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Benchmarking agility assessment approaches: a case study

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# Benchmarking agility assessment approaches: a case study

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## Abstract

**Purpose** – The purpose of this paper is to benchmark the assessment approaches of agility in a manufacturing organization.

**Design/methodology/approach** – The criteria for agility assessment were identified comprehensively based on literature review. The agility assessment was done using Multi Grade Fuzzy and Fuzzy logic approaches, and the results were benchmarked.

**Findings** – Based on Multi Grade Fuzzy approach, the agility index was found to be 6.6; Fuzzy logic approach reveals the agility index as (5.37, 6.91, 8.45) which indicated the case organization is agile. The gaps were identified from both the approaches and the results were corroborated.

**Research limitations/implications** – In the present study, Multi Grade Fuzzy and Fuzzy logic approaches were only benchmarked. Also, the benchmarking exercise was done only in one manufacturing organization.

**Practical implications** – The benchmarking study was conducted in a manufacturing organization. The practitioners' views were gathered and they were involved in the study to substantiate the practical validity.

**Originality/value** – The benchmarking study between two approaches for agility assessment was found to be original and adds value to the agility assessment field.

**Keywords** Performance measurement, Benchmarking, Agility, Agile production

**Paper type** Case study

## 1. Introduction

Due to increasing customer needs, manufacturing firms face uncertainty in their production processes (Gunasekaran, 1999; Hormozi, 2001; Gunasekaran *et al.*, 2008). This is due to rapid market change because of high competitiveness (Alexopoulos *et al.*, 2007; Jagadeesh, 1999). Uncertain and unexpected market conditions can be handled by adopting Agile Manufacturing (AM) principles (Brown and Bessant, 2003). The researchers proposed ideas and principles related to AM, which are further widely developed and also implemented successfully in many manufacturing organizations (Vinodh *et al.*, 2008). In this context, the assessment of agility gains importance. Few researchers have performed studies on agility assessment. The research hypotheses based on the literature gap deployed in the study are: how to evaluate the agility of a firm comprehensively? How to validate the agility assessment results? How to benchmark agility assessment approaches? This research study reports on agility assessment using two different approaches, namely multi-grade fuzzy and fuzzy logic (Gao *et al.*, 2009; Rao and Peng, 2009). The agility gaps have been identified and proposals have been derived. The uniqueness/novelty of the study is that it comprehensively uses various agility criteria, and addresses all aspects of agility, as well as benchmarking

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agility assessment results coupled with practical feasibility. The paper is exemplified with a case study conducted in an Indian pump manufacturing organization. The results derived from both approaches were benchmarked.

## 2. Literature review

The literature review was conducted on various agility assessment approaches.

Kumar and Motwani (1995) took a vital first step towards the development of a reliable, accurate measure of a firm's time-based competitiveness. They developed a strategic framework to systematically evaluate an organization's effectiveness within the dimensions of agility. The authors tested and validated the work in realistic settings, and developed a comprehensive list of agility determinants and metrics.

Cho *et al.* (1996) introduced a new thought to manufacturing firms, namely agility, as it focuses on the vibrant changes in markets and the manufacturing firm in question's rapid response. The authors stressed the necessity of flexibility in the chain to improve the firm's agility. Agile practice has been implemented in various firms such as semi-conductor, textile, service and maintenance.

Gunasekaran (1998) instigated AM and various criteria which influenced the need for AM in the manufacturing arena. The need for AM over and above existing manufacturing practice is reviewed and justified in this work. The authors developed a new agile model with virtual enterprise, rapid prototyping, E-commerce, concurrent engineering, rapid partnership and physically distributed teams for assessing a manufacturing organization.

Feng and Zhang (1998) presented their work on reconfiguring market changes with the help of computer aided process planning and by providing appropriate software support. The limitation in the older version is that it does not extend support to new updates, and due to this, complex problems occur. The new software has better connectivity as well as ease in updating to the newer techniques, which improves the system agility.

Sharifi and Zhang (1999) presented a scoring model for determining the agility need level. This model also enabled the identification of strengths and weaknesses of agile dimensions practiced by the organization. The drawback in this work is that there is a need for improvement of the agility model's comprehensiveness.

Zhang and Sharifi (2000) introduced their first tool to determine whether a company needs to implement AM programme or not, and the second tool assesses the agility level. Following this, they proposed the neural network to determine the required agile capabilities and the providers. This work has prepared for the model to deal with vague and complex situations.

Gunasekaran *et al.* (2002) deployed their AM work in the context of an aerospace manufacturing firm. The firm's prime manufacturing units are pumping, actuator and pneumatic systems related to aerospace. This study assessed the firm's agility by conducting a technical survey with the help of a suitable questionnaire.

Yang and Li (2002) proposed a procedure to assess agility using a multi-grade fuzzy approach. They identified the ranges in a scale of 2 to 10 to indicate the company's agility. This approach is better than a conventional scoring approach even though there exists minimal vagueness. To resolve this issue, there exists a need to deploy fuzzy methods for assessment.

Tsourveloudis and Valavanis (2002) performed an agility assessment by focusing on the agility perspectives, namely direct, knowledge-based and holistic. The authors used a new approach for assessing agility, Fuzzy If-Then approach. The agility focuses on all the levels of the firm as well as the various driving factors of agility, such as infrastructure, production, market, people and information.

Ebrahimpur and Jacob (2001) did their work in an automotive firm by modifying the workflow and improving the flexibility in order to develop the organization's agility. This case study was done in a Volvo car technical service centre. The customer's requirements were increased flexibility and serviceability which can be developed with the help of AM.

