The Application of a Decision-making Approach based on Fuzzy ANP and TOPSIS for Selecting a Strategic Supplier

Rajesri Govindaraju, Muhammad I. Akbar, Leksananto Gondodiwiryo & Tota Simatupang

Industrial Systems and Techno-economics Research Group
Industrial Technology Faculty
Institut Teknologi Bandung
Jalan Ganesha 10, Bandung 40132, Indonesia
Email: rajesri_g@ti.itb.ac.id

Abstract. Supplier selection becomes very important when used in the context of strategic partnerships because of the long-term orientation of the relationship. This paper describes the application of a decision-making approach for selecting a strategic partner (supplier). The approach starts with defining a set of criteria that fits the company's condition. In the next steps, a combination of fuzzy-ANP and TOPSIS methods is used to determine the weight for each criterion and rank all the alternatives. The application of the approach in an Indonesian manufacturing company showed that the three factors that got the highest weight were "geographical location", "current operating performance", and "reliability". Geographical location got the highest weight because it affects many other factors such as reaction to changes in demand, after-sales service, and delivery lead-time. Application of the approach helps decision-makers to gain effectiveness and efficiency in the decision-making process because it facilitates them to express their group's collective preferences while also providing opportunities for members to express their individual preferences. Future research can be directed at combining qualitative and quantitative criteria to develop the best criteria and methods for the selection of the best suppliers based on fuzzy ANP and TOPSIS.

Keywords: *strategic supplier selection; group decision-making (GDM); partner selection; multi-criteria decision-making (MCDM); fuzzy ANP; TOPSIS.*

1 Introduction

Supplier selection is an important issue in supply chain management [1]. Supplier selection heavily contributes to overall supply-chain performance [2]. On average, 70 to 80 percent of the value of a product is related to raw material purchasing costs and payments to service providers [3]. Therefore, selecting the right suppliers leads to significant savings, especially in companies spending the largest part of their sales income for purchasing raw materials [4]. Choosing the right supplier can reduce purchasing costs, which will in turn increase competitiveness in the market and increase satisfaction of the end customers [5].

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Recently, many companies have been making partnerships with suppliers a foundation of their supply strategies [6]. At an operational level, the main goals to be achieved are: reduced production lead-time, reduced cost and improved quality. At a strategic level, the benefits include sustainable improvements in product quality and innovation, enhanced competitiveness, and increased market share [7]. A strategic partnership between a company and its buyer or supplier involves a reciprocal commitment for an indefinite time horizon to achieve mutual benefits for both parties [8].

Construction of a proper partner selection method/approach is one of the most important issues before a partnership can be built. Reviewing previous research, various methods have been developed for supplier selection, including data envelopment analysis (DEA) [9], a heuristic method [10], analytic hierarchy process (AHP) [11], fuzzy AHP [12-14], fuzzy goal programming [15,16], analytic network processing (ANP) [17], fuzzy analytic network processing (fuzzy ANP) [18-20], integration of Taguchi loss function, AHP and multi-choice goal programming (MCGP) [21], integration of fuzzy AHP and fuzzy TOPSIS [22], integration of fuzzy AHP, fuzzy TOPSIS and DEA [23], integration of fuzzy ANP and fuzzy TOPSIS [5], and integration of fuzzy ANP and fuzzy TOPSIS with the use of fuzzy DEMATEL [24].

The results of the studies by Ho, *et al.* [25], Wu and Barnes [26], and Chai, *et al.* [27] show that AHP is the most popular approach in the supplier selection problem. AHP helps in decomposing a complex problem into a hierarchy, assessing the relative importance of decision criteria, comparing alternatives with respect to the decision for each criterion, and determining the overall priority for each decision alternative. The advantages of AHP over other multi-criteria methods, as often cited by its proponents, are its flexibility, intuitive appeal to the decision-makers (experts and stakeholders), and its ability to check the inconsistencies in judgments [28].

