5.00, 7.50)	(2.50, 5.00, 7.50)	(2.50, 5.00, 7.50)	(2.50, 5.00, 7.50)	(2.50, 5.00, 7.50)	(0.01, 2.50, 5.00)	(2.50, 5.00, 7.50)	(5.00, 7.50, 10.0)
A_6	(7.50, 10.0, 10.0)	(5.00, 7.50, 10.0)	(0.01, 2.50, 5.00)	(0.01, 2.50, 5.00)	(0.01, 2.50, 5.00)	(5.00, 7.50, 10.0)	(5.00, 7.50, 10.0)	(0.01, 2.50, 5.00)
A_7	(7.50, 10.0, 10.0)	(7.50, 10.0, 10.0)	(5.00, 7.50, 10.0)	(0.01, 0.01, 2.50)	(0.01, 2.50, 5.00)	(0.01, 2.50, 5.00)	(0.01, 2.50, 5.00)	(0.01, 0.01, 2.50)
A_8	(2.50, 5.00, 7.50)	(5.00, 7.50, 10.0)	(0.01, 2.50, 5.00)	(2.50, 5.00, 7.50)	(0.01, 2.50, 5.00)	(2.50, 5.00, 7.50)	(2.50, 5.00, 7.50)	(0.01, 2.50, 5.00)
A_9	(2.50, 5.00, 7.50)	(2.50, 5.00, 7.50)	(0.01, 2.50, 5.00)	(2.50, 5.00, 7.50)	(2.50, 5.00, 7.50)	(0.01, 2.50, 5.00)	(2.50, 5.00, 7.50)	(5.00, 7.50, 10.0)
A_{10}	(5.00, 7.50, 10.0)	(5.00, 7.50, 10.0)	(5.00, 2.50, 5.00)	(7.50, 0.01, 2.50)	(0.01, 2.50, 5.00)	(0.01, 0.01, 2.50)	(0.01, 0.01, 2.50)	(5.00, 7.50, 10.0)
A_{11}	(5.00, 7.50, 10.0)	(7.50, 10.0, 10.0)	(0.01, 2.50, 5.00)	(2.50, 5.00, 7.50)	(0.01, 0.01, 2.50)	(5.00, 7.50, 10.0)	(2.50, 5.00, 7.50)	(0.01, 0.01, 2.50)
A_{12}	(7.50, 10.0, 10.0)	(2.50, 5.00, 7.50)	(7.50, 10.0, 10.0)	(7.50, 10.0, 10.0)	(2.50, 5.00, 7.50)	(2.50, 5.00, 7.50)	(7.50, 10.0, 10.0)	(0.01, 2.50, 5.00)
A_{13}	(5.00, 7.50, 10.0)	(5.00, 7.50, 10.0)	(5.00, 7.50, 10.0)	(5.00, 7.50, 10.0)	(0.01, 0.01, 2.50)	(0.01, 2.50, 5.00)	(7.50, 10.0, 10.0)	(2.50, 5.00, 7.50)
A_{14}	(7.50, 10.0, 10.0)	(7.50, 10.0, 10.0)	(2.50, 5.00, 7.50)	(7.50, 10.0, 10.0)	(0.01, 2.50, 5.00)	(0.01, 0.01, 2.50)	(7.50, 10.0, 10.0)	(0.01, 0.01, 2.50)
A_{15}	(7.50, 10.0, 10.0)	(7.50, 10.0, 10.0)	(0.01, 2.50, 5.00)	(0.01, 2.50, 5.00)	(0.01, 0.01, 2.50)	(2.50, 5.00, 7.50)	(5.00, 7.50, 10.0)	(0.01, 2.50, 5.00)
A_{16}	(5.00, 7.50, 10.0)	(7.50, 10.0, 10.0)	(5.00, 7.50, 10.0)	(7.50, 10.0, 10.0)	(0.01, 2.50, 5.00)	(5.00, 7.50, 10.0)	(2.50, 5.00, 7.50)	(0.01, 0.01, 2.50)
A_{17}	(7.50, 10.0, 10.0)	(5.00, 7.50, 10.0)	(2.50, 5.00, 7.50)	(2.50, 5.00, 7.50)	(0.01, 0.01, 2.50)	(2.50, 5.00, 7.50)	(7.50, 10.0, 10.0)	(0.01, 0.01, 2.50)
Weights of criteria	(0.75, 1.00, 1.00)	(0.75, 1.00, 1.00)	(0.25, 0.50, 0.75)	(0.50, 0.75, 1.00)	(0.25, 0.50, 0.75)	(0.50, 0.75, 1.00)	(0.25, 0.50, 0.75)	(0.75, 1.00, 1.00)