Arteta and Giachetti (2004) proposed a different and novel approach to use complexity as a surrogate measure for agility. This is a newer approach for assessing complexity. The major drawback in this method is that the methodology fails to identify the specific changes that the company should effect for achieving agility.

Vinodh *et al.* (2008) designed a tool for quantifying agility in organizations. The authors used a scoring approach for measuring agility. The authors developed a 20 criteria-based agility model for evaluating the firm, the model comprising criteria related to the entire manufacturing firm. The drawback of this work is that subjectivity exists with assessment.

Vinodh *et al.* (2010) did their agility assessment using combined scoring and multi-grade fuzzy approaches for the agility assessment. The agility index of the organization is found out by using two approaches, but the drawback is that the approaches cannot deal with vague situations.

Based on the literature review, it was found that no case study was reported in the context of benchmarking the agility assessment approaches. In this context, this study was conducted.

## 3. Research methodology

Figure 1 show the research methodology followed in this study. The literature review on agility assessment methods was conducted and the research gap identified. A suitable agility assessment model was identified and the assessment was carried out. In the study, multi-grade fuzzy and fuzzy logic approaches were used to find the agility index, and further, the gaps prevailing across the organization were identified and proposals were derived for agility improvement.

## 4. Case study

The case study was conducted in an Indian pump manufacturing organization. The organization has adopted world class manufacturing strategies to improve their productivity as well as to cope with customers' varying needs across the world. Providing a suitable benchmark in terms of agility helps the manufacturing firm to improve their current level. The criteria used in the agility assessment were adopted from a previous research study (Vinodh and Aravindraj, 2012).

Table I shows an excerpt of 40 criteria model pertaining to "Manufacturing Strategy" enabler.

The agility assessment model consists of five major enablers, namely management responsibility agility, manufacturing management agility, workforce agility, technology agility and manufacturing strategy agility. Management responsibility consists of organizational structure, devolution of authority and nature of management. Manufacturing management consists of certain criteria, namely customer response adoption, change in business and technical process, outsourcing, resource optimization, agile customization, flexible business practices, knowledge management, business

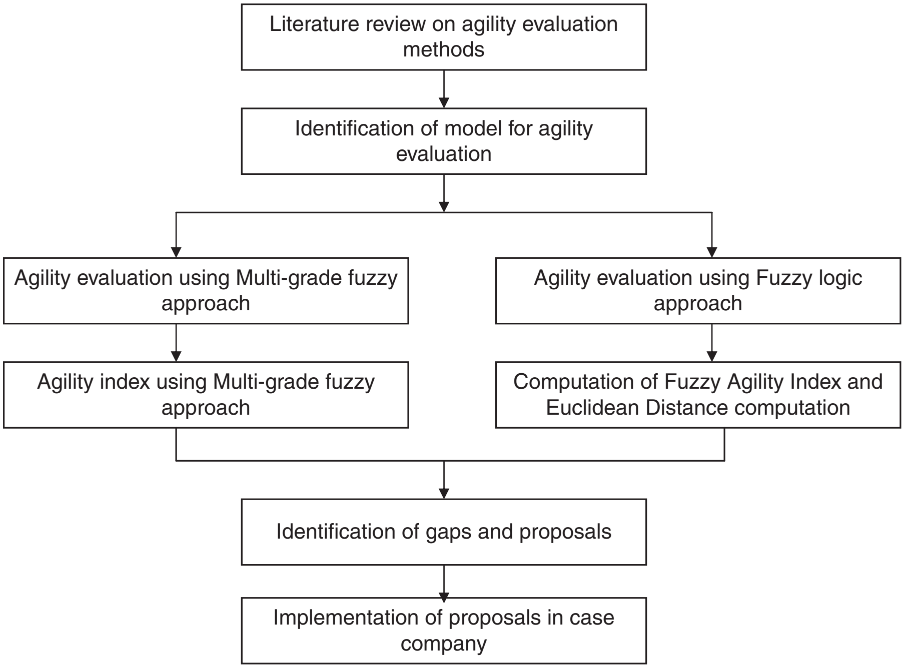



**Figure 1.** Research methodology

support system, product variety, rapid manufacturing system and inter organizational system. Workforce consists of the following criteria: employee status, employee involvement, team working, creativity, fast production and delivery. Technology agility consists of criteria such as manufacturing setups, product lifecycle, product service, design improvement, production methodology, manufacturing planning, automation type, IT integration, advances in design, concurrent engineering, new product development, data management and virtual enterprise. Manufacturing strategy consists of various criteria, namely status of quality, status of productivity, cost management, time management, collaboration and networking, flexible volume production, seasonality, flexible delivery time and locations.

### *4.1 Agility assessment using multi-grade fuzzy method*

The multi-grade fuzzy method consists of grades of individual criteria. The agility index of the firm is represented by $\bar{I}$. The assessment grade is divided into five levels $X=\{a1, a2, a3, a4, a5\}$ from a1 to a5 the grade keeps decreasing. The levels include extremely agile (8-10), agile (6-8), generally agile (4-6), not agile (2-4), extremely unagile ($<2$). Five experts who possess rich experience of the organization's working culture have provided ratings and weights for attributes, criteria and enablers (Vinodh *et al.*, 2010). The experts head various departments, namely design, production, customer service, quality and product development. The experts decided the ratings and weights during exclusive sessions conducted for data collection in consultation with the customers and suppliers.