Though AHP is very often used in supplier selection, the assumption of criteria independence is a limitation of AHP. Most of the decision-making problems cannot be structured hierarchically because in many cases there are dependencies and interactions between higher-level and lower-level variables. If all criteria and alternatives are connected in a network system and there are dependencies among criteria, a more holistic approach such as analytic network processing (ANP) is needed [29]. ANP is a generalization of AHP, which structures the problem as a network in which the goal, criteria (and if applicable sub-criteria) and alternatives are nodes in the network. In this manner, ANP allows for feedback connections and loops within and between nodes to illustrate interdependence. ANP builds upon pairwise comparison of the AHP, in which criteria are pairwise compared with respect to each alternative and it also includes comparisons in which alternatives are compared with respect to each criterion. This additional set of comparisons allows the weight of the criteria to be influenced by the alternatives being considered. For example, in the context of supplier selection, if the following question is posed: “Which is the most prominent feature of Alternative 1, its cost or its cycle time?” If all the alternatives are equal in terms of cost, the importance of cost as a decision criterion would be reduced.

In a real supplier selection case, decision-makers do not have complete and exact information related to the decision criteria. Decision-making often contains ambiguity. Judgments are often subjective and imprecise. Fuzzy set theories can be used as a tool to handle uncertainty. The approach developed in this study incorporates fuzzy ANP to determine the weight for all criteria. To get a more simple and systematic process in ranking the alternatives, the TOPSIS method is used considering that TOPSIS has a simple computation process, a systematic procedure and a sound logic that represents the rationale of human choice. Using TOPSIS, pairwise comparisons required by methods such as AHP and ANP can be avoided.

2 Criteria for Strategic Supplier Selection

Garfamy [30] proposes five major factors to be considered in long-term supplier selection. These five factors are: quality, service, organization, relationship and cycle time. In Table 1, the results of our literature review on long-term supplier selection criteria combined with the results from Garfamy [30] are presented.

Quality. The quality factor describes the overall quality of the products or services offered by the candidate suppliers. The quality aspect is very important because the quality of components purchased from a supplier will have an impact on the quality of the product, delivery and cost on the customer side.

Service. The criteria underlying the service factor are: reaction to service demand, ability to modify products/services, technical support and after-sales service. In a long-term relationship it is possible that the buyer needs a change in a particular specification of products. Furthermore, with recent rapid technological advances, purchased materials have become more sophisticated. The supplier’s ability to provide the necessary technical assistance must be considered when selecting a strategic supplier.

Organization. The organization factor consists of quality performance, current technology, geographical location, production capacities and facilities, technological capability and innovativeness. This factor describes the quality of the candidate supplier’s organization. The criteria underlying this factor reflect the performance and capability of the supplier organization. Performance is defined as the demonstrated ability of a supplier to meet a purchaser's short-term requirements. Capability is defined as the supplier's potential that can be leveraged to the buyer's advantages in the long term [31]. Though the supplier's performance and capability are important in supplier selection, it is critical to emphasize their future potential if a long-term relationship is sought [8].

Relationship. The relationship factor describes the quality of the relationship between the company and the supplier. The criteria included for this factor are electronic data interchange capabilities, compatibility with levels and functions of the buyer firm, customer base, flexibility in payment, price reductions, order amount and frequency, the ability to identify the needs, the ability to maintain commercial relations and availability.

Cycle Time. Cycle time consists of delivery lead-time and development speed. Development speed describes the company's ability to move quickly so that new products and technologies can always be brought to market quickly [8].

Cost. Some earlier studies did not include price or cost as a selection criterion, for example [32,33]. In this study, the cost of having a relationship with a supplier is deemed noteworthy considering that the cost of co-operation will affect the cost of procuring components and this will have an impact on the company's ability to compete in the market. Analysis of the cost criterion is necessary to examine all potential costs that may be incurred due to the procurement process [34] and the relationship maintenance process in the partnership.

Table 1 Criteria for long-term supplier selection (adapted from Garfamy [30]).