Table 13
Normalized and weighted fuzzy decision matrix of the fuzzy TOPSIS model 2.

	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}	C_{11}
A_1	(0.56, 1.00, 1.00)	(0.56, 1.00, 1.00)	(0.19, 0.50, 0.75)	(0.25, 0.56, 1.00)	(0.01, 0.50, 0.75)	(0.25, 0.56, 1.00)	(0.19, 0.50, 0.75)	(0.03, 1.00, 1.00)
A_2	(0.56, 1.00, 1.00)	(0.38, 0.75, 1.00)	(0.13, 0.38, 0.75)	(0.13, 0.38, 0.75)	(0.01, 0.02, 0.75)	(0.38, 0.75, 1.00)	(0.13, 0.38, 0.75)	(0.01, 0.02, 0.04)
A_3	(0.38, 0.75, 1.00)	(0.38, 0.75, 1.00)	(0.19, 0.50, 0.75)	(0.38, 0.75, 1.00)	(0.01, 0.50, 0.75)	(0.25, 0.56, 1.00)	(0.06, 0.25, 0.56)	(0.02, 0.04, 1.00)
A_4	(0.56, 1.00, 1.00)	(0.38, 0.75, 1.00)	(0.13, 0.38, 0.75)	(0.25, 0.56, 1.00)	(0.01, 0.50, 0.75)	(0.13, 0.38, 0.75)	(0.00, 0.13, 0.38)	(0.01, 0.02, 0.04)
A_5	(0.19, 0.50, 0.75)	(0.19, 0.50, 0.75)	(0.06, 0.25, 0.56)	(0.13, 0.38, 0.75)	(0.00, 0.01, 0.03)	(0.01, 0.19, 0.50)	(0.06, 0.25, 0.56)	(0.01, 0.01, 0.02)
A_6	(0.56, 1.00, 1.00)	(0.38, 0.75, 1.00)	(0.00, 0.13, 0.38)	(0.01, 0.19, 0.50)	(0.01, 0.02, 0.75)	(0.25, 0.56, 1.00)	(0.13, 0.38, 0.75)	(0.02, 0.04, 1.00)
A_7	(0.56, 1.00, 1.00)	(0.56, 1.00, 1.00)	(0.13, 0.38, 0.75)	(0.01, 0.01, 0.25)	(0.01, 0.02, 0.75)	(0.01, 0.19, 0.50)	(0.00, 0.13, 0.38)	(0.03, 1.00, 1.00)
A_8	(0.19, 0.50, 0.75)	(0.38, 0.75, 1.00)	(0.00, 0.13, 0.38)	(0.13, 0.38, 0.75)	(0.01, 0.02, 0.75)	(0.13, 0.38, 0.75)	(0.06, 0.25, 0.56)	(0.02, 0.04, 1.00)
A_9	(0.19, 0.50, 0.75)	(0.19, 0.50, 0.75)	(0.00, 0.13, 0.38)	(0.13, 0.38, 0.75)	(0.00, 0.01, 0.03)	(0.01, 0.19, 0.50)	(0.06, 0.25, 0.56)	(0.01, 0.01, 0.02)
A_{10}	(0.38, 0.75, 1.00)	(0.38, 0.75, 1.00)	(0.13, 0.13, 0.38)	(0.38, 0.01, 0.25)	(0.01, 0.02, 0.75)	(0.01, 0.01, 0.25)	(0.00, 0.01, 0.19)	(0.01, 0.01, 0.02)
A_{11}	(0.38, 0.75, 1.00)	(0.56, 1.00, 1.00)	(0.00, 0.13, 0.38)	(0.13, 0.38, 0.75)	(0.01, 0.50, 0.75)	(0.25, 0.56, 1.00)	(0.06, 0.25, 0.56)	(0.03, 1.00, 1.00)
A_{12}	(0.56, 1.00, 1.00)	(0.19, 0.50, 0.75)	(0.19, 0.50, 0.75)	(0.38, 0.75, 1.00)	(0.00, 0.01, 0.03)	(0.13, 0.38, 0.75)	(0.19, 0.50, 0.75)	(0.02, 0.04, 1.00)
A_{13}	(0.38, 0.75, 1.00)	(0.38, 0.75, 1.00)	(0.13, 0.38, 0.75)	(0.25, 0.56, 1.00)	(0.01, 0.50, 0.75)	(0.01, 0.19, 0.50)	(0.19, 0.50, 0.75)	(0.01, 0.02, 0.04)
A_{14}	(0.56, 1.00, 1.00)	(0.56, 1.00, 1.00)	(0.06, 0.25, 0.56)	(0.38, 0.75, 1.00)	(0.01, 0.02, 0.75)	(0.01, 0.01, 0.25)	(0.19, 0.50, 0.75)	(0.03, 1.00, 1.00)
A_{15}	(0.56, 1.00, 1.00)	(0.56, 1.00, 1.00)	(0.00, 0.13, 0.38)	(0.01, 0.19, 0.50)	(0.01, 0.50, 0.75)	(0.13, 0.38, 0.75)	(0.13, 0.38, 0.75)	(0.02, 0.04, 1.00)
A_{16}	(0.38, 0.75, 1.00)	(0.56, 1.00, 1.00)	(0.13, 0.38, 0.75)	(0.38, 0.75, 1.00)	(0.01, 0.02, 0.75)	(0.25, 0.56, 1.00)	(0.06, 0.25, 0.56)	(0.03, 1.00, 1.00)
A_{17}	(0.56, 1.00, 1.00)	(0.38, 0.75, 1.00)	(0.06, 0.25, 0.56)	(0.13, 0.38, 0.75)	(0.01, 0.50, 0.75)	(0.13, 0.38, 0.75)	(0.19, 0.50, 0.75)	(0.03, 1.00, 1.00)

