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Supplier selection by using a fuzzy approach in just-in-time: A case study

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Supplier selection has received extensive attention in the just-in-time approach. Supplier selection and evolution are decisions of strategic importance to companies. Thus, supplier performance evaluation is very important in choosing the right supplier for the right product. In this paper, a method for supplier selection using fuzzy logic was performed. Fuzzy logic enables us to emulate the human reasoning process and make decisions based on imprecise data. The method is based on calculating a fuzzy suitability index for the efficient vendor alternatives, and then ranking the fuzzy indices to select the best supplier alternatives.

Keywords: just-in-time; fuzzy sets; decision-making/process; supplier selection; fuzzy suitability index (FSI)

1. Introduction

In today’s highly competitive environment, an effective supplier selection process is very important to the success of any manufacturing organisation (Liv and Hai 2005). In this case, selection of the right supplier becomes more important. This is confirmed by many researchers (Bevilacqua and Petroni 2002, Kumar et al. 2004, Liv and Hai 2005, and Kumar et al. 2006). In designing a supply chain, a decision maker must consider the selection of the right supplier and their quota allocation (Kumar et al. 2004). As a result, increased concern for supplier selection has taken place, which is probably owing to the fact that supplier selection may be the single most important phase of the purchasing process (Pearson and Ellram 1995). Purchasing managers need periodically to evaluate supplier performance in order to retain those suppliers who meet their requirements in terms of several performance criteria (Bevilacqua and Petroni 2002).

In recent years, research into just-in-time (JIT) production from various viewpoints has been carried out all over the world (Takahashi et al. 2004) and the application of JIT concept to supply chain management has been attempted (Zimmer 2002, Kim and Ha 2003). In general, a supply chain is defined as follows (Mabert and Venkatamaman 1998):

‘A supply chain is network of facilities and activities that performs the functions of product development, procurement of material from vendor, the movement of materials between facilities, the manufacturing products, the distribution of finished goods to the customer, and after-market support for sustainment.’

One of the most important points of supply chain is the fact that each link must be very strong. The stronger the link in the chain, the easier and the better the process; and the strength of the link in the chain basically depends on the selection of the supplier. The material and equipment supplied from supplier play an important role in the management of a supply chain. Many issues in the supply chain are influenced by the proper selection of supplier (Kumar et al. 2006).

In the JIT approach, many manufacturers consider suppliers the first step of their process. Choosing the right supplier is important in order to verify the most important of JIT goals, including minimising the cost, minimising the rejection, and minimising delivery times. JIT depends very much on supplier loyalty (Stevenson 1990). This is the reason to choose the right and appropriate supplier.

Based on Mabert and Venkatamaman’s definition, this network contains a high degree of fuzziness and uncertainty. This is mainly due to its real-world character and its imprecise interfaces among the factors, where uncertainties in activities from raw material procurement to the end user make the supply chain imprecise (Zarandi et al. 2002). Fuzzy set theory provides a solution for the uncertainties of this type. Zadeh (1965) initiated fuzzy set theory and Bellman and Zadeh (1970) presented some applications of fuzzy theories to the various decision-making processes in a fuzzy environment. Fuzzy logic enables the decision-maker to emulate the human reasoning process and make decisions based on value or imprecise data (Bevilacqua and Petroni 2002). Our purpose is to reduce the uncertainties in supplier selection. The
optimal alternative is formed by the relative weight of each evaluation criterion’s elements combined over all the criterion membership functions. Much research and many applications such as those of Bevilacqua and Petroni (2002) have tested the effectiveness and applicability.

The rest of this paper is organised as follows. Section 2 presents a review of Just-in-time and the important points of supplier selection including relationship with JIT and supplier selection. Section 3 describes supplier selection criteria. In section 4, there is a case study. Finally, conclusions and suggestions are in section 5.

2. Just-in-time and supplier selection

JIT is defined by Wallace (1990) as ‘an approach to achieving excellence in a manufacturing company based on continuing elimination of waste and consistent improvement in productivity’. Zhu and Meredith (1995) state the key point in understanding JIT is that JIT is a continuously goal-oriented process to eliminate waste and improve productivity.

