Supply Chain Agility Assessment Module in Fuzzy Paradigm

Chhabi Ram Matwale[1], Dr. Saurav Datta[2*], Prof. Siba Sankar Mahapatra[3]

[1,2,3] Department of Mechanical Engineering
National Institute of Technology, Rourkela-769008

[*]Corresponding Author detail: (Email: sdattaju@gmail.com, Ph. No. 0661-246 2524)

Abstract

Nowadays, in turbulent and violate global marketplaces, agility has been viewed as a fundamental key strategic consideration of a supply chain needed for survival. To achieve the competitive edge, industries must align with suppliers as well as their customers to streamline operations. Consequently, Agile Supply Chain (ASC) is considered as a dominant competitive advantage. However, so far a little effort has been made for designing, operating and evaluating agile supply chain in recent years. To this end, the present work attempts to develop a procedural hierarchy towards estimating an overall performance metric for an agile supply chain; in an Indian perspective. The theories behind generalized Interval-Valued Fuzzy Numbers (IVFNs) have been utilized in this appraisement cum decision-modeling. Apart from estimating supply chainsô overall agility extent, the study has been extended towards identifying ill-performing areas (called agile barriers) which require future improvement. The concept of ódegree of similarityô between two fuzzy numbers has been explored to rank various agile criterions in accordance with their performance extent.

Keywords: Agile Supply Chain; Interval-Valued Fuzzy Numbers; agile barriers; degree of similarity

1. Introduction and State of Art

Agility refers to the capability of an organization to respond quickly in accordance with the dynamic demands of the customers (Vinodh et al., 2010). Supply Chain Agility is an operational strategy focused on inducing velocity and flexibility in the supply chain. A supply chain is the process of moving goods from the customer order through the raw materials stage, supply, production, and distribution of products to the customer. All organizations have supply chains of varying degrees, depending upon the size of the organization and the type of product manufactured. These networks obtain supplies and components, change these materials into finished products and then distribute them to the customer. Included in this supply chain process are customer orders, order processing, inventory, scheduling, transportation, storage, and customer service. A necessity in coordinating all these activities is the information service network.

The difference between supply chain management and supply chain agility is the extent of capability that the organization possesses. Key to the success of an agile supply chain is the speed and flexibility with which these activities can be accomplished and the realization that customer needs and customer satisfaction are the very reasons for the network. Customer satisfaction is paramount. Achieving this capability requires all physical and logical events within the supply chain to be enacted swiftly, accurately, and effectively. The faster parts, information, and decisions flow through an organization, the faster it can respond to customer needs. [Source: *http://rockfordconsulting.com/supply-chain-agility.htm*]

Kumar et al. (2006) developed a conceptual framework for implementing and managing supply chain flexibility in supply chain organizations.

Jassbi et al. (2010) developed an approach based on Adaptive Neuro Fuzzy Inference System (ANFIS) for evaluating agility in supply chain considering agility capabilities such as Flexibility, Competency, Cost, Responsiveness and Quickness. Vinodh et al. (2010) investigated to assess the agility level of an organization using a multi-grade fuzzy approach. Yaghoubi et al. (2011) highlighted the concept, importance and necessity of accessing agility with the Goldman methodology based on fuzzy approach. Garbie (2011) proposed a conceptual model to measure the agility level of the petroleum companies based on existing technologies, level of qualifying human resources, production strategies, and organization management systems. Kaveh et al. (2011) proposed an approach to measure the relative efficiency of agility in supply chains. First, a conceptual model including capabilities and providers of agility in supply chains has been represented. Then, a supply chain has been associated to a Decision Making Unit (DMU) which consumes providers of agility to produce capabilities of agility. A Fuzzy Data Envelopment Analysis (FDEA) has been proposed for measuring the efficiency of transformation process in which a given supply chain transforms providers of agility into capabilities of agility. In the last step a simulation process has been provided to rank the interval efficiency of proposed FDEA.

Radfar et al. (2011) presented a model for evaluating the agility in supply chain of two dominant telecommunication companies in Iran. To avoid any ambiguities which are caused by linguistic methods, in this evaluation model we have used Fuzzy Inference System (FIS) which is neither stochastic nor random. Somuyiwa et al. (2011) revealed that an organizationôs supply chain agility through its information system capabilities has a positive influence on its supply chain performance. The study however recommended that organizations should be more committed to other areas of operational performance other than organizational learning in their supply chains since remaining competitive goes beyond acquiring and disseminating information only. Karuppusami et al. (2011) analyzed to quantify the efficiency of the agile supply chain chain, a model called ñTADSò is proposed. This paper discusses the functions of TADS, the prior works carried on it and enumerates the desirable effects of adapting TADS in the firms to make their supply chains more responsive in order to survive in the contemporary market scenario. Zandi and Tavana (2011) presented a novel structured approach to evaluate and select the best agile electronic customer relationship management (e-CRM) framework in a rapidly changing manufacturing environment.