Table 14
Distances of the ratings of each alternative from A^+ with respect to each criterion.

	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}	C_{11}	d_i^+
$d(A_1,A^+)$	0.253	0.253	0.355	0.501	0.451	0.501	0.355	0.560	3.230
$d(A_2,A^+)$	0.253	0.389	0.421	0.637	0.602	0.389	0.421	0.977	4.088
$d(A_3,A^+)$	0.389	0.389	0.355	0.389	0.451	0.501	0.503	0.794	3.770
$d(A_4,A^+)$	0.253	0.389	0.421	0.501	0.451	0.637	0.603	0.977	4.231
$d(A_5,A^+)$	0.569	0.569	0.503	0.637	0.736	0.796	0.503	0.986	5.299
$d(A_6,A^+)$	0.253	0.389	0.603	0.796	0.602	0.501	0.421	0.794	4.358
$d(A_7,A^+)$	0.253	0.253	0.421	0.920	0.602	0.796	0.603	0.560	4.407
$d(A_8,A^+)$	0.569	0.389	0.603	0.637	0.602	0.637	0.503	0.794	4.734
$d(A_9,A^+)$	0.569	0.569	0.603	0.637	0.736	0.796	0.503	0.986	5.399
$d(A_{10},A^+)$	0.389	0.389	0.554	0.804	0.602	0.920	0.690	0.986	5.334
$d(A_{11},A^+)$	0.389	0.253	0.603	0.637	0.451	0.501	0.503	0.560	3.896
$d(A_{12},A^+)$	0.253	0.569	0.355	0.389	0.736	0.637	0.355	0.794	4.089
$d(A_{13},A^+)$	0.389	0.389	0.421	0.501	0.451	0.796	0.355	0.977	4.278
$d(A_{14},A^+)$	0.253	0.253	0.503	0.389	0.602	0.920	0.355	0.560	3.834
$d(A_{15},A^+)$	0.253	0.253	0.603	0.796	0.451	0.637	0.421	0.794	4.207
$d(A_{16},A^+)$	0.389	0.253	0.421	0.389	0.602	0.501	0.503	0.560	3.617
$d(A_{17},A^+)$	0.253	0.389	0.503	0.637	0.451	0.637	0.355	0.560	3.785

Table 15
Distances of the ratings of each alternative from A^- with respect to each criterion.