While the goal of JIT is ‘zero defects’ and ‘no waste’, it involves changes in several basic elements of an organization such as people, procedure and process. Dong et al. (2001) defined what the basic elements of a JIT purchasing strategy would include:

(a) reduction in order sizes;
(b) reduction in order lead time;
(c) quality control measures, including supplier quality certification, preventive maintenance programs, and receiving quality inspection;
(d) supplier selection and evaluation.

Traditionally, buyers regard price as a major factor to select vendors and tend to have multiple sourcing to avoid locking themselves into a single source (Zhu and Meredith 1995). Evans (1991) states that price and reliable delivery are the most important attributes. Stevenson (1990) states the downside of this strategy is that it is hard to maintain a long-term relationship when JIT relies very much on vendor loyalty. With single-sourcing, buyers intend to build trust with the supplier in delivering high-quality raw materials at the desired frequency. McIvor (2001) states that the reduced supplier base means that closer, longer-term relationships can be established with a few suppliers, significantly reducing costs and constantly improving quality.

The advantages of using a single-source supplier include:

(a) being able to focus on that one source;
(b) consolidating volume;
(c) consolidating by commodity;
(d) maintaining better control;
(e) monitoring of quality and supplier performance.

Also, a supplier getting the whole loaf instead of half or quarter or a slice is much more inclined to keep the buyer pleased. The buyer has more time to focus on a smaller number of suppliers and is better able to monitor performance and contract flexibility (Costanza 1990).

In the JIT approach, the price is one of the criteria in the supplier selection but not the most important one. Suppliers are chosen based on geographical location, product and delivery quality, etc. so that other JIT purchasing activities such as lead time reduction and quality control can be undertaken. Some researchers have emphasised the importance of a reduced supplier base as part of the JIT purchasing strategy and others have suggested single sourcing (Dong et al. 2001). There has been a shift in supplier selection criteria in which those based on price are being replaced with criteria based on quality, minimum net cost, flexibility, technological support etc.

Another progressive shift has been in buyer-seller relationships, in that the traditional adversary, short-term relationships are being replaced with longer term partnerships (Krause 1999). A JIT production requires high quality, small lot sizes and frequent delivery of raw materials. A good relationship with suppliers is crucial to achieve these requirements (Zhu and Meredith 1995).

Sako’s (1992) conclusion, among others, was that neither long term nor short term contractual relationships were clearly superior.

JIT, on the other hand, refers to those practices, most notably the frequent deliveries of small lot sizes that facilitate inventory reduction of raw materials (Dong et al. 2001). As defined in White et al. (1999), the objective of JIT purchasing is to improve quality, flexibility and levels of service from suppliers by developing a buyer-supplier long-term coordination based on mutual trust.

Another necessity in JIT is delivery. Nahmias (1997) states, ‘Deliveries must be on an as-needed basis only’, and even more, ‘production begins only when requested in pull systems’. Zhu and Meredith (1995) state that supplier lead time is a key factor when selecting a supplier to establish a long-term co-producer relationship. In the same paper, they indicate that buyers may even allow vendors to set up production lines in their own plants so that lead time for delivery can be shortened in some cases. In JIT, it can be just as bad to receive delivery early, which could be dangerous in an inventory system without a
storeroom, as it is to receive a delivery late (Costanza 1990).

For all these requirements and more, it is simple to perceive the importance of supplier selection. Hence, the choice of the right supplier is important to reduce the problems and increase the advantages. These results attempt to address the following question: What is the criterion in the supplier selection? Or which criterion is suitable for the selection of the right supplier?

3. Supplier selection criteria

The first step of supplier selection is to establish the criteria. Different companies have different specific requirements concerning vendor evaluation. For example, functions of logistic performance measurement include strategy formulation and clarification, management information, communication, motivation of supplier, coordination and alignment, decision making, priority, and learning in the automotive industry in Europe (Schmitz and Platts 2004).

Dickson (1966) published the most important work in this context in 1966. After that, many researchers used his criteria and ranking changes for a period of years. Weber et al. (1991, 1993) reviewed and classified various articles related to vendor selection and discussed the impact of the JIT manufacturing strategy on supplier selection. They used Dickson’s 23 criteria and indicated that net price, delivery and quality were discussed in 61 (82%), 44 (59%), and 40 (51%) of the 74 articles, respectively.