Factor	Criteria	Authors
Quality	*Durability*	Larson [35], Tracey & Tan [36]; Dzever, *et al.* [37]
	Ergonomic quality	Dzever, *et al.* [37]
	Flexibility of operation	Dzever, *et al.* [37]
	Simplicity of operation	Dzever, *et al.* [37]
	Reliability	Larson [35], Tracey & Tan [36], Choi & Hartley [38], Kotabe & Murray [39], Shahadat [40], Rezaei & Ortt [41], Shen & Yu [32], Shahgholian, *et al.* [33]
Service	*Reaction to demand*	3s, *et al.* [42], Dzever *et al.* [37], Kannan & Tan [7], Vinodh, *et al.* [22], Chang, *et al.* [43], Shen& Yu [32], Shahgholian, *et al.* [33]
	Ability to modify product	Handfield [44], Kannan & Tan [7]

Factor	Criteria	Authors
	Technical Support	Handfield [44], Min [45], Dzever, *et al*. [37], Shen & Yu [32], Shahgholian, *et al.* [33]
	After Sales Service	Choi & Hartley [38], Dzever, *et al.* [37], Bevilacqua & Petroni [46], Bharadwaj [47], Rezaei & Ortt [41], Roshandel, *et al.* [48].
Organization	*Quality performance*	Goffin, *et al.* [49], Humphreys, *et al.* [42], Kannan & Tan [7], Shahgholian, *et al.* [33]
	Current technology	Handfield [44], Dzever, *et al.*[37], Pearson & Ellram [50], Kannan & Tan [7], Kannan, *et al*. [24]
	Geographic location	Dzever, *et al.* [37], Noordwier, et al. [51], Bhutta & Huq [52], Bevilacqua & Petroni [46], Kannan & Tan [7], Rezaei & Ortt [41], Roshandel, *et al.* [48], Shahgholian, *et al*. [33]
	Production facilities &capacities	Ellram [8], Rezaei & Ortt [41], Shyur &Shih [53], Shahgholian, *et al.* [33]
	Technological capability	Choi & Hartley [38], Dzever, *et al.* [37], Bevilacqua & Petroni [46], Shahadat [40], Kannan & Tan [7], Kannan, *et al.* [24], Rezaei & Ortt [41], Tam & Tummala [54], Shen & Yu [32], Shahgholian, *et al.* [33]
	Innovativeness	Goffin *et al*. [49], Dzever et al. [37], Rezaei & Ortt [41], Shen & Yu [32]
Relationship	*EDI capability*	Min [45], Humphreys, *et al.* [42], Kannan & Tan [7], Rezaei & Ortt [41]
	Compatibility of buyer firm	Ellram [8]
	Customer base	Ellram [8], Shen & Yu [32]
	Flexibility	Noordewier [51], Verma & Pullman [55], Dzever, *et al.* [37], Bevilacqua & Petroni [46], Kannan & Tan [7], Shahgholian, *et al.* [33]
	Ability to identify needs	Dzever, *et al.* [37], Shyur & Shih [53], Shen & Yu [32]
	Ability to maintain commercial relations	Dzever, *et al.* [37]
	Availability	Dzever, *et al.* [37], Dursun & Karsak [56], Onder & Dag [57]
Cycle Time	*Delivery lead-time*	Handfield [44], Choi & Hartley [38], Verma & Pullman [55], Bhawadwaj [58], Kannan *et al.* [24], Chu & Varma [59], Chang, *et al.* [43], Tam & Tummala [54], Shahgholian et al. [33]
	Development speed	Ellram [8], Shen & Yu [32]
Cost	-	Min [45], Shahadat [40], Chan *et al.* [34], Shyur & Shih [53]

3 Proposed Approach

Supplier selection is a decision or a set of decisions that requires intervention from several departments of the company [60]. It requires a group decision-making (GDM) approach. Group decision is understood as aggregating different individual preferences on a given set of alternatives to a single collective preference [61]. The approach developed in this study is presented in Figure 1.

In the developed approach, the group members' individual preferences and the group's collective preferences are both accommodated. In some steps, the individual decision-maker (stakeholder) expresses his individual preferences for further processing into collective preferences. In other steps, all the individual decision-makers together determine their collective preferences through a brainstorming process. A brainstorming method is used because of its effectiveness in providing a better shared understanding when used in a group decision-making process.

"G" in Figure 1 indicates a GDM process to determine a group's collective preferences through brainstorming and "I" indicates a GDM process in which each group member individually determines his/her preferences using questionnaires. The approach consists of six main steps, namely: 1) identifying the initial criteria, 2) forming the multi-stakeholder decision-making team, 3) determining the final selection criteria, 4) determining the interdependencies, 5) determining the criteria weight using fuzzy ANP, and 6) ranking the alternatives using TOPSIS. In the next part of this section each step will be elaborated.