	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}	C_{11}	d_i^-
$d(A_1,A^-)$	0.70	0.70	0.53	0.67	0.52	0.67	0.53	0.81	5.130
$d(A_2,A^-)$	0.70	0.58	0.49	0.49	0.43	0.75	0.49	0.02	3.939
$d(A_3,A^-)$	0.58	0.58	0.53	0.75	0.52	0.67	0.36	0.57	4.559
$d(A_4,A^-)$	0.70	0.58	0.49	0.67	0.52	0.49	0.23	0.02	3.689
$d(A_5,A^-)$	0.37	0.37	0.36	0.49	0.02	0.30	0.36	0.01	2.267
$d(A_6,A^-)$	0.70	0.58	0.23	0.30	0.43	0.67	0.49	0.57	3.975
$d(A_7,A^-)$	0.70	0.70	0.49	0.14	0.43	0.30	0.23	0.81	3.797
$d(A_8,A^-)$	0.37	0.58	0.23	0.49	0.43	0.49	0.36	0.57	3.509
$d(A_9,A^-)$	0.37	0.37	0.23	0.49	0.02	0.30	0.36	0.01	2.138
$d(A_{10},A^-)$	0.58	0.58	0.24	0.26	0.43	0.14	0.11	0.01	2.342
$d(A_{11},A^-)$	0.58	0.70	0.23	0.49	0.52	0.67	0.36	0.81	4.347
$d(A_{12},A^-)$	0.70	0.37	0.53	0.75	0.02	0.49	0.53	0.57	3.951
$d(A_{13},A^-)$	0.58	0.58	0.49	0.67	0.52	0.30	0.53	0.02	3.694
$d(A_{14},A^-)$	0.70	0.70	0.36	0.75	0.43	0.14	0.53	0.81	4.412
$d(A_{15},A^-)$	0.70	0.70	0.23	0.30	0.52	0.49	0.49	0.57	3.990
$d(A_{16},A^-)$	0.58	0.70	0.49	0.75	0.43	0.67	0.36	0.81	4.785
$d(A_{17},A^-)$	0.70	0.58	0.36	0.49	0.52	0.49	0.53	0.81	4.462

performance improvement" to "maintain relationship". For alternative A_9, in test 1, the categorization of this alternative in relation to the application case changed from "replace supplier" to "in need of cost reduction". Again, it happened because the weights of the criteria related to delivery performance were decreased in relation to the application case.

Regarding the effect of variation of ratings of the alternatives on the categorization results, several alternatives were categorized in the same group despite differences in the ratings. For instance, alternatives A_5 and A_{10} have different ratings in 9 of the criteria but were categorized in the same group. The same effect happens with alternatives A_1 and A_8. This can be explained by the compensation effect caused by the fuzzy TOPSIS technique. However, the compensation between the criteria is desired and purposefully embedded in the decision making process. On the other hand, alternatives A_6 and A_9, were categorized in different groups. However, in the dimension cost, the only rating difference was in the criterion C_1, which shows that a small variation in the rating can lead to a different categorization.

Finally, regarding the consistency of the results, alternatives A_{13} and A_{15} have got the same ratings in the criteria related to cost and therefore the same CCn_i values and categorization. It also happened to alternatives A_2 and A_{12}, which demonstrates that the method yields consistent outputs. Therefore, the sensitivity analysis shows that:

- Change in the weights of the criteria can cause a change in the categorization of the alternatives close to the border in the categorization grid;
- Alternatives with different ratings can be categorized in the same group because of the compensation effect of the fuzzy TOPSIS technique;
- Alternatives with similar ratings can be grouped in different categories due to the sensitivity of the method in relation to the input values;
- Alternatives with equal ratings will be categorized in the same groups.