As a sample, Table II shows the ratings and weights pertaining to "Manufacturing Strategy" enabler.

| Serial number | Agile enabler (Level 1 index) | Agile criteria (Level 2 index) | Agile attributes (Level 3 index) |
|---|---|---|---|
| 1 | Manufacturing strategy agility ($AC_5$) | Status of quality ($AC_{51}$) | Products exceeding the customers' expectations ($AC_{511}$) |
| | | | Incorporation of new ideas into products ($AC_{512}$) |
| | | | Conduct of survey/studies to ensure quality status ($AC_{513}$) |
| | | | Usage of TQM tools ($AC_{514}$) |
| | | | Inculcation of innovation into product design ($AC_{515}$) |
| | | Status of productivity ($AC_{52}$) | Productivity improvement in all functions ($AC_{521}$) |
| | | | Productivity linked to the personnel prosperity ($AC_{522}$) |
| | | | Reduction of non value-adding costs ($AC_{523}$) |
| | | | Quality is not infused at the cost of productivity ($AC_{524}$) |
| | | | Application of totality concepts in achieving productivity ($AC_{525}$) |
| | | Cost management ($AC_{53}$) | Activity based method of product pricing ($AC_{531}$) |
| | | | Costing system focusing on the identification of value adding and Non-value adding activities ($AC_{532}$) |
| | | | Costing system enabling the evaluation of future resource consumption ($AC_{533}$) |
| | | | Product cost fixed based on customer's pricing ($AC_{534}$) |
| | | Time management ($AC_{54}$) | Scheduled activities ($AC_{541}$) |
| | | | IT based communication system ($AC_{542}$) |
| | | | Training programme on time management concepts ($AC_{543}$) |
| | | | Adoption of time compression technologies ($AC_{544}$) |
| | | Collaboration and networking ($AC_{55}$) | Networking ($AC_{141}$) |
| | | | Customer relationship management ($AC_{142}$) |
| | | | Competitor relationship ($AC_{144}$) |
| | | | Mutual trust between organization and competitor |
| | | Flexible volume production ($AC_{56}$) | Advance manufacturing technologies ($AC_{551}$) |
| | | | Technologies to vary quantities ($AC_{552}$) |
| | | | Lead time compression ($AC_{553}$) |
| | | Seasonality ($AC_{57}$) | Flexible workforce ($AC_{561}$) |
| | | | Forecasting method ($AC_{563}$) |
| | | | Seasonal demand variation s($AC_{564}$) |
| | | Flexible delivery time and locations ($AC_{58}$) | Collaboration with customers and suppliers ($AC_{571}$) |
| | | | Supply chain linkages and management ($AC_{572}$) |

**Table I.**
Excerpt of 40 criteria model pertaining to "management responsibility" enabler



*4.1.1 Primary assessment*. The calculation pertaining to the "Status of Quality" criterion is shown as follows. Weight corresponding to "Status of Quality" criterion is:

$$\mathbf{W}_{51} = \begin{bmatrix} 0.3 & 0.2 & 0.2 & 0.15 & 0.15 \end{bmatrix}$$

| $AC_i$ | $AC_{ij}$ | $AC_{ijk}$ | $R_1$ | $R_2$ | $R_3$ | $R_4$ | $R_5$ | $W_{ij}$ | $W_i$ | $W$ |
|---|---|---|---|---|---|---|---|---|---|---|
| $AC_5$ | $AC_{51}$ | $AC_{511}$ | 7 | 7 | 6 | 8 | 7 | 0.3 | 0.15 | 0.1 |
| | | $AC_{512}$ | 6 | 6 | 5 | 4 | 6 | 0.2 | | |
| | | $AC_{513}$ | 8 | 9 | 8 | 9 | 6 | 0.2 | | |
| | | $AC_{514}$ | 7 | 7 | 8 | 9 | 6 | 0.15 | | |
| | | $AC_{515}$ | 8 | 6 | 7 | 8 | 7 | 0.15 | | |
| | $AC_{52}$ | $AC_{521}$ | 7 | 7 | 6 | 8 | 7 | 0.3 | 0.15 | 0.1 |
| | | $AC_{522}$ | 8 | 8 | 6 | 7 | 8 | 0.2 | | |
| | | $AC_{523}$ | 7 | 7 | 6 | 7 | 8 | 0.2 | | |
| | | $AC_{524}$ | 8 | 8 | 7 | 6 | 8 | 0.2 | | |
| | | $AC_{525}$ | 7 | 7 | 6 | 8 | 7 | 0.1 | | |
| | $AC_{53}$ | $AC_{531}$ | 7 | 8 | 7 | 6 | 6 | 0.3 | 0.2 | 0.1 |
| | | $AC_{532}$ | 5 | 6 | 5 | 8 | 6 | 0.3 | | |
| | | $AC_{533}$ | 5 | 6 | 5 | 6 | 6 | 0.2 | | |
| | | $AC_{534}$ | 6 | 6 | 7 | 6 | 5 | 0.2 | | |
| | $AC_{54}$ | $AC_{541}$ | 6 | 6 | 7 | 6 | 5 | 0.3 | 0.2 | 0.1 |
| | | $AC_{542}$ | 7 | 5 | 6 | 7 | 6 | 0.2 | | |
| | | $AC_{543}$ | 7 | 6 | 5 | 6 | 7 | 0.3 | | |
| | | $AC_{544}$ | 6 | 7 | 6 | 5 | 7 | 0.2 | | |
| | $AC_{55}$ | $AC_{551}$ | 6 | 6 | 5 | 7 | 6 | 0.3 | 0.05 | 0.1 |
| | | $AC_{552}$ | 5 | 5 | 6 | 7 | 6 | 0.2 | | |
| | | $AC_{553}$ | 6 | 6 | 5 | 7 | 6 | 0.3 | | |
| | | $AC_{554}$ | 5 | 5 | 6 | 7 | 6 | 0.2 | | |
| | $AC_{56}$ | $AC_{561}$ | 5 | 5 | 6 | 7 | 6 | 0.3 | 0.1 | 0.1 |
| | | $AC_{562}$ | 5 | 6 | 7 | 6 | 5 | 0.3 | | |
| | | $AC_{563}$ | 5 | 5 | 6 | 6 | 7 | 0.4 | | |
| | $AC_{57}$ | $AC_{571}$ | 7 | 7 | 7 | 8 | 7 | 0.4 | 0.1 | 0.1 |
| | | $AC_{572}$ | 6 | 8 | 7 | 6 | 5 | 0.3 | | |
| | | $AC_{573}$ | 5 | 6 | 7 | 6 | 5 | 0.3 | | |
| | $AC_{58}$ | $AC_{581}$ | 6 | 6 | 7 | 6 | 7 | 0.5 | 0.05 | 0.1 |
| | | $AC_{582}$ | 7 | 6 | 8 | 7 | 6 | 0.5 | | |

