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# A Fuzzy Based Decision Support Framework towards Benchmarking of Enterprise (Supply Chain) Agility: An Empirical Research

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**Abstract**

In current scenario, selection of agile enterprises is very crucial to the supply chain agility and competition. Due to the vague and ill-defined performance indicators which exist within agility assessment, most measures are described subjectively by linguistic terms which are characterized by ambiguity and multi-possibility. Therefore, this work presents a fuzzy-TOPSIS approach to handle with the alternative selection problem in agile supply chain systems. In this concept, a closeness coefficient is defined to determine the ranking order of all the alternatives by calculating the distances to the both fuzzy positive ideal solution and fuzzy negative ideal solution, simultaneously. Finally the effectiveness of the model is illustrated using a case empirical study.

## 1. Introduction and State of Art

Agile supply chain (ASC) is an advanced concept in global manufacturing and collective enterprise management. Agile Supply Chain Management (ASCM) is the combination of agile conception and SCM, which makes enterprises work together through collaborative manage and improves the agility enterprises, even whole supply chain management. The key of building double profit ASCM is select agile, strength and consistent suppliers [1-2]. It can also improve SCM efficiency. Traditional supply relationship can't adapt global competition and product requirement variety. As business environments have become more sensitive and dynamic, the response of many organizations has been to adopt the concept of the ASC [3-4]. Although the concept of agility begins from the manufacturing environment, it has been increasingly applied to the entire supply chain [5]. It is essential that the attributes are transformed into strategic competitive bases of speed, flexibility, pro-activity, innovation, cost, quality, profitability and robustness. More importantly; these attributes are of very little significance to practitioners unless there is a way of deploying them. Additionally, the changing nature of the market requirements suggests the need for a dynamic deployment tool for evaluating agility. A fuzzy analytic network process (ANP) has been proposed for agile concept selection in a single manufacturing organization [6].

## 2. General Concepts of Agility

Agile Manufacturing was first introduced with the publication of a report by Goldman [7] entitled, "21st Century Manufacturing Enterprise Strategy". Since then, the concept was used for agile manufacturing and agile corporations. The concept was extended to supply chains and business networks and to enterprise information systems [8]. According to Desouza [9] being agile is generally result in the ability to

(i) Sense signals in the environment
(ii) Process them adequately
(iii) Mobilize resources and processes to take advantage of future opportunities
(iv) Continuously learn and improve the operations of the enterprise.

Agile firm require a number of distinguishing capabilities or ''fitness'' to deal with the change, uncertainty and unpredictability within their business environment [10-11]. These capabilities consist of four principle elements:

(i) Responsiveness which is the ability to identify changes and respond quickly to them, reactively or proactively, and recover from them.
(ii) Competency which is the ability to efficiently and effectively reach enterprises' aims and goals.
(iii) Flexibility/adaptability which is the ability to process different processes and achieve different goals with the same facilities.
(iv) Quickness/ speed which is the ability to carry out activity in the shortest possible time

These must be taken into account if an organization is to carry out agile enterprise.

## 3. A fuzzy TOPSIS Approach

Fuzzy TOPSIS (Technique for Order Performance by similarity to Ideal solution) was first developed by Hwang and Yoon [12]. It is one of the most classical methods for solving MCDM problem. It is based on the assumption that the chosen alternative should have the longest distance from the negative ideal solution, so that the solution that maximizes the cost criteria and minimizes the benefits criteria and the shortest distance from the positive ideal solution, so that the solution that maximizes the benefit criteria and minimizes the cost criteria. In classical TOPSIS the weights and ratings of the criteria are known accurately. However, under many real situations crisp data are inadequate to model day-to-day situation since human judgments are vague and cannot be estimated with exact numeric values [12]. To resolve the vagueness frequently arising in information from human judgments fuzzy set theory has been incorporated in many MCDM methods including TOPSIS. Chen and Hwang [13] first applied fuzzy numbers to establish fuzzy TOPSIS. Triantaphyllou and Lin [14] developed a fuzzy TOPSIS method in which relative closeness for each alternative is evaluated based on fuzzy arithmetic operations. Liang [15] suggested Fuzzy MCDM based on ideal and anti-ideal concepts. Chen [11] considered triangular fuzzy numbers and defined crisp Euclidean distance between two fuzzy numbers for extend the TOPSIS method.