In addition, Swift (1995) showed that different criteria are more relevant for single sourcing relationships than for multiple sourcing relationships. She studied purchasing managers who work in different industrial areas (chemical, electronic and transportation equipment industries) about their purchasing strategies. She found out that managers who had a preference for single sourcing evaluated the following criteria as being more relevant than managers who preferred multiple sourcing: available technical support, reliability of product (or quality), and total product cost.

In addition to Dickson and other researcher’s criteria, other criteria can be found which leads to supplier selection. Although defining criteria to be used in every situation is very difficult, some conditions that are related to the JIT approach call for the definition of particular criteria.

We tried to find some criteria that have influence on supplier selection within the JIT approach. After a search of the literature, criteria were determined that impact JIT. These criteria and attributes relevant to supplier selection are described below.

3.1. Quality

One of the most important issues is quality-at-source (‘jidoka’) in the JIT approach. Accordingly, the buyer should investigate whether or not potential suppliers are certified for strict quality assurance and have a strong commitment to preventing quality failures (Hokey 1994). Suppliers must have the required quality certificate and consciousness for quality production. If it is necessary, the buyer can establish a team visit for an assessment of the supplier’s technical capability and quality commitment. Starting with qualified materials eliminates waste time (e.g. control time).

3.2. Technological capabilities

With the help of the technological advances, the quality of materials has become higher and the material production term has become shorter. Technological capabilities contribute to product development and improve supplier’s ability.

3.3. Total cost

The emphasis will shift away from the traditional, standard material cost of purchased materials towards the total cost of the part. Other costs, in addition to the standard material cost, must be considered. Ordering, transportation, packaging, carrying inventory costs and the potential for price reduction are other elements of total cost. It may be that the supplier with the lowest standard cost may not have the lowest total cost due to high rework, scrap or transportation cost.

3.4. Buyer–supplier partnerships

As mentioned before, a closer buyer-supplier partnership is important in JIT; therefore, a buyer-supplier partnership, which allows the buyers to spend less time order launching and expediting and more time on flexibility management, contract negotiation, packaging and transportation aspects of the procurement process all must be factored into the supplier selection decision.

3.5. Geographic location

Geographical position affects many elements of JIT, such as long-term contracts, total cost and on-time delivery. In choosing the most appropriate supplier, the buyer should assess the length of the supply chain as well as the strength of the supplier’s commitment for on-time delivery services, which includes follow up or expediting services (Hokey 1994).
3.6. **Flexibility**

Flexibility is another key factor in JIT. It can include payment, price reduction, order frequency amount and flexibility in response to the customer's requirements in terms of volume and product design. Suppliers must be able to adjust to buyer's requests.

3.7. **Production performance**

In this criterion, decision makers evaluate suppliers' performance, such as production ability and history, financial position, reputation and position in industry. Suppliers' past business practice must be considered by decision makers as a way of predicting how things may progress.

3.8. **JIT delivery**

Cycle times and JIT delivery capability, as opposed to traditionally considered speed of delivery, must be considered. In addition, recent surveys have discovered that a major obstacle to global sourcing is transport delays and the subsequent increase in lead times, which disrupt the successful implementation of JIT principles. In choosing the most appropriate supplier, the buyer should assess the length of the supply chain as well as the strength of the supplier's commitment for on-time delivery services, which include follow up or expediting services (Hokey 1994).

4. **Supplier selection methods**

According to Weber et al. (2000), supplier selection is difficult for three reasons: First of all, there are a very large number of potential suppliers to choose from. If you consider a combination of a distinct number of vendors combined with some personal preferences of the buyer, there are a lot of options to choose from. Second, there is usually no single best supplier that offers the best performance in all criteria. Therefore, the potential suppliers must be compared on various criteria. Additionally, suppliers might change their offers/performance on important selection criteria. If a supplier that was regarded as 'bad' lowers the price of the offered goods or service, he might at once become a 'good' supplier that is worthy to be considered.

If supplier selection is too difficult, how can we select the best supplier? Which approach is the best one for supplier selection?