**Table II.** Ratings and weights pertaining to "manufacturing strategy" enabler

Assessment vector corresponding to "Status of Quality" criterion is given by:

$$\mathbf{R}_{51} = \begin{bmatrix} 7 & 7 & 6 & 8 & 7 \\ 6 & 6 & 5 & 4 & 6 \\ 8 & 9 & 8 & 9 & 6 \\ 7 & 7 & 8 & 9 & 6 \\ 8 & 6 & 7 & 8 & 7 \end{bmatrix}$$

Index corresponding to "Status of Quality" criterion is given by:

$$\mathbf{I}_{51} = \mathbf{W}_{51} \times \mathbf{R}_{51}$$

$$\mathbf{I}_{51} = \begin{bmatrix} 7.15 & 7.05 & 6.65 & 7.55 & 6.45 \end{bmatrix},$$

$$\mathbf{I}_{53} = \begin{bmatrix} 5.8 & 6.6 & 6 & 6.6 & 5.8 \end{bmatrix}$$

$$\mathbf{I}_{54} = \begin{bmatrix} 6.5 & 6 & 6 & 6 & 6.2 \end{bmatrix}$$

$$\mathbf{I}_{55} = \begin{bmatrix} 5.6 & 5.6 & 5.4 & 7 & 6 \end{bmatrix}$$

$$\mathbf{I}_{56} = \begin{bmatrix} 5 & 5.3 & 6.3 & 6.3 & 6.1 \end{bmatrix}$$

$$\mathbf{I}_{57} = \begin{bmatrix} 6.1 & 7 & 7 & 6.8 & 5.8 \end{bmatrix}$$

$$\mathbf{I}_{58} = \begin{bmatrix} 6.5 & 6 & 7.5 & 6.5 & 6.5 \end{bmatrix}$$

Similar calculations have been performed for individual agile criteria.

*4.1.2 Secondary assessment*. The calculation pertaining to "Manufacturing Strategy" enabler is shown as follows. Weights corresponding to "Manufacturing Strategy" enabler is:

$$\mathbf{W}_5 = \begin{bmatrix} 0.15 & 0.15 & 0.2 & 0.2 & 0.05 & 0.1 & 0.1 & 0.05 \end{bmatrix}$$

Assessment vector corresponding to "Manufacturing Strategy" enabler is given by:

$$\mathbf{R}_1 = \begin{bmatrix} 7.15 & 7.05 & 6.65 & 7.55 & 6.45 \\ 7.4 & 7.4 & 6.2 & 7.2 & 7.6 \\ 5.8 & 6.6 & 6 & 6.6 & 5.8 \\ 6.5 & 6 & 6 & 6 & 6.2 \\ 5.6 & 5.6 & 5.4 & 7 & 6 \\ 5 & 5.3 & 6.3 & 6.3 & 6.1 \\ 6.1 & 7 & 7 & 6.8 & 5.8 \\ 6.5 & 6 & 7.5 & 6.5 & 6.5 \end{bmatrix}$$

Index corresponding to "Manufacturing Strategy" enabler is given by:

$$\mathbf{I}_5 = \mathbf{W}_5 \times \mathbf{R}_5$$

$$\mathbf{I}_5 = \begin{bmatrix} 6.54 & 6.58 & 6.54 & 6.83 & 6.59 \end{bmatrix}$$

Applying the same principle, the indices have been calculated for the remaining agile enablers:

$$\mathbf{I}_1 = \begin{bmatrix} 5.47 & 5.58 & 5.81 & 5.88 & 6.11 \end{bmatrix}$$

$$\mathbf{I}_2 = \begin{bmatrix} 6.53 & 6.64 & 7.14 & 7.15 & 6.75 \end{bmatrix}$$

$$\mathbf{I}_3 = \begin{bmatrix} 7.85 & 8.04 & 7.4 & 7.88 & 7.96 \end{bmatrix}$$

$$\mathbf{I}_4 = \begin{bmatrix} 6.27 & 6.57 & 6.46 & 6.42 & 6.30 \end{bmatrix}$$

*4.1.3 Tertiary assessment.* The agility index of the organization can be found out using the following computation:

$$\mathbf{W} = \begin{bmatrix} 0.3 & 0.2 & 0.2 & 0.2 & 0.1 \end{bmatrix}$$

$$\mathbf{R} = \begin{bmatrix} 5.47 & 5.58 & 5.81 & 5.88 & 6.11 \\ 6.53 & 6.64 & 7.14 & 7.15 & 6.79 \\ 7.96 & 7.88 & 7.4 & 8.04 & 7.85 \\ 6.27 & 6.57 & 6.46 & 6.42 & 6.30 \\ 6.54 & 6.58 & 6.54 & 6.83 & 6.59 \end{bmatrix}$$

$$\mathbf{I} = \mathbf{W} \times \mathbf{R} = \begin{bmatrix} 6.42 & 6.58 & 6.59 & 6.73 & 6.70 \end{bmatrix}$$

Overall agility index $\bar{\mathrm{I}} = 6.6$ which belongs to the range (6-8).