## 4. Empirical Research

In the context towards conducting a cross-sectional study, which has been aimed to exploring the selection of agile enterprises (corresponding supply chains); the proposed appraisement module has been studied through a case empirical research. After extensive literature review and periodic discussions with the industries top management, an integrated hierarchy model towards agility assessment has been constructed, in which a three-level criteria hierarchy has been designed as shown in Table 1. The model encompasses of various agile capabilities as well as agile attributes.

**Table 1**: Agility appraisement index: General hierarchy criteria.

| **Goal, C** | **1st level indices, $C_i$** | **2nd level indices, $C_{ij}$** | **3rd level indices, $C_{ijk}$** |
|---|---|---|---|
| Supply Chain Capabilities, C | Flexibility, $C_1$ | Sourcing Flexibility, $C_{11}$ | Numerous available suppliers, $C_{111}$ |
| | | | Flexibility in volume, $C_{112}$ |
| | | | Flexibility in variety, $C_{113}$ |
| | | Manufacturing Flexibility, $C_{12}$ | Flexibility manufacturing system, $C_{121}$ |
| | | | CAM based manufacturing, $C_{122}$ |
| | | | Varity and volume of production, $C_{123}$ |
| | | Delivery Flexibility, $C_{13}$ | Varity of supply schedules for meeting customers' needs, $C_{131}$ |
| | | | Flexibility in volume of product, $C_{132}$ |

| | | | |
|---|---|---|---|
| | Responsiveness, $C_2$ | Sourcing Responsiveness, $C_{21}$ | Adaptability of delivery time by suppliers, $C_{211}$ |
| | | | Suppliers delivery time, $C_{212}$ |
| | | | Supplier relation management, $C_{213}$ |
| | | Manufacturing Responsiveness, $C_{22}$ | Time of establishment and changing parts, $C_{221}$ |
| | | | Responsiveness level to the market changes, $C_{222}$ |
| | | Delivery Responsiveness, $C_{23}$ | Delivery Responsiveness, $C_{231}$ |
| | Competency, $C_3$ | Cooperation and interval-external balance, $C_{31}$ | Cooperation and interval-external balance, $C_{311}$ |
| | | Manufacturing Competency, $C_{32}$ | New product introduction, $C_{321}$ |
| | | | Quality of products or services, $C_{322}$ |
| | | | Integration, $C_{323}$ |
| | | | Time of new product development, $C_{324}$ |
| | | Capability of human resources, $C_{33}$ | Capability of human resources, $C_{331}$ |
| | Cost, $C_4$ | Sourcing Cost, $C_{41}$ | Sourcing Cost, $C_{411}$ |
| | | Manufacturing Cost, $C_{42}$ | Production cost, $C_{421}$ |
| | | | Establishment cost, $C_{421}$ |
| | | | Cost of changing parts, $C_{423}$ |
| | | Delivery Cost, $C_{43}$ | Delivery Cost, $C_{431}$ |

The assessment procedures for agile enterprise selection are as follows: initially an evaluation team consisting of five experts has been deployed to assign priority weights (importance extent) against different agile capabilities as well as agile attributes considered in the proposed appraisement model. In order to provide priority weight against various criteria; the decision-making group has been instructed to use the following five member linguistic terms: **Very Low (VL)**, **Low (L)**, **Medium (M)**, **High (H)**, and **Very High (VH)** at each level. Similarly, the following linguistic scale has been utilized to assign performance appropriateness rating against indices: **Very Poor (VP)**, **Poor (P)**, **Medium, (M)**, **Satisfactory (S)** and **Extremely Satisfactory (ES)** to express DMs subjective judgment against performance rating of each evaluation indices of alternatives. The five-member linguistic terms and their corresponding triangular fuzzy numbers are shown in Table 2. Then a questionnaire has been formed and circulated among the decision-makers (experts) to provide the required detail as priority weights at each level as shown in Table 3-5. Similarly the appropriateness rating of each alternative for 3$^{rd}$ level have been collected from the DMs.