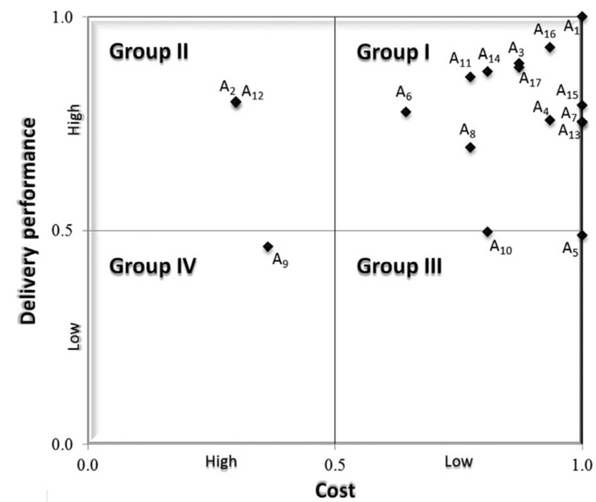

Fig. 5. Final classification of suppliers.

Table 16
Outranking of alternative suppliers according to the fuzzy TOPSIS model 2.

Suppliers	CC_i
A_1	0.614
A_2	0.491
A_3	0.547
A_4	0.466
A_5	0.300
A_6	0.477
A_7	0.463
A_8	0.426
A_9	0.284
A_{10}	0.305
A_{11}	0.527
A_{12}	0.491
A_{13}	0.463
A_{14}	0.535
A_{15}	0.487
A_{16}	0.570
A_{17}	0.541

Table 18
Weights of the criteria used in the sensitivity tests.

SCOR attribute	Criterion	Test 1	Test 2	Test 3	Test 4
Cost	C_1	AI	MI	MI	MI
	C_2	AI	MI	MI	MI
	C_3	AI	MI	MI	MI
Reliability	C_4	MI	AI	MI	MI
	C_5	MI	AI	MI	MI
	C_6	MI	AI	MI	MI
	C_7	MI	AI	MI	MI
Responsiveness	C_8	MI	MI	AI	MI
Agility	C_9	MI	MI	MI	AI
	C_{10}	MI	MI	MI	AI
	C_{11}	MI	MI	MI	AI

Table 17
Classification of suppliers and directives suggested.

	CCn_i (cost)	Classification	CCn_i (delivery performance)	Classification	Group	Directives for action plan
A_1	1.000	Low	1.000	High	Group I	Follow up to maintain relationship
A_2	0.300	High	0.800	High	Group II	In need of cost reduction
A_3	0.872	Low	0.892	High	Group I	Follow up to maintain relationship
A_4	0.935	Low	0.759	High	Group I	Follow up to maintain relationship
A_5	1.000	Low	0.488	Low	Group III	In need of delivery performance improvement
A_6	0.644	Low	0.777	High	Group I	Follow up to maintain relationship
A_7	1.000	Low	0.754	High	Group I	Follow up to maintain relationship
A_8	0.774	Low	0.694	High	Group I	Follow up to maintain relationship
A_9	0.364	High	0.462	Low	Group IV	Replace supplier
A_{10}	0.810	Low	0.497	Low	Group III	In need of delivery performance improvement
A_{11}	0.774	Low	0.859	High	Group I	Follow up to maintain relationship
A_{12}	0.300	High	0.801	High	Group II	In need of cost reduction
A_{13}	1.000	Low	0.755	High	Group I	Follow up to maintain relationship
A_{14}	0.810	Low	0.872	High	Group I	Follow up to maintain relationship
A_{15}	1.000	Low	0.793	High	Group I	Follow up to maintain relationship
A_{16}	0.935	Low	0.928	High	Group I	Follow up to maintain relationship
A_{17}	0.872	Low	0.882	High	Group I	Follow up to maintain relationship

Table 19
Normalized closeness coefficients (CCn_i) for the two fuzzy TOPSIS models for the four sensitivity tests.