*4.2 Agility assessment using fuzzy logic method*

The performance ratings and weights were gathered from five experts as linguistic variables. The linguistic variables are converted to equivalent numerical values called fuzzy numbers. Using fuzzy numbers, the agility index has been calculated. Fuzzy numbers are used to overcome the vagueness and ambiguity associated with crisp assessment (Lin *et al.*, 2006). Using the Euclidean method, the agility level has been determined and the Fuzzy Performance Importance Index (FPII) is used to find weaker areas.

Table III shows the linguistic responses for the "Manufacturing Strategy" enabler, which consists of weights and ratings for individual criteria.

Linguistic variables for calculating importance weights are Very Low (VL), Low (L), Fairly Low (FL), Medium (M) and Fairly High (FH). Linguistic variables for performance ratings are Worst (W), Very Poor (VP), Poor (P), Fair (F) and Good (G) (Lin *et al.*, 2006).

Triangular fuzzy numbers are used in the study because previous researchers have recommended their usage, as well as the experts of the case organization also approving their usage. The triangular fuzzy numbers used for performance rating include: Worst (W) (0, 0.5, 1.5), Very Poor (VP) (1, 2, 3), Poor (P) (2, 3.5, 5), Fair (F) (3, 5, 7), Good (G) (5, 6.5, 8), Very Good (VG) (7, 8, 9), Excellent (E) (8.5, 9.5, 10).

The fuzzy numbers used for importance weighting include Very Low (VL) (0, 0.05, 0.15), Low (L) (0.1, 0.2, 0.3), Fairly Low (FL) (0.2, 0.35, 0.5), Medium (M) (0.3, 0.5, 0.7), Fairly High (FH) (0.5, 0.65, 0.8), High (H) (0.7, 0.8, 0.9), Very High (VH) (0.85, 0.85, 0.1).

Table IV shows the aggregated ratings and weights pertaining to "Manufacturing Strategy" enabler. The calculation has been performed using Equation (1).

| $AC_i$ | $AC_{ij}$ | $AC_{ijk}$ | $W_{ij}$ | $W_i$ | $W$ |
|---|---|---|---|---|---|
| $AC_5$ | $AC_{51}$ | $AC_{511}$ | FH | FH | FH |
| | | $AC_{512}$ | | | M |
| | | $AC_{513}$ | | | FH |
| | | $AC_{514}$ | | | FH |
| | | $AC_{515}$ | | | FH |
| | $AC_{52}$ | $AC_{521}$ | FH | FH | FH |
| | | $AC_{522}$ | | | M |
| | | $AC_{523}$ | | | M |
| | | $AC_{524}$ | | | FH |
| | | $AC_{525}$ | | | M |
| | $AC_{53}$ | $AC_{531}$ | FH | M | FH |
| | | $AC_{532}$ | | | M |
| | | $AC_{533}$ | FH | M | M |
| | | $AC_{534}$ | | | M |
| | $AC_{54}$ | $AC_{541}$ | FH | M | FH |
| | | $AC_{542}$ | | | M |
| | | $AC_{543}$ | | | M |
| | | $AC_{544}$ | | | M |
| | $AC_{55}$ | $AC_{551}$ | FH | FL | FL |
| | | $AC_{552}$ | | | M |
| | | $AC_{553}$ | | | M |
| | | $AC_{554}$ | | | M |
| | $AC_{56}$ | $AC_{561}$ | FH | FH | M |
| | | $AC_{562}$ | | | M |
| | | $AC_{563}$ | | | FH |
| | $AC_{57}$ | $AC_{571}$ | FH | M | M |
| | | $AC_{572}$ | | | M |
| | | $AC_{573}$ | | | FH |
| | $AC_{58}$ | $AC_{581}$ | FH | FL | M |
| | | $AC_{582}$ | | | FL |

**Table III.**
Linguistic variables pertaining to "manufacturing strategy" enabler

The computation pertaining to "Status of Quality" criterion is shown as follows:

$$\sum_{i=1}^{n} = \left(W_{ijk} \times R_{ijk}\right)/W_{ijk} \quad (1)$$

$$\mathbf{A}_{51} = \begin{bmatrix} 3.2 & 5 & 6.7 \end{bmatrix}$$

Similarly calculations have been performed for other criteria:

$$\mathbf{A}_{52} = \begin{bmatrix} 4.0 & 5.6 & 7.4 \end{bmatrix}$$

$$\mathbf{A}_{53} = \begin{bmatrix} 3.7 & 5.4 & 7.2 \end{bmatrix}$$

$$\mathbf{A}_{54} = \begin{bmatrix} 4.1 & 5.8 & 7.5 \end{bmatrix}$$

$$\mathbf{A}_{55} = \begin{bmatrix} 3 & 5 & 7 \end{bmatrix}$$

| $AC_i$ | $AC_{ij}$ | $AC_{ijk}$ | $W_{ij}$ | $W_i$ | $W$ | $R_{ijk}$ |
|---|---|---|---|---|---|---|
| $AC_5$ | $AC_{51}$ | $AC_{511}$ | (0.5, 0.65, 0.8) | (0.5, 0.65, 0.8) | (0.5, 0.65, 0.8) | (3, 5, 7) |
| | | $AC_{512}$ | | | (0.3, 0.5, 0.7) | (3, 5, 7) |
| | | $AC_{513}$ | | | (0.5, 0.65, 0.8) | (5, 6.5, 8) |
| | | $AC_{514}$ | | | (0.5, 0.65, 0.8) | (2, 3.5, 5) |
| | | $AC_{515}$ | | | (0.5, 0.65, 0.8) | (3, 5, 7) |
| | $AC_{52}$ | $AC_{521}$ | (0.5, 0.65, 0.8) | (0.5, 0.65, 0.8) | (0.5, 0.65, 0.8) | (5, 6.5, 8) |
| | | $AC_{522}$ | | | (0.3, 0.5, 0.7) | (3, 5, 7) |
| | | $AC_{523}$ | | | (0.3, 0.5, 0.7) | (3, 5, 7) |
| | | $AC_{524}$ | | | (0.5, 0.65, 0.8) | (5, 6.5, 8) |
| | | $AC_{525}$ | | | (0.3, 0.5, 0.7) | (3, 5, 7) |
| | $AC_{53}$ | $AC_{531}$ | (0.5, 0.65, 0.8) | (0.3, 0.5, 0.7) | (0.5, 0.65, 0.8) | (5, 6.5, 8) |
| | | $AC_{532}$ | | | (0.3, 0.5, 0.7) | (3, 5, 7) |
| | | $AC_{533}$ | (0.5, 0.65, 0.8) | (0.3, 0.5, 0.7) | (0.3, 0.5, 0.7) | (3, 5, 7) |
| | | $AC_{534}$ | | | (0.3, 0.5, 0.7) | (3, 5, 7) |
| | $AC_{54}$ | $AC_{541}$ | (0.5, 0.65, 0.8) | (0.3, 0.5, 0.7) | (0.5, 0.65, 0.8) | (5, 6.5, 8) |
| | | $AC_{542}$ | | | (0.3, 0.5, 0.7) | (5, 6.5, 8) |
| | | $AC_{543}$ | | | (0.3, 0.5, 0.7) | (3, 5, 7) |
| | | $AC_{544}$ | | | (0.3, 0.5, 0.7) | (3, 5, 7) |
| | $AC_{55}$ | $AC_{551}$ | (0.5, 0.65, 0.8) | (0.2, 0.35, 0.5) | (0.2, 0.35, 0.5) | (3, 5, 7) |
| | | $AC_{552}$ | | | (0.3, 0.5, 0.7) | (3, 5, 7) |
| | | $AC_{553}$ | | | (0.3, 0.5, 0.7) | (3, 5, 7) |
| | | $AC_{554}$ | | | (0.3, 0.5, 0.7) | (3, 5, 7) |
| | $AC_{56}$ | $AC_{561}$ | (0.5, 0.65, 0.8) | (0.5, 0.65, 0.8) | (0.3, 0.5, 0.7) | (3, 5, 7) |
| | | $AC_{562}$ | | | (0.3, 0.5, 0.7) | (3, 5, 7) |
| | | $AC_{563}$ | | | (0.5, 0.65, 0.8) | (7, 8, 9) |
| | $AC_{57}$ | $AC_{571}$ | (0.5, 0.65, 0.8) | (0.3, 0.5, 0.7) | (0.3, 0.5, 0.7) | (5, 6.5, 8) |
| | | $AC_{572}$ | | | (0.3, 0.5, 0.7) | (3, 5, 7) |
| | | $AC_{573}$ | | | (0.5, 0.65, 0.8) | (3, 5, 7) |
| | $AC_{58}$ | $AC_{581}$ | (0.5, 0.65, 0.8) | (0.2, 0.35, 0.5) | (0.3, 0.5, 0.7) | (3, 5, 7) |
| | | $AC_{582}$ | | | (0.2, 0.35, 0.5) | (2, 3.5, 5) |

**Table IV.** Aggregated weights and ratings for "manufacturing strategy" enabler

$$\mathbf{A}_{56} = \begin{bmatrix} 4.8 & 6.1 & 7.7 \end{bmatrix}$$

$$\mathbf{A}_{57} = \begin{bmatrix} 3.5 & 5.4 & 7.3 \end{bmatrix}$$

$$\mathbf{A}_{58} = \begin{bmatrix} 2.6 & 4.3 & 6.1 \end{bmatrix}$$

Similar computations performed at enabler level and weights and ratings for enablers are as follows: management responsibility $AC_1$ {(0.5, 0.65, 0.8), (5.81, 7.21, 8.98)}, manufacturing management $AC_2$ {(0.3, 0.5, 0.7), (5.92, 7.01, 8.53)}, workforce $AC_3$ {(0.5, 0.65, 0.8), (5.88, 7.35, 8.67)}, technology agility $AC_4$ {(0.3, 0.5, 0.7), (6.02, 7.85, 9.02)} and manufacturing strategy $AC_5$ {(0.5, 0.65, 0.8), (3.74, 5.40, 7.17)}.

Then Fuzzy Agility Index (FAI) is computed as follows:

$$\mathbf{FAI} = \begin{bmatrix} 5.37 & 6.91 & 8.45 \end{bmatrix}$$

The agility index using the fuzzy logic approach is $\bar{I} = \begin{bmatrix} 5.37 & 6.91 & 8.45 \end{bmatrix}$.

## 5. Results and discussions

The results are presented in the following subsections.

### *5.1 Multi-grade fuzzy method*

After calculating the weights and ratings pertaining to the 40 criteria, it results in the overall Agility index of $\bar{I} = 6.6$ which belongs to the range of (6-8). Hence the organization's current position is "Agile".