3.1 Identifying the Initial Criteria Set

The initial criteria set were developed based on a literature study. Previous studies on long-term supplier relationships (supplier partnerships) and supplier selection were reviewed. Six factors are included in the initial criteria set, namely: quality, service, organization, relationship and cycle time, and cost. Further, a number of criteria are identified for each factor, except cost. A detailed description is presented in Section 2.

3.2 Forming the Multi-Stakeholder Decision-Making Team

A supplier selection problem requires the intervention of several departments of a company [60]. A decision-making team needs to be formed, comprising of decision-makers with area-related competence. General and specific competences need to be available in the team if the group process is to result in a good quality decision. Elanchezhian, *et al.* [62] propose a team that consists of the purchasing director, purchasing manager, quality manager, product manager, and production manager. Shahgholian, *et al.* [43] propose a team comprising of production manager, the design and engineering manager, the marketing manager, and the quality manager. Internal experts or external experts (consultants) who are competent in strategic (long-term) buyer and

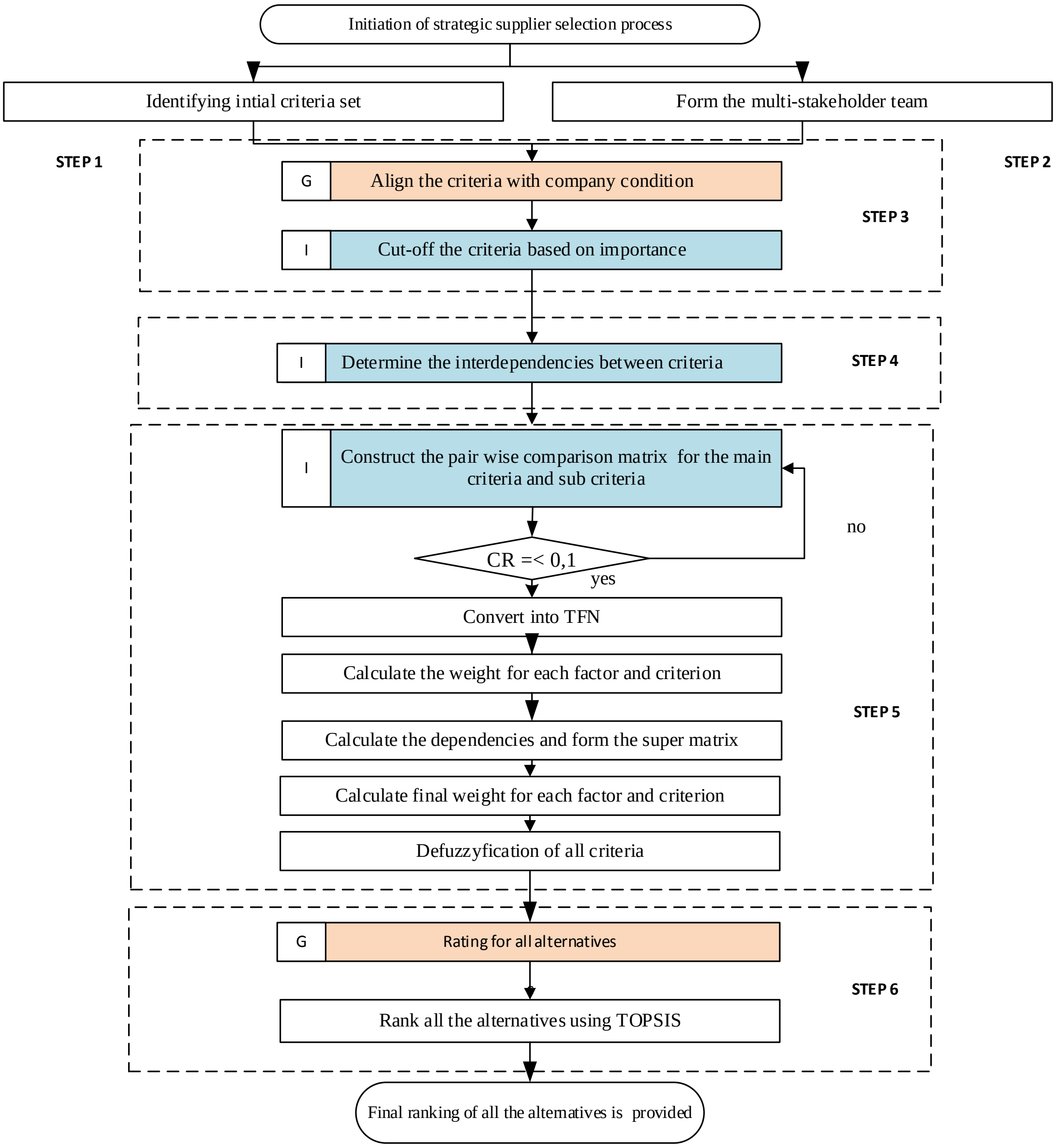

Figure 1 Proposed approach for selection of strategic supplier.

supplier relationships can be involved to provide a more holistic view in the selection process. Regarding the size of the team, Mitchel and Wasil [63] have observed that in applications, smaller groups are more efficient but larger groups are often required for effective decision-making so that all stakeholders are represented, the final decision is accepted and implementation is (better) facilitated. Though a larger group may lead to increased decision quality, the size of the group should not be too large since supporting a group decision-making process can be difficult due to the presence of multiple decision-makers, each with their own perceptions on the way the problem should be tackled and the decision should be made [64].

3.3 Determining the Final Criteria

Having an initial criteria set, two steps are proposed to determine the final criteria: alignment of the criteria to the organization's context through a brainstorming process and a cut-off of the criteria using the natural cut-off point method [64]. Alignment to the organizational context is needed in order to make sure that the criteria being used are in line with the company's policies and strategies for the products and also in line with the desired supporting roles of suppliers [42,43]. Apart from that, the company's external conditions, including government regulations, are also important considerations in the alignment process.