Now using the concept of fuzzy set theory and fuzzy operation rules, we have aggregated the fuzzy weight as well as aggregated fuzzy rating (pulled opinion of the decision-makers) for each of the selection criterion. Then calculated 2nd level (rating of $j_{th}$ 2nd level index) appropriateness rating values using the following formula

$$U_{ij} = \frac{\sum U_{ijk} \otimes w_{ijk}}{\sum w_{ijk}} \quad (1)$$

**Table 2**: Five-member linguistic terms and their corresponding fuzzy numbers.

| Linguistic terms for weight assignment | Linguistic terms for ratings | Triangular fuzzy numbers |
|---|---|---|
| Very low, VL | Very poor, VP | (0.00, 0.00, 0.25) |
| Low, L | Poor, P | (0.00, 0.25, 0.50) |
| Medium, M | Medium, M | (0.25, 0.50, 0.75) |
| High, H | Satisfactory, S | (0.50, 0.75, 1.00) |
| Very High, VH | Extremely Satisfactory, ES | (0.75, 1.00, 1.00) |

**Table 3**: Priority weight (in linguistic scale) of 3nd level indices assigned by DMs.

| 3nd level metrics | Priority weights in linguistic term | | | | |
|---|---|---|---|---|---|
| | DM1 | DM2 | DM3 | DM4 | DM5 |
| $C_{111}$ | H | H | H | VH | H |
| $C_{112}$ | H | H | VH | H | VH |
| $C_{113}$ | H | VH | VH | H | H |
| $C_{121}$ | VH | H | H | H | H |
| $C_{122}$ | M | M | H | H | H |
| $C_{123}$ | M | H | H | M | M |
| $C_{131}$ | M | M | H | H | H |
| $C_{132}$ | M | H | H | H | VH |
| $C_{211}$ | M | M | H | H | H |
| $C_{212}$ | H | H | H | H | H |
| $C_{213}$ | H | H | M | M | M |
| $C_{221}$ | M | M | M | M | M |
| $C_{222}$ | H | H | H | M | M |
| $C_{231}$ | M | M | M | M | L |
| $C_{311}$ | M | M | L | L | M |
| $C_{321}$ | M | M | M | M | M |
| $C_{322}$ | H | H | H | H | M |
| $C_{323}$ | M | M | L | L | M |

| | | | | | |
|---|---|---|---|---|---|
| $C_{324}$ | L | M | M | M | M |
| $C_{331}$ | L | L | M | M | M |
| $C_{411}$ | H | H | H | VH | VH |
| $C_{421}$ | VH | VH | VH | H | H |
| $C_{421}$ | H | VH | VH | VH | H |
| $C_{423}$ | L | L | M | M | M |
| $C_{431}$ | M | M | M | M | M |

**Table 4**: Priority weight (in linguistic scale) of 2nd level indices assigned by DMs.

| **2nd level metrics** | **Priority weights in linguistic term** | | | | |
|---|---|---|---|---|---|
| | **DM1** | **DM2** | **DM3** | **DM4** | **DM5** |
| $C_{11}$ | H | H | H | VH | VH |
| $C_{12}$ | H | VH | H | H | H |
| $C_{13}$ | H | H | H | H | H |
| $C_{21}$ | VH | H | H | H | VH |
| $C_{22}$ | VH | H | H | VH | VH |
| $C_{23}$ | H | H | H | H | VH |
| $C_{31}$ | H | H | H | H | M |
| $C_{32}$ | M | H | M | H | H |
| $C_{33}$ | M | M | M | H | H |
| $C_{41}$ | H | H | VH | VH | VH |
| $C_{42}$ | H | VH | VH | VH | VH |
| $C_{43}$ | H | H | H | VH | VH |

**Table 5**: Priority weight (in linguistic scale) of 1st level indices assigned by DMs.

| **1st level metrics** | **Priority weights in linguistic term** | | | | |
|---|---|---|---|---|---|
| | **DM1** | **DM2** | **DM3** | **DM4** | **DM5** |
| $C_1$ | VH | VH | VH | H | H |
| $C_2$ | H | H | H | VH | VH |
| $C_3$ | H | H | H | M | M |
| $C_4$ | H | H | H | H | VH |

Here $U_{ijk}$ represents aggregated performance measure (rating); $w_{ijk}$ represents aggregated fuzzy weight corresponding to criterion $C_{ijk}$ at 3rd level. Also, $U_{ij}$ represents the computed performance measure (rating) corresponding to attribute $C_{ij}$ at 2nd level.