### *5.2 Fuzzy logic method*

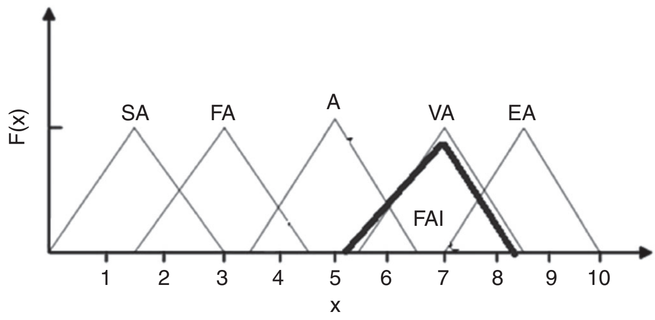
The computed FAI = [5.37 6.91 8.45]. The Euclidean distance method was used to decide the agility nature of the organization. FPII was used to find the factors that impede the organization's attainment of agility.

*5.2.1 Euclidean distance method*. Many methods are available for matching the agility labels, out of which we have employed the Euclidean distance method (Guesgen and Albrecht, 2000). The Euclidean distance method is the most widely used method for matching the membership function with linguistic terms. Its advantage is that it is the most intuitive form of human perception of proximity (Lin *et al.*, 2006). The general linguistic term is compared with the computed FAI value using Euclidean distance. In this method, the natural-language expression set AL = {Extremely Agile [EA], Very Agile [VA], Agile [A], Fairly Agile [FA], Slowly Agile [SA]} is selected for labelling, and the linguistics and corresponding membership functions are shown in Figure 2. The Euclidean distance is calculated using Equation (2):

$$D(FAI, AL_i) = \sqrt{\sum_{x \epsilon p} \left( f_{FAI}(x) - f_{AL}(x)^2 \right)} \tag{2}$$

The calculation using the Euclidean method is shown as follows:

*D (FAI, SA)* = 4.02 units, *D (FAI, FA)* = 3.63 units, *D (FAI, A)* = 2.39 units, *D (FAI, VA)* = 0.51units, *D (FAI, EA)* = 2.18 units. From the above result, it is clear that the current level of the firm is closer to the very agile region *D (FAI, VA)* = 0.51 units. Hence, the organization is very agile.




[SA (0, 1.5, 3), FA (1.5, 3, 4.5), A (3.5, 5, 6.5), VA (5.5, 7, 8.5), EA (7, 8.5, 10), FAI (3.79, 6.91, 8.45)]

**Figure 2.**
Euclidean distance method

*5.2.2 FPII.* To improve the agility level of the firm, we need to identify the principal obstacles using the FPII computation of agile element capabilities. This deals with the performance rating and the importance weight of individual agile criteria. Finally, it computes the agility level of the organization which is calculated using Equations (3) and (4):

$$FPII_{ijk} = W_{ijk} \times AC_{ijk} \quad (3)$$

$$W_{ijk} = (1,1,1) - W'_{ijk} \quad (4)$$

$$\text{FPII for } A_{511} = (3,5,7) \times (0.5, 0.65, 0.8) = (1.5, 3.25, 5.6)$$

FPII scores for "Manufacturing Strategy" are shown in Table V. The ranking score is calculated using the centroid method.

| Agile Attributes | Fuzzy performance rating | (1,1,1) – $W_{ijk}$ | Fuzzy performance importance index | Ranking score |
|---|---|---|---|---|
| $AC_{511}$ | (3, 5, 7) | (0.5, 0.35, 0.2) | (1.5, 1.75, 1.4) | *1.65** |
| $AC_{512}$ | (3, 5, 7) | (0.7, 0.5, 0.3) | (2.1, 2.5, 2.1) | 2.366 |
| $AC_{513}$ | (5, 6.5, 8) | (0.5, 0.35, 0.2) | (2.5, 2.275, 1.6) | 2.366 |
| $AC_{514}$ | (2, 3.5, 5) | (0.5, 0.35, 0.2) | (1.0, 1.225, 1.0) | *1.15** |
| $AC_{515}$ | (3, 5, 7) | (0.5, 0.35, 0.2) | (1.5, 1.75, 1.4) | *1.65** |
| $AC_{521}$ | (5, 6.5, 8) | (0.5, 0.35, 0.2) | (2.5, 2.275, 1.6) | 2.366 |
| $AC_{522}$ | (3, 5, 7) | (0.7, 0.5, 0.3) | (2.1, 2.5, 2.1) | 2.366 |
| $AC_{523}$ | (3, 5, 7) | (0.7, 0.5, 0.3) | (2.1, 2.5, 2.1) | 2.366 |
| $AC_{524}$ | (5, 6.5, 8) | (0.5, 0.35, 0.2) | (2.5, 2.275, 1.6) | 2.366 |
| $AC_{525}$ | (3, 5, 7) | (0.7, 0.5, 0.3) | (2.1, 2.5, 2.1) | 2.366 |
| $AC_{531}$ | (5, 6.5, 8) | (0.5, 0.35, 0.2) | (2.5, 2.275, 1.6) | 2.366 |
| $AC_{532}$ | (3, 5, 7) | (0.7, 0.5, 0.3) | (2.1, 2.5, 2.1) | 2.366 |
| $AC_{533}$ | (3, 5, 7) | (0.7, 0.5, 0.3) | (2.1, 2.5, 2.1) | 2.366 |
| $AC_{534}$ | (3, 5, 7) | (0.7, 0.5, 0.3) | (2.1, 2.5, 2.1) | 2.366 |
| $AC_{541}$ | (5, 6.5, 8) | (0.5, 0.35,0.2) | (2.5, 2.275, 1.6) | 2.366 |
| $AC_{542}$ | (5, 6.5, 8) | (0.7, 0.5, 0.3) | (3.5, 3.25, 2.4) | 3.15 |
| $AC_{543}$ | (3, 5, 7) | (0.7, 0.5, 0.3) | (2.1, 2.5, 2.1) | 2.366 |
| $AC_{544}$ | (3, 5, 7) | (0.7, 0.5, 0.3) | (2.1, 2.5, 2.1) | 2.366 |
| $AC_{551}$ | (3, 5, 7) | (0.8, 0.65, 0.5) | (2.4, 3.25, 3.5) | 3.15 |
| $AC_{552}$ | (3, 5, 7) | (0.7, 0.5, 0.3) | (2.1, 2.5, 2.1) | 2.366 |
| $AC_{553}$ | (3, 5, 7) | (0.7, 0.5, 0.3) | (2.1, 2.5, 2.1) | 2.366 |
| $AC_{554}$ | (3, 5, 7) | (0.7, 0.5, 0.3) | (2.1, 2.5, 2.1) | 2.366 |
| $AC_{561}$ | (3, 5, 7) | (0.7, 0.5, 0.3) | (2.1, 2.5, 2.1) | 2.366 |
| $AC_{562}$ | (3, 5, 7) | (0.7, 0.5, 0.3) | (2.1, 2.5, 2.1) | 2.366 |
| $AC_{563}$ | (7, 8, 9) | (0.5, 0.35, 0.2) | (3.5, 2.8, 1.8) | 2.75 |
| $AC_{571}$ | (5, 6.5, 8) | (0.7, 0.5, 0.3) | (3.5, 3.25, 2.4) | 3.15 |
| $AC_{572}$ | (3, 5, 7) | (0.7, 0.5, 0.3) | (2.1, 2.5, 2.1) | 2.366 |
| $AC_{573}$ | (3, 5, 7) | (0.5, 0.35, 0.2) | (1.5, 1.75, 1.4) | *1.65** |
| $AC_{581}$ | (3, 5, 7) | (0.7, 0.5, 0.3) | (2.1, 2.5, 2.1) | 2.366 |
| $AC_{582}$ | (2, 3.5, 5) | (0.8, 0.65, 0.5) | (1.6, 2.275, 2.5) | *2.2** |