In their classic 1991 update of Dickson's analysis of supplier selection decisions, Weber et al. (1991) reviewed the literature surrounding supplier selection criteria and identified several basic techniques or models that have appeared in studies over the previous 25 years (Bevilacqua and Petroni 2002). Since 1991, many techniques have been applied to the supplier selection problem, such as the analytic hierarchy process (AHP), multi-objective programming, interpretative structural modelling (ISM), and neural networks.

Each of these methods has its advantages and drawbacks.

Weber et al. (1991) classified the articles (among other criteria) on which methods were presented. It appeared that most articles used quantitative models to evaluate vendor performance.

These models were classified as follows:

(a) linear weighting models;
(b) mathematical programming models;
(c) statistical/probabilistic approaches;

In addition to that, de Boer et al. (2001) in a similar review found two more categories:

(a) total cost of ownership models (TCO);
(b) artificial intelligence (AI)-based models

4.1. **Linear weighting models**

Generally, in linear weighting models, a decision-maker assigns weights to the criteria he considers in his decision. The higher the number assigned to the weight, the higher its importance. In a second step, ratings on the criteria used are multiplied by their weights and summed so as to yield one single number per supplier. According to this number, potential suppliers can be ranked, and usually the supplier with the highest overall rating is selected. For example: benefit analysis, AHP.

4.2. **Statistical models**

Statistical models deal with stochastic uncertainty, in this special context with the uncertainty related to supplier selection. Although uncertainty is included in almost all types of purchasing decisions, only a few models have been presented. Existing models include a decision support system that considers order lead time as uncertain (Ronen and Trietsch 1988) or the use of cluster analysis for supplier evaluation.

4.3. **Mathematical programming methods**

Mathematical programming (MP) allows a decision maker to formulate a certain decision problem in terms of a mathematical objective function. By adjusting the
values of the variables in the function, the function is then (according to what the decision maker wants to achieve) maximised (e.g. profits) or minimised (e.g. ordering costs). Considering the need to explicitly formulate the objective function, it can be argued that MP is a very objective way of selecting one or more suppliers. On the other hand, a disadvantage of MP is that mathematical programming models are mostly only able to deal with quantitative data. (multi objective programming (MOP)).

Generally, MP models that have been suggested to be used for supplier selection problems can be classified in linear, non-linear and goal programming models. Weber and Ellram (1993) propose MOP to solve vendor selection problems in a JIT setting, operating in a computerised decision support system.

4.4. Total cost of ownership (TCO)

'Total cost of ownership (TCO) attempts to quantify all of the costs related to the purchase of a given quantity of products or services from a given supplier.' (Cavinato 1992). According to this approach, price is an important, but not the only factor influencing purchasing cost. In addition, cost factors like quality shortcomings, transportation cost, ordering costs, reception costs etc. need to be taken into account. Thus, the supplier offering the cheapest price need not necessarily be the cheapest supplier overall, if he shows poor performance in the other mentioned cost factors.

Degraeve and Roodhooft (1999) define three hierarchic levels that they used in this model: supplier level, ordering level, unit level. Degraeve and Roodhooft (1999) present a mathematical programming model that can be used for supplier selection purposes. Their objective is to 'select the ideal number of suppliers,' taking account of different products to be purchased from different suppliers at different times.

4.5. Artificial intelligence (AI)-based models

AI-models are based on computer-aided systems that can be ‘trained’ either by a purchasing expert or by historical data and examples (De Boer et al. 2001). These programs usually act very autonomously and provide the user, who does not have to be an expert anymore, with a ranking of the potential suppliers for a given sourcing problem. In this section, we want to take a closer look at two models: neural networks and intelligent software agents. There are two important models:

Albino and Garavelli (1998) suggest the use of neural networks for sourcing problems, especially in the very complex case of subcontracting in the construction industry. Neural networks are systems learning directly by example and therefore able to cope with decision models that are not very structured or affected by uncertainty and ambiguity.

Khoo et al. (1998) present intelligent software agents as a method of facilitating the procurement process. They define ISAs as ‘self-contained programs with decision making abilities which act in pursuit of one or more objectives on their perceptions of the environment’.