Brainstorming is used because of its simplicity and effectiveness. For the brainstorming process a meeting is necessary to consider effectiveness in the decision-making process. The result of this process is the criteria set that has been adjusted based on the organization's internal and external conditions. With too many criteria, supplier selection becomes difficult and time-consuming. It may also lead to evaluator's assessment bias [54]. In this study, criteria cut-off is processed based on the level of importance of each criterion using the natural cut-off point method [64]. The assessment is conducted by each individual decision-maker. To determine the most important criteria, respondents are given a questionnaire that aims to assess the level of importance using a 3-point scale, i.e.: not important, quite important, and very important. The next step is to find the total value for each criterion using the formula developed by Matsatsinis, *et al.* [64]. Then, the average score for each criterion is calculated using the following formula:

$$\boldsymbol{Average\ score = total\ score\ /number\ of\ respondents} \tag{1}$$

These criteria are further shorted from the largest average score to the smallest. From the average scores, the natural cut-off point is calculated using the following formula:

$$\textbf{Natural cut} - \textbf{off point} = (\textbf{minimum score} + \textbf{maximum score})/2 \qquad (2)$$

A criterion that will be used for the supplier selection process is a criterion that has an average score equal to or greater than the natural cut-off point. Using these steps, a recommendation for criteria elimination is provided. The recommendation is then evaluated by the decision team and if some criteria are still considered important, they are not eliminated.

3.4 Determining Dependence Among Criteria

The selection criteria do not need to be independent of each other. Instead, the criteria may influence each other [53]. Kasirian & Yusuf [65] have proposed a method to determine the dependency among criteria. This method is started by preparing a checklist that is meant to capture the existence of interdependencies among criteria. This checklist includes blocks that are marked only if any of the left column elements influences any of the top row elements. Furthermore, the questionnaires containing the checklist are distributed to the N members of the decision-makers team. After completion of the questionnaire, Eq. 3 is utilized to determine which blocks of the interdependency matrix m x m are qualified to represent interdependency [65]:

$$\boldsymbol{Q} = \frac{\boldsymbol{N}}{\boldsymbol{2}} \qquad (3)$$

If $V_{ij} \geq Q$, block is qualified
If $V_{ij} < Q$, block is disqualified

where N is the number of decision-makers, V_{ij} is the total number of votes assigned to the block corresponding to the i^{th} row and the j^{th} column of the interdependencies matrix, and i,j = 1,2,..., m. This means that blocks that were voted for by at least more than half of the decision-makers will be taken as interdependent blocks.