	Application case		Test 1		Test 2		Test 3		Test 4	
	Model 1	Model 2	Model 1	Model 2	Model 1	Model 2	Model 1	Model 2	Model 1	Model 2
A_1	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
A_2	0.300	0.800	0.307	0.844	0.367	0.824	0.367	0.809	0.367	0.812
A_3	0.872	0.892	0.903	0.943	0.942	0.941	0.942	0.952	0.942	0.855
A_4	0.935	0.759	0.903	0.809	0.942	0.843	0.942	0.843	0.942	0.645
A_5	1.000	0.488	1.000	0.580	1.000	0.552	1.000	0.504	1.000	0.497
A_6	0.644	0.777	0.741	0.842	0.732	0.720	0.732	0.807	0.732	0.828
A_7	1.000	0.754	1.000	0.793	1.000	0.765	1.000	0.766	1.000	0.699
A_8	0.774	0.694	0.736	0.790	0.727	0.666	0.727	0.763	0.727	0.723
A_9	0.364	0.462	0.425	0.549	0.419	0.499	0.419	0.477	0.419	0.477
A_{10}	0.810	0.497	0.806	0.554	0.886	0.579	0.886	0.567	0.886	0.388
A_{11}	0.774	0.859	0.736	0.888	0.727	0.782	0.727	0.908	0.727	0.867
A_{12}	0.300	0.801	0.307	0.834	0.367	0.876	0.367	0.729	0.367	0.817
A_{13}	1.000	0.755	1.000	0.833	1.000	0.829	1.000	0.862	1.000	0.729
A_{14}	0.810	0.872	0.806	0.883	0.886	0.900	0.886	0.842	0.886	0.831
A_{15}	1.000	0.793	1.000	0.847	1.000	0.749	1.000	0.873	1.000	0.796
A_{16}	0.935	0.928	0.903	0.943	0.942	0.940	0.942	0.893	0.942	0.899
A_{17}	0.872	0.882	0.903	0.920	0.942	0.834	0.942	0.934	0.942	0.916

Table 20
Results of categorization of the alternatives in the sensitivity tests.

	Categorization				
	Application case	**Test 1**	**Test 2**	**Test 3**	**Test 4**
A_1	Group I	Group I	Group I	Group I	Group I
A_2	Group II	Group II	Group II	Group II	Group II
A_3	Group I	Group I	Group I	Group I	Group I
A_4	Group I	Group I	Group I	Group I	Group I
A_5	Group III	Group I	Group I	Group I	Group III
A_6	Group I	Group I	Group I	Group I	Group I
A_7	Group I	Group I	Group I	Group I	Group I
A_8	Group I	Group I	Group I	Group I	Group I
A_9	Group IV	Group II	Group IV	Group IV	Group IV
A_{10}	Group III	Group I	Group I	Group I	Group III
A_{11}	Group I	Group I	Group I	Group I	Group I
A_{12}	Group II	Group II	Group II	Group II	Group II
A_{13}	Group I	Group I	Group I	Group I	Group I
A_{14}	Group I	Group I	Group I	Group I	Group I
A_{15}	Group I	Group I	Group I	Group I	Group I
A_{16}	Group I	Group I	Group I	Group I	Group I
A_{17}	Group I	Group I	Group I	Group I	Group I

6. Conclusion

This paper presented a new approach to evaluate suppliers based on the performance metrics suggested by the SCOR® model. The proposed approach combines two fuzzy TOPSIS models for evaluating and categorizing the suppliers in the cost and delivery performance dimensions so as to indicate needs of improvements. It was applied in an illustrative case to evaluate the performance of 17 of its suppliers. In a final interview with the decision makers, the results of the application presented in Fig. 5 and Table 17 were shown to them. When asked about the adequacy of the categorization result, they both endorsed that the categorization of suppliers was generally in accordance with the linguistic ratings of the alternatives given by them (Table 6). This general impression was indeed confirmed by the results of the sensitivity analysis of the proposed method. The decision makers also confirmed the usefulness of grouping the suppliers in categories of performance so as to propose courses of actions to suppliers' development. However, they were not asked about the usability of the proposed approach since they didn´t use it. They just provided the judgments and afterwards analyzed the categorization results. Therefore, evaluation of the usability of the proposal in practice would depend on its implementation as an expert system, with graphical interface and other functionalities required by fuzzy set theory non-specialist users.