Again we evaluated the appropriateness rating for each of the 1st level capability $U_i$ (rating of $i_{th}$ 1st level index) by the following formula:

$$U_i = \frac{\sum U_{ij} \otimes w_{ij}}{\sum w_{ij}} \tag{2}$$

Here $U_{ij}$ represents computed performance measure (rating) and $w_{ij}$ represent aggregated fuzzy weight corresponding to attributes $C_{ij}$ at 2nd level. Also, $U_i$ represents the computed performance measure (rating) corresponding to the index $C_i$ at 1st level. After estimated aggregated fuzzy priority weight and Computed fuzzy rating of indices, then we proceed to construct a fuzzy multi-criteria group decision making (FMCGDM) matrix. Then we normalized the fuzzy multi-criteria group decision making (FMCGDM) matrix and the normalized decision matrix represented in Table 6.Then we have calculated the fuzzy positive ideal solution (FPIS) and the fuzzy negative ideal solution (FNIS) as shown in Table 7. After that the Euclidean distance of each alternative from FPIS and FNIS has been calculated which presented in Table 8. Finally, a closeness coefficient of each alternative is calculated by using (Eq. 3) to determine the ranking order of all alternatives

$$C^*(x_j) = \frac{D^{*-}(x_j)}{D^{*+}(x_j) + D^{*-}(x_j)} \tag{3}$$

**Table 6**: A fuzzy multi-criteria group decision making (FMCGDM) matrix and Normalized decision matrix.

| **Alternatives** | **FMCGDM matrix** | | | | **Normalized decision matrix** | | | |
|---|---|---|---|---|---|---|---|---|
| | **Criteria** | | | | **Criteria** | | | |
| | **C1** | **C2** | **C3** | **C4** | **C1** | **C2** | **C3** | **C4** |
| A1 | 0.344 | 0.283 | 0.255 | 0.244 | 0.539 | 0.553 | 0.505 | 0.477 |
| A2 | 0.396 | 0.332 | 0.377 | 0.342 | 0.621 | 0.648 | 0.747 | 0.668 |
| A3 | 0.363 | 0.268 | 0.219 | 0.293 | 0.569 | 0.523 | 0.434 | 0.572 |

**Table 7**: Positive and Negative Ideal Solution.

| **Ideal solution** | **Criteria** | | | |
|---|---|---|---|---|
| | **C1** | **C2** | **C3** | **C4** |
| V1*+ | 0.214 | 0.211 | 0.189 | 0.147 |
| V2*- | 0.185 | 0.171 | 0.11 | 0.206 |

**Table 8**: The Distance of alternative to FPIS/FNIS, the related closeness coefficient and ranking.

| Alternatives | Distance D*+ | Distance D*- | Closeness coefficients(C*) | Ranking order |
|---|---|---|---|---|
| A1 | 0.072 | 0.062 | 0.464 | 2 |
| A2 | 0.059 | 0.093 | 0.610 | 1 |
| A3 | 0.093 | 0.031 | 0.250 | 3 |

The calculated closeness coefficients for alternative are (**0.464, 0.610,** and **0.250**). The higher value of closeness coefficient indicates that an alternative is closer to FPIS and farther from FNIS simultaneously. Finally, the agile supply chains (enterprises) are ranked on the basis of value of closeness coefficient based on their agile performance the ranking of each alternative are shown in Table 8. According to the closeness coefficient, the ranking order of three alternatives is $\mathbf{A_2} > \mathbf{A1} > \mathbf{A3}$. So, enterprise '$\mathbf{A_2}$' can be chosen for best agile supply chain.

## 5. Conclusion

In the foregoing research, a fuzzy-TOPSIS approach is used to select the best agile supply chain (corresponding enterprise) amongst a group of possible alternative enterprises. The main criteria and sub-criteria are decided considering the current business scenario and experience of the experts in the respective area.

The main contributions of this work have been summarized as follows:

(i) Improvement as well as case implementation of an efficient decision making tool has to support performance evaluation and selection of agile enterprises/ supply chain.

(ii) The proposed model make simpler to the agile enterprise selection process, and also enables decision makers to deal with inconsistent judgments systematically.

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