In the last decades, some main techniques have been applied to the supplier selection problem:

(a) AHP (Masella and Rangone 2001);
(b) expert systems (Vokurka et al. 1996);
(c) multi-objective programming (Weber & Ellram 1993);
(d) total cost of ownership (Ellram 1995);
(e) statistical analysis (Mummalaneni et al. 1996);
(f) interpretative structural modelling (ISM) (Mandal and Deshmukh 1994);
(g) data envelopment analysis (Liu et al. 2000);
(h) neural networks (Albino and Garavelli 1998).

Also, some researchers (Benyoucef et al. 2003) present different categorisations of vendor selection methods from the one presented in this paper. The advantages and disadvantages of each of the above methods are summarised in Table 1. Almost all of these methods tend to ignore the behaviours of people in organisational settings. Choosing a supplier in organisations has several phases, and many departments attend in these phases. It means that various opinions based on different cultures and experiences are considered in this decision term.

Emergent uncertainties in decision-making, also in term of human judgments, have serious impacts on the firm performance. Thus, these decisions are usually made on the basis of the opinions of experts. Even though these experts might use rigorous mathematical models in their decision-making processes, intuitive executive judgement is also used side by side (Bevilacqua and Petroni 2002).

Therefore, the fuzzy logic-based approach has more natural expressions for many human judgemental rules and statements than mathematical equations; a fuzzy logic-based approach is used in this paper.

In recent years, fuzzy logic-based approaches in the area of supplier selection have received considerable attention. Kumar et al. (2006) proposed a ‘fuzzy multi-objective integer programming vendor selection problem’ (f-MIP_VSP) that incorporates the goals of supplier selection problem as cost-minimisation, quality-maximisation and maximisation of on-time delivery with the buyers’ demand and suppliers’ capacity. For the first time in a fuzzy supplier selection problem, Amid et al. (2006) applied an asymmetric
fuzzy-decision making technique that enables the decision-makers to assign different weights to various criteria in the problem. In another article, Amid et al. (2007) developed a fuzzy weighted additive and mixed integer linear programming method to solve a supplier selection problem that includes three objective functions as minimising the net cost, minimising the net rejected items and minimising the net late deliveries while satisfying capacity and demand requirement constraints. Faez et al. (2007) applied a hybrid method that integrates case-based reasoning (CBR) and mathematical programming with fuzzy set theory (FST) approach to solve the problem. Chan and Kumar (2006) presented a hierarchical multiple criteria decision making (MCDM) model based on FST and technique for order preference by similarity to ideal solution (TOPSIS) to deal with the supplier selection problem in supply chain management. Lin and Chang (2008) proposed a model that applies triangular fuzzy numbers to evaluate buyers for both positive and negative selection criteria and integrates the concept of mixed integer programming (MIP) and TOPSIS for order selection and pricing of manufacturer with make-to-order basis when orders exceed production capacity. Chou and Chang (2008) presented a strategy-aligned fuzzy simple multi-attribute rating technique (SMART) approach for solving the supplier selection problem under a fuzzy group decision making environment from the perspective of strategic management of the supply chain.

As the articles stated above, fuzzy set theory is applied as an efficient tool to handle vagueness and uncertainty in practice. Within this common approach, in this article linguistic variables are used to assess the weights of each selection criterion.

## 5. The case study

### 5.1. Introduction of the method

The case study company is a medium-sized manufacturer of plaster and cement-based productions. The company has a turnover of $50 million and aims to enlarge its capacity.

After all conversation, eight suppliers are determined to be suitable out of more than 10 suppliers in the marketplace for this type of component. These determined suppliers include past suppliers, present suppliers and potential future suppliers.

The fuzzy-based ranking procedure consists of four sequential steps: Firstly, identification of the relevant evaluation criteria: a set of N decision makers define