6.1. Benefits of the proposed approach

Differently from other approaches based on techniques such as AHP (Park et al., 2010), artificial neural networks (Aksoy and Öztürk, 2011), fuzzy inference (Osiro et al., 2014), ANP (Dou et al., 2014; Hsu et al., 2014; Liou et al., 2014) and DEMATEL (Ho et al., 2012), the fuzzy TOPSIS technique enables the use of linguistic terms to judge the importance of the criteria and the rates of the alternatives. The fuzzy TOPSIS technique does not require the parameterization of decision rules, as in fuzzy inference (Osiro et al., 2014) or data for training as in neural networks (Aksoy and Öztürk, 2011), which contributes to its simplicity and agility of implementation and reviewing of the decision process. Another benefit of using fuzzy TOPSIS is that the number of alternatives and criteria simultaneously evaluated is unlimited, unlike comparative approaches such as AHP (Park et al., 2010), ANP (Hsu et al., 2014) and fuzzy AHP (Rezaei and Ortt, 2013), in which the number of alternatives is limited by the human ability to simultaneous comparative judgment. In addition to that, in comparison with models based on AHP, ANP and fuzzy AHP, it does not cause the ranking reversal problem when a new supplier is included in the evaluation process.

Other benefits of the proposed method include:

- Directives for action plans according to the categorization of the supplier: differently from other studies found in the literature (Zeydan et al., 2011; Liou et al., 2014; Sahu et al., 2014), the proposed method suggest course of action according to the supplier performance categorization;
- Use of the performance metrics proposed by the SCOR® model for supplier evaluation: adoption of the standardized metrics defined by the SCC facilitates the communication and integration of the evaluation of the suppliers and the evaluation of the supply chain. It also enables the practice of global benchmarking against other supply chains (using the SCORmark) to set targets and push improvement efforts.

6.2. Drawbacks of the proposed approach

On the other hand, the drawbacks associated with the use of the fuzzy TOPSIS are:

- Greater computational complexity when compared to methods such as Fuzzy AHP, AHP and TOPSIS;
- When using cost criteria the normalization procedure (as in Eq. (8)) causes a low spread of the values of the closeness coefficient. For instance, for the Fuzzy TOPSIS model 1, although alternative A_1 performed very well in all the three cost criteria, the calculated closeness coefficient is of 0.558, not so close to the positive ideal solution. However, this problem of the Fuzzy TOPSIS technique is compensated by the normalization procedure (Eq. (17)) in step 3 of the proposed model.

Another limitation of the proposed approach relates to the number of groups resulting from the 2×2 categorization grid. However, the option for four groups followed other similar studies as presented in Section 2 (Olsen and Ellram, 1997; Aksoy and Öztürk, 2011; Rezaei and Ortt, 2013; Osiro et al., 2014). As a consequence, for development of action plans, the decision maker has to consider not only the group in which the supplier falls but also its position in each evaluated dimension based on the CCn_i values.

6.3. Suggestions for further research

Further studies can apply the proposed method for supplier evaluation and management in manufacturing companies for different supply chain competitive strategies, such as agile, lean and flexible supply chains. Moreover, the method can be used for evaluation of the third-party logistics providers (3PL). Further implementation of the proposed method can reconsider some choices made by the authors. First, a subset of the criteria used in this study, listed in Table 3, could be used, depending on the need of evaluation. The second point regards the transition point between the low and high categories. In this study, the center of the scale, 0.5, was adopted as the transition point. However, this choice is also dependent on the requirements of the buyer company.

Moreover, this proposed method can be incremented by increasing the number of categorization groups or by including another dimension for categorization of suppliers. For instance, another dimension could consider the type of supplier, according to the type of purchased item. For that purpose, the Kraljic classification model (Kraljic, 1983) could be the starting point.

Suggestions of further research can also include the development and application of a supply chain performance management system based on the SCOR® model that explicitly include in it the evaluation of suppliers and improvement programs. Following this approach, fuzzy TOPSIS could also be used to evaluate the effectiveness of such programs.

Finally, multiple case studies could be pursued in order to evaluate the acceptability and usability by practitioners of a tool such as this for supporting supplier evaluation and development management. However, to carry out this line of research, the proposed model should be implemented as an expert system.

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