3.5 Determining the Weight of Criteria Using Fuzzy ANP

The ANP technique is used to address the relative importance of each criterion. The relative importance or strength of impacts on a given element is measured on a ratio scale, similar to AHP. ANP is able to handle interrelationships between the decision levels and attributes by obtaining composite weights through the development of a super matrix [28]. However, this method recognizes only crisp comparison ratios. In the real world, a lot of information may be marked by uncertainty that can be handled by a fuzzy-based approach. This study uses a combination of fuzzy theory with ANP as used in Onut *et al.* [5] to determine the weight of each criterion. Initially, the decision-makers use the AHP scale (1-9), but due to the fuzzy integration we have to convert the crisp AHP scale into TFN with equal meaning. The TFN method is illustrated in Zeydan, *et al.* [25]. After aggregating the pairwise comparisons, the next step is to determine the normalized matrix. We use the integration between the original normalization equation [66-68] with the division technique for TFN in Zeydan, *et al.* [23].

The weight without interdependencies is calculated using Eq. (4) (adapted from Zeydan, *et al.* [25]).

$$\boldsymbol{w_i} = \left(\sum_{j=1}^{n} \boldsymbol{l_{ij}}, \sum_{j=1}^{n} \boldsymbol{m_{ij}}, \sum_{j=1}^{n} \boldsymbol{u_{ij}}\right) \left(\frac{\boldsymbol{1}}{\sum_{i=1}^{m}(\sum_{j}^{n} \boldsymbol{u_{ij}})}, \frac{\boldsymbol{1}}{\sum_{i=1}^{m}(\sum_{j=1}^{n} \boldsymbol{u_{ij}})}, \frac{\boldsymbol{1}}{\sum_{i=1}^{m}(\sum_{j=1}^{n} \boldsymbol{u_{i,}}}\right. \tag{4}$$

$$weight\ without\ interdependencies = W = (w_{1,} w_2, w_3, \ldots\ w_p)$$

In order to reflect the interdependencies in a network, a set of pairwise comparison matrices is constructed for each criterion and their consistency ratios are calculated. For each criterion it is necessary to perform pairwise comparisons with all the influencing criteria. These matrices are used to identify the relative impacts of the relationships between interdependent criteria. These relative impacts are shown in a super matrix, S, in which zeroes are assigned in the matrix if there is no relationship between the related criteria [31]. Finally, the weights of the criteria are calculated based on Sarkar & Mohapatra [31]. To get the final weight, we defuzzify the TFN value using a method adapted from Shahgholian, *et al.* [43].

3.6 Ranking the Alternatives Using TOPSIS

TOPSIS [69] is based on the concept that the positive ideal alternative has the highest values for all attributes, whereas the negative ideal is the one with all the lowest attribute values. A positive ideal solution maximizes the benefit criteria or attributes and minimizes the cost criteria or attributes, whereas a negative ideal solution maximizes the cost criteria or attributes and minimizes the benefit criteria or attributes.

TOPSIS uses a simple computation process and systematic procedure, while including an unlimited range of criteria and performance attributes, and allows explicit trade-offs between attributes. Using TOPSIS for alternative ranking, pairwise comparisons can be reduced in the whole selection process. A more detailed description of TOPSIS can be found in Shih, *et al.* [70].

4 Methodology

The first step taken in this study was to develop an approach for selecting a strategic supplier based on a literature review. The developed approach is described in Section 3. Next, each step in the proposed approach was executed by conducting a case illustration in a manufacturing company. In accordance with the proposed approach, at the beginning of the selection process, an initial set of criteria needed to be determined. This initial set of criteria was determined by studying relevant literature. Then, the decision team members were selected based on the result of the literature study and discussion with the general manager of the Procurement Department. The next step was to determine the weights of the criteria and assessing all the alternatives based on the steps defined in the proposed approach.