<table>
<thead>
<tr>
<th>Method</th>
<th>Decision Objective</th>
<th>Advantage</th>
<th>Disadvantage</th>
</tr>
</thead>
<tbody>
<tr>
<td>ISM</td>
<td>Criteria formulation</td>
<td>Supports the distinction between sorting criteria and ranking criteria</td>
<td>Does not support the final choice phase</td>
</tr>
<tr>
<td>Expert Systems</td>
<td>Criteria formulation, pre-qualification and final choice of suppliers</td>
<td>Supports data warehousing for non-experts</td>
<td>Building the knowledge base and training the system are highly time and resource consuming</td>
</tr>
<tr>
<td>Data Envelopment</td>
<td>Pre-qualification of suitable suppliers</td>
<td>Does not require weighting of criteria and can be used as a tool for negotiating with inefficient suppliers</td>
<td>There should be a strict proportion between the number of criteria and the number of suppliers</td>
</tr>
<tr>
<td>Analysis</td>
<td></td>
<td></td>
<td>Rank reversal problem (ie. by adding a criterion the classification might modify)</td>
</tr>
<tr>
<td>AHP</td>
<td>Final choice of suppliers</td>
<td>Requires verbal and qualitative pairwise comparisons among criteria and alternatives</td>
<td>Only for single-deal cases and do not consider service and delivery performances</td>
</tr>
<tr>
<td>Total Cost of</td>
<td>Final choice of suppliers</td>
<td>Relatively simple to use</td>
<td>Limited to quantitative criteria; assume predefined levels of quality and service; need to combine with other methods</td>
</tr>
<tr>
<td>Ownership</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Multi-objective</td>
<td>Final choice of suppliers</td>
<td>By stating the objective function, these methods are more objective; consider multi-products cases</td>
<td></td>
</tr>
<tr>
<td>Mathematical</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Programming</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Neural Networks</td>
<td>Final choice of suppliers</td>
<td>Fitting high complexity and uncertainty</td>
<td>Not suitable for modified re-buy</td>
</tr>
</tbody>
</table>
the K criteria relevant to M supplier’s choice. After that, we determine the relative importance of each single attribute with respect to the overall objectives of the selection procedure. In the third step, we determine the impact of each alternative supplier on the attributes considered. And, in the final step, we build the final ranking based on the fuzzy suitability index (FSI).

5.2. Case study at firm

Every decision-maker states the weight of each criterion using a linguistic variable. In this study, five different levels are used. These are very low (VL), low (L), medium (M), high (H) and very high (VH). The importance level of criteria is given in Table 2.

The linguistic variables were translated into fuzzy numbers which are defined by Liang and Wang (1993). Considering this definition, each criterion weight is assigned as follows:

- VL (0; 0; 0.3)
- L (0; 0.3; 0.5)
- M (0.2; 0.5; 0.8)
- H (0.5; 0.7; 1)
- VH (0.7; 1; 1)

The triangular membership functions are illustrated in Figure 1.

### Table 2. The importance level of the criteria.

<table>
<thead>
<tr>
<th>Criteria</th>
<th>DM-1</th>
<th>DM-2</th>
<th>DM-3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quality</td>
<td>VH</td>
<td>H</td>
<td>VH</td>
</tr>
<tr>
<td>Technological Capabilities</td>
<td>M</td>
<td>L</td>
<td>H</td>
</tr>
<tr>
<td>Total Cost</td>
<td>H</td>
<td>H</td>
<td>VH</td>
</tr>
<tr>
<td>Buyer-Supplier Partnership</td>
<td>M</td>
<td>M</td>
<td>M</td>
</tr>
<tr>
<td>Geographic Location</td>
<td>VL</td>
<td>L</td>
<td>M</td>
</tr>
<tr>
<td>Flexibility</td>
<td>M</td>
<td>H</td>
<td>H</td>
</tr>
<tr>
<td>Production Performance</td>
<td>L</td>
<td>M</td>
<td>M</td>
</tr>
<tr>
<td>JIT Delivery</td>
<td>H</td>
<td>M</td>
<td>M</td>
</tr>
<tr>
<td>DM: Decision Maker</td>
<td></td>
<td></td>
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</tbody>
</table>

Decision-makers’ judgements for each supplier under the specified criteria are stated in this step. The decision-makers propose a rating described by a linguistic variable for each supplier. These linguistic variables are worst (W), poor (P), fair (F), good (G) and best (B). Nevertheless, the justification of the judgements was performed by using the same triangular fuzzy numbers used for the weights, where ‘very low’ corresponds to ‘worst’, ‘low’ to ‘poor’, ‘medium’ to ‘fair’, ‘high’ to ‘good’ and ‘very high’ to ‘best’. Table 3 shows the judgements expressed by the three decision makers in this regard.