**Note:** *Weaker attributes

**Table V.** Fuzzy Performance Importance Index for "manufacturing strategy" enabler

Ranking score for agile attribute "Products exceeding the customers" expectations' is computed as:

$$\text{Ranking Score} = \frac{a+4b+c}{6}$$

After calculating the ranking score for all the attributes, in order to identify the principal obstacles for agile implementation, the management threshold has been fixed as 2.35. The attributes whose ranking score is <2.35 are found to be weak. The weaker attributes need to be concentrated on for improvement.

*5.3 Industrial implications*

This section deals with the industrial implications for various agility enablers.

Management responsibility: effort has been made to transform the hierarchical levels within the organization to improve its performance; for example to interchange personnel between various departments to share knowledge and suggestions. The workforce have clear definitions regarding their work and responsibility in the organization. They are also engaged to work as a small team to work towards the critical jobs. Suggestions were given to the management personnel to consider the social improvement of the workforce towards profit motivation and turnover. To overcome this difficulty, the organization is planning to arrange periodical meetings with the workforce.

Manufacturing management: suggestions were provided to capture the customers' voice in the market and to implement the development of products to sustain the company in competitive market conditions. Efforts have been made to implement continuous improvement in the firm. Management personnel should address customer problems on time and solve them rapidly. Employees should be motivated to adopt newer technologies and management principles into their routine processes. Suggestions were given regarding the improvement of supply chain concepts to improve efficiency in outsourcing. Advanced optimization techniques have to be incorporated to generate the highly customized products required by the customer. Suggestions were provided to incorporate rapid tooling and digital manufacturing concepts in the firm.

Workforce: suggestions were given regarding improving the multi-skilling aspects of the workforce; employees used to work in cross functional teams to gather extensive knowledge of all relevant fields in the firm. The workforce is made flexible to tackle various business changes which reflect immediately on the shop floor. Team working has been put into practice to form the new teams quickly with respect to the work.

Technology agility: efforts have been made to implement newer technologies in manufacturing and also in support of manufacturing. Facilities like the concurrent development of new products, and IT support for products which was lagging in this organization; steps have been taken to improve this level. Investment in computer aided Design, Computer Aided Manufacturing and Rapid Prototyping (RP) has been made to deploy automated processes correspondingly. The usage of design for manufacturing concepts is recommended during the design stage of the product. The management is currently planning to provide training on lean principles. Standard components like fasteners can be outsourced to improve the lead time in product delivery. Suggestions were made regarding the implementation of a virtual team of experts to clarify and discuss the product/process, irrespective of their physical presence in the plant.

Manufacturing strategy: Suggestions were provided in the field of quality and cost management. Training programs on advanced concepts of total quality management and total productive maintenance (TPM) have been imparted to a selected group from the workforce to improve quality standards. Cost management should be effective by incorporating activity-based costing rather full spending on a single process. Efforts have been made to forecast the market needs and implement product development.

## 6. Conclusions

The assessment of agility gains vital importance in a contemporary scenario. Modern researchers are focusing on agility assessment using various approaches (Vinodh *et al.*, 2008). Benchmarking the results of the agility assessment also gains importance (Sarkis, 2001). The criteria used in the assessment must be comprehensive enough to address various aspects of an agile system. In the present study, the assessment results of multi-grade fuzzy and fuzzy logic approaches were compared. The multi-grade fuzzy approach indicates an agility level of 66 per cent whereas, using the Fuzzy logic approach, the agility level was found to be 69.6 per cent after defuzzification. The agility gaps and improvement proposals were identified and subjected to implementation in the case organization.

### *6.1 Limitations and future research directions*

The study reports on the benchmarking analysis of agility assessment approaches. The results of two agility assessment approaches were compared. In future work, a greater number of benchmarking studies could be conducted.

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