5 Application of the Proposed Approach

The model was applied in a manufacturing company in Bandung producing generator components. Copper wire is the most important material required in its manufacturing process. Currently the company has not established a strategic partnership with any supplier for the procurement of copper wire. The company has a make-to-order production system, in which for each incoming production order, the procurement department orders the raw materials needed from suppliers. The ordering process takes approximately 2 weeks. The current procurement process is seen as less effective by the top management, especially in case of high fluctuations in market demand. Therefore, the company wants to establish long-term co-operations with major raw material suppliers. At the operational level, the main objectives to be achieved are shorter production lead-time, cost reduction and improved quality of raw materials. At the strategic level, benefits to be gained include continuous improvement in product quality, improved company's innovation process, and increased competitiveness. Currently, three suppliers are deemed competent to provide the copper components. Relationships with these suppliers are at the moment still transactional. Partnership is expected to contribute to reducing the risk and maximizing the total value from the company's purchasing.

A decision-makers team was formed to select one supplier from three qualified suppliers. The team consisted of five experts, including senior managers of procurement, production, quality, and business development, as well as one external consultant. The initial criteria set was prepared through a literature study. The criteria are presented in Table 1. To determine the final criteria set, first a brainstorming session was conducted to align the criteria to the organization's internal and external conditions. At this stage, the decision team members jointly agreed to dispose of three criteria, namely: ergonomic quality, development speed, and flexibility of operation. After the brainstorming session, for criteria cut-off firstly each decision-maker filled in a questionnaire to assess the level of importance of each criterion using a 3-point scale, i.e.: not important, quite important, and very important. Based on all the individual answers, a calculation was performed using Eq. (1) and Eq. (2) from Matsatsinis, *et al.* [64].

From the criteria cut-off process, a number of criteria, including “production facilities and capacities”, “innovativeness”, “EDI capability”, “ability to maintain commercial relationships”, “availability”, “ability to modify the product”, “compatibility of the buyer firm”, and “customer base”, were scored below the cut-off point. However, the team agreed that “production facilities and capacities” is necessary to be included in the selection criteria because for a long-term cooperation it is essential that the supplier should have facilities that support the company’s needs, both current and future. This criterion was then combined with the “current technology” criterion and both criteria together were called “current operating performance”. The use of the term “performance” instead of “capability” here was meant to highlight the current state and not a future condition. Sarkar & Mohaputra [37] state that a capability is a picture of the ability of a company in the future, whereas performance illustrates the ability of the company in the current situation. The future ability of the company in managing technology is already accommodated by technological capability.

		Reliability	*Durability*	Simplicity of operation	Geographical location	Quality performance	Current operating performance	Technological capability	Ability to identify needs	Flexilibility	Reaction to demand	After sales service	Technical support	Delivery Lead Time	Cost
Quality	Reliability		v	v		v									v
	Durability	v		v		v									v
	Simplicity of operation	v	v												v
Organization	Geographical location	v									v	v		v	v
	Quality performance						v								
	Current operating performan	v	v			v									v
	Technological capability														
Relationship	Ability to identify needs														
	Flexilibility										v				
Service	Reaction to demand									v		v	v		
	After sales service										v				
	Technical support										v				
Delivery Lead Time															v
Cost		v	v	v			v							v	

Figure 2 Interdependent relationships among criteria.

To determine the dependence among criteria each decision-maker filled in a questionnaire containing a checklist that captures the existence of interdependencies among criteria. The final criteria and the interdependence among criteria are presented in Figure 2. The next step was to determine the weight of each criterion using fuzzy ANP. First, five team members individually performed pairwise comparisons. Then consistency ratio calculations were executed. All pairwise comparisons were consistent because CR was less than 0.1.

The weight of the influence from all the influencing criteria was calculated for each criterion using the geometric mean method and then normalized based on Razmi *et al.* [69]. The weight was determined using Eq. 4. The weighted dependences of all criteria were presented in the form of super matrix S. Furthermore, to determine the final weights, the global weights (w) were multiplied with the super matrix (S). The results of the final weights were still fuzzy, so they had to go through a defuzzification process to produce crisp weights. Finally, the final normalized weight was calculated. The weights are shown in Table 2. As can be seen in Table 2, taking into account dependencies among criteria, the three factors that got the highest weight in this study were "the geographical location" (0,195), "current operating performance" (0,161), and "reliability" (0.132).