Thus, the weighted average of each decision-maker’s opinion regarding each criterion’s importance is obtained by using a weight vector as given in Table 4. The weight vector is shown below:

\[
\text{Weight} = \{w_i|i = 1, 2 \ldots k\} \\
\quad w_i = (1/n) \cdot (w_{k1} w_{k2} \ldots w_{kn})
\]

(1)

In the next step, the scores obtained by each supplier under a specified criterion are weighted to specify the three decision-makers’ opinions. A rating matrix for supplier 1 is given in Table 5.

\[
\text{Rating} = \{r_{ij}|i = 1, 2, \ldots k; j = 1, 2, \ldots m\} \\
\quad r_{ijn} = (1/n) \cdot (r_{ij1} r_{ij2} \ldots r_{ijn})
\]

(2)

In the above, Weight is the vector of the weighted importance levels of the generic kth criterion and Rating is the matrix of the ratings of mth alternative under the kth criterion that results from the aggregation of the decision-maker’s opinion. It is worth noting that each element of the Weight vector and the Rating matrix is a triangular fuzzy number, which can be defined as \[w_k(w_{k1}; w_{k2}; w_{k3}), r_{mk}(r_{mk1}; r_{mk2}; r_{mk3}).\]

The next step of the procedure is the evolution of the fuzzy suitability index (FSI) (Moon and Kang 1999). FSI is a triangular fuzzy number that can be evaluated via the following expressions, applying the mean operator. The operation consists of averaging the aggregated rating previously obtained by multiplying them by the weight of each criterion.

\[
\text{FSI} = \{\text{FSI}_i|i = 1, 2, \ldots m\} \\
\quad = (1/k) \cdot [(r_{m1} \equiv w_{1}) (r_{m2} \equiv w_{2}) \ldots (r_{mkn} \equiv w_{k})]
\]

(3)

The fuzzy suitability index is defined by the values FSI \(\alpha, \beta, \gamma\) whose components \(\alpha, \beta, \gamma\) can be evaluated as:

\[
\begin{align*}
\alpha_i &= (1/k) \sum_{j}^k r_{ija} w_{ija} \\
\beta_i &= (1/k) \sum_{j}^k r_{ijb} w_{ijb} \\
\gamma_i &= (1/k) \sum_{j}^k r_{ijc} w_{ijc}
\end{align*}
\]

(4)
In this part of the paper, the method for determining the specific value of the fuzzy suitability index for supplier 1 was obtained. The weight matrix of criteria weight is given in Table 4.

The value of 0.63 is obtained for quality as the mean value of 0.7, 0.5 and 0.7, which are the first values of each triplet for VH, H, VH, which are the judgements of the three decision makers as shown in the first row of Table 2.

These fuzzy numbers are now multiplied by a vector for the fuzzy score of supplier 1 according to the different criteria in Table 5. (Shown as Rating matrix of supplier 1).

After these, each fuzzy suitability index \((\alpha, \beta, \gamma)\) is calculated as the matrix product of Rating matrix by the Weight matrix. In the chosen method, the final score \((FS)\) for each supplier is simply calculated using the following formula:

\[
FS = (\alpha + 2\beta + \gamma)/4
\]

And the final classification of suppliers is shown in Table 6.

### Table 3. Rating of suppliers.

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<th></th>
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<td>G</td>
<td>F</td>
<td>F</td>
<td>G</td>
<td>F</td>
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<td>P</td>
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<td>P</td>
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<td>F</td>
<td>G</td>
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<td>F</td>
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</tr>
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<td>P</td>
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<td>B</td>
<td>P</td>
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</tr>
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<td>W</td>
<td>F</td>
<td>P</td>
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</table>

### Table 4. Weight matrix for supplier 1.

<table>
<thead>
<tr>
<th>Quality</th>
<th>0.63</th>
<th>0.90</th>
<th>1.00</th>
</tr>
</thead>
<tbody>
<tr>
<td>Technological Capabilities</td>
<td>0.23</td>
<td>0.50</td>
<td>0.76</td>
</tr>
<tr>
<td>Total Cost</td>
<td>0.56</td>
<td>0.80</td>
<td>1.00</td>
</tr>
<tr>
<td>Buyer-Supplier Partnership</td>
<td>0.20</td>
<td>0.50</td>
<td>0.80</td>
</tr>
<tr>
<td>Geographic Location</td>
<td>0.06</td>
<td>0.26</td>
<td>0.53</td>
</tr>
<tr>
<td>Flexibity</td>
<td>0.40</td>
<td>0.63</td>
<td>0.93</td>
</tr>
<tr>
<td>Production Performance</td>
<td>0.13</td>
<td>0.46</td>
<td>0.70</td>
</tr>
<tr>
<td>JIT Delivery</td>
<td>0.30</td>
<td>0.56</td>
<td>0.86</td>
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</tbody>
</table>

### Table 5. Rating matrix for supplier 1.

<table>
<thead>
<tr>
<th>Quality</th>
<th>0.50</th>
<th>0.70</th>
<th>1.00</th>
</tr>
</thead>
<tbody>
<tr>
<td>Technological Capabilities</td>
<td>0.30</td>
<td>0.57</td>
<td>0.87</td>
</tr>
<tr>
<td>Total Cost</td>
<td>0.30</td>
<td>0.57</td>
<td>0.87</td>
</tr>
<tr>
<td>Buyer-Supplier Partnership</td>
<td>0.30</td>
<td>0.57</td>
<td>0.87</td>
</tr>
<tr>
<td>Geographic Location</td>
<td>0.13</td>
<td>0.43</td>
<td>0.70</td>
</tr>
<tr>
<td>Flexibity</td>
<td>0.30</td>
<td>0.57</td>
<td>0.87</td>
</tr>
<tr>
<td>Production Performance</td>
<td>0.23</td>
<td>0.50</td>
<td>0.77</td>
</tr>
<tr>
<td>JIT Delivery</td>
<td>0.07</td>
<td>0.43</td>
<td>0.70</td>
</tr>
</tbody>
</table>

Table 6. Final ranking of suppliers.

<table>
<thead>
<tr>
<th>Suppliers</th>
<th>Final Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Supplier 4</td>
<td>0.355</td>
</tr>
<tr>
<td>Supplier 1</td>
<td>0.352</td>
</tr>
<tr>
<td>Supplier 2</td>
<td>0.314</td>
</tr>
<tr>
<td>Supplier 3</td>
<td>0.303</td>
</tr>
<tr>
<td>Supplier 8</td>
<td>0.298</td>
</tr>
<tr>
<td>Supplier 6</td>
<td>0.296</td>
</tr>
<tr>
<td>Supplier 5</td>
<td>0.293</td>
</tr>
<tr>
<td>Supplier 7</td>
<td>0.262</td>
</tr>
</tbody>
</table>

In this part of the paper, the method for determining the specific value of the fuzzy suitability index for supplier 1 was obtained. The weight matrix of criteria weight is given in Table 4.

The value of 0.63 is obtained for quality as the mean value of 0.7, 0.5 and 0.7, which are the first values of each triplet for VH, H, VH, which are the
Optimal or ideal alternative suppliers are formed by the relative weight for each criterion’s elements. The best alternative was defined by a set of best rated attributes. Supplier 4 was chosen as the best alternative for this illustration.

6. Conclusion
In JIT production, the choice of supplier is one of the key factors and selection in this factor is important because it affects all levels of production. In the literature, there are a lot of methods about the best supplier selection. In this paper, one of the easy and practicable methods is used and the best criteria try to facilitate the selection of the right supplier.

Methodology based on fuzzy logic makes decisions based on the company strategy. After the illustration, the best supplier among the alternative suppliers was found using the defined criteria. The fuzzy logic contributed to the decision of the best supplier.

This methodology used in the selection of the supplier has an important role in the evolution of suppliers who have similar properties. Future study is needed to define the criteria in a more objective way and to perform sensitivity analysis for understanding their effects on the results. In addition, we want to enhance the proposed method so that it can be used in concurrent application where more designers are expected to be involved. Also, this method can be used to evaluate the existing suppliers.

As a result, this methodology, which includes qualities and subjective judgements by multiple persons, can be managed in the priority setting process in order to evaluate suppliers more realistically.

References