To rate the alternatives, a brainstorming session was arranged. Each alternative was rated using linguistic variables (very poor, poor, fair, good, very good). The analyst converted the linguistic variables into 5-point scale scores. From these ratings, the analyst constructed the decision matrices.

Table 2 Final weight.

Criteria	TFN			Defuzzification	Weight
Reliability	0,027	0,118	0,546	0,202	0,132
Durability	0,026	0,111	0,520	0,192	0,125
Simplicity of operation	0,007	0,030	0,140	0,052	0,034
Geographical location	0,072	0,217	0,685	0,298	0,195
Quality performance	0,003	0,020	0,127	0,043	0,028
Current operating performance	0,032	0,141	0,675	0,247	0,161
Technological capability	0,004	0,016	0,076	0,028	0,018
Ability to identify needs	0,025	0,060	0,150	0,074	0,048
Flexibility	0,006	0,018	0,056	0,025	0,016
Reaction to demand	0,040	0,107	0,290	0,136	0,089
After sales service	0,005	0,016	0,048	0,021	0,014
Technical support	0,005	0,016	0,048	0,021	0,014
Delivery lead time	0,007	0,021	0,059	0,027	0,018
Cost	0,034	0,110	0,409	0,166	0,108

The next step was to use the TOPSIS method as explained by Shih *et al.* [70] to rank the alternatives. With this method, firstly the positive ideal and negative ideal solutions were determined. Then, the separation measures of each alternative from the positive ideal solution (**Si*)** and the negative ideal solution (**Si**$^{-}$) were calculated. Finally, the relative closeness (**Ci***) of each alternative to the ideal solution was calculated. The result of the final calculation of the alternatives is presented in Table 3. The higher the closeness, the better the rank. Thus, supplier B was selected as this alternative was considered the best way to maximize the expected benefits from a strategic (long-term) supplier relationship.

Table 3 Separation measure from PIS and NIS.

	Si*	**Si**$^{-}$	**Ci***
Supplier A	0,001238	0,000584	0,320524
Supplier B	0,000534	0,001222	0,695964
Supplier C	0,000583	0,001131	0,559916

6 Conclusion, Contribution and Future Directions

This paper described the application of an approach for strategic supplier selection based on the fuzzy ANP and TOPSIS techniques. The use of TOPSIS with group collective judgment in alternatives assessment is effective and simple because the method avoids too many pairwise comparisons and facilitates decision-makers to make judgments based on a better shared understanding of the different aspects of supplier evaluation. The use of a combination of group collective judgment and individual judgment in different phases of the proposed approach has a positive impact on the overall decision-making process. The approach can be applied by companies from different industries to select their strategic partners.

A case illustration showed that using the group brainstorming session after the individual judgments had been made for determining the selection criteria, the team members together could get a final criteria set that was considered better than the original result of processing the individual judgments. In determining dependencies among criteria, individual judgment after the brainstorm session was an effective scenario since the session helped the members of the group enhance their mutual understanding of the strategic partnership context and various considerations that are important in selecting a strategic partner. Regarding the selection criteria, before incorporating dependencies among criteria, cost and delivery lead-time were the two criteria with the highest weight. Geographical location, current operating performance and reliability got the highest weight after taking into account dependencies among criteria, because geographic location affects many other factors, such as reaction to changes in demand, after-sales service, and delivery lead-time. Finally, the use of group collective judgment in the alternative assessment process allowed the assessment to be done comprehensively because the team had the opportunity to have an intensive discussion before jointly agreeing on an assessment score for every aspect of each alternative.

This study has provided an understanding regarding the way a group of decision-makers is formed and the way group members contribute to the decision process, considering the specific goal of the method, which is selecting a strategic partner or supplier. Apart from this, the study also presented the result of a literature review on criteria for selecting strategic partners. Future research can be directed at combining qualitative and quantitative criteria to develop the best criteria and methods for the selection of the best suppliers, based on fuzzy ANP and TOPSIS.

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