Tseng and Lin (2011) suggested an agility development method for dealing with the interface and alignment issues among the agility drivers, capabilities and providers using the QFD relationship matrix and fuzzy logic. Vinodh et al. (2012) attempted to assess the agility of the manufacturing organization using a 30-criteria agility assessment model which could be utilized to measure agility and to identify the agile characteristics of organization.

Literature reveals that considerable amount of work has been carried out by pioneer researchers towards agile system modeling followed by agility appraisement module in Agile Supply Chain Management (ASCM). Most of the agile parameters (agile enablers/capabilities, agile attributes and agile criterions) being subjective in nature, fuzzy analysis of expert opinion is indeed logical as well as scientific. However, it has been reported that instead of generalized fuzzy number, fuzzy representation (in terms of interval) surely provides precise prediction. Motivated by this, present work aims to develop an agility assessment module in ASCM exploring the concept of generalized Interval-Valued Fuzzy Numbers (GIVFNs). Apart from obtaining an overall supply chainʹs agility index; the work has been illustrated towards identifying agile barriers as well.

2. Mathematical Basis

2.1 Theory behind Interval-Valued Trapezoidal Fuzzy Numbers

Wang and Li (2001) represented the interval-valued trapezoidal fuzzy numbers as follows:

$$\tilde{\tilde{A}} = \left[\tilde{\tilde{A}}^L, \tilde{\tilde{A}}^U\right] = \left[\left(a_1^L, a_2^L, a_3^L, a_4^L; w_{\tilde{\tilde{A}}^L}\right), \left(a_1^U, a_2^U, a_3^U, a_4^U; w_{\tilde{\tilde{A}}^U}\right)\right]$$

Here, $0 \le a_1^L \le a_2^L \le a_3^L \le a_4^L \le 1,$ $0 \le a_1^U \le a_2^U \le a_3^U \le a_4^U \le 1,$ and $\tilde{\tilde{A}}^L \subset \tilde{\tilde{A}}^U$. $0 \le w_{\tilde{\tilde{A}}^L} \le w_{\tilde{\tilde{A}}^U}$

From Fig. 1, it can be concluded that interval-valued trapezoidal fuzzy number $\tilde{\tilde{A}}$ consists of two level of values such as, lower values of interval-valued trapezoidal fuzzy number $\tilde{\tilde{A}}^L$ and the upper values of interval-valued trapezoidal fuzzy number $\tilde{\tilde{A}}^U$ (Liu and Wang, 2011).

The operation rules of interval-valued trapezoidal fuzzy numbers as given by Wei and Chen (2009) have been reproduced below.

Suppose that,

$\tilde{\tilde{A}} = \left[\tilde{\tilde{A}}^L, \tilde{\tilde{A}}^U\right] = \left[\left(a_1^L, a_2^L, a_3^L, a_4^L; w_{\tilde{\tilde{A}}^L}\right), \left(a_1^U, a_2^U, a_3^U, a_4^U; w_{\tilde{\tilde{A}}^U}\right)\right]$ and

$\tilde{\tilde{B}} = \left[\tilde{\tilde{B}}^L, \tilde{\tilde{B}}^U\right] = \left[\left(b_1^L, b_2^L, b_3^L, b_4^L; w_{\tilde{\tilde{B}}^L}\right), \left(b_1^U, b_2^U, b_3^U, b_4^U; w_{\tilde{\tilde{B}}^U}\right)\right]$ are the two interval-valued trapezoidal fuzzy numbers, where,

$$0 \le a_1^L \le a_2^L \le a_3^L \le a_4^L \le 1,$$
$$0 \le a_1^U \le a_2^U \le a_3^U \le a_4^U \le 1,$$
$$0 \le w_{\tilde{\tilde{A}}^L} \le w_{\tilde{\tilde{A}}^U} \le 1, \quad \tilde{\tilde{A}}^L \subset \tilde{\tilde{A}}^U$$

$$0 \le b_1^L \le b_2^L \le b_3^L \le b_4^L \le 1,$$
$$0 \le b_1^U \le b_2^U \le b_3^U \le b_4^U \le 1,$$
$$0 \le w_{\tilde{\tilde{B}}^L} \le w_{\tilde{\tilde{B}}^U} \le 1, \quad \tilde{\tilde{B}}^L \subset \tilde{\tilde{B}}^U$$

1.The sum of two interval-valued trapezoidal fuzzy numbers $\tilde{\tilde{A}} \oplus \tilde{\tilde{B}}$:

$$\tilde{\tilde{A}} \oplus \tilde{\tilde{B}} = \left[\left(a_1^L, a_2^L, a_3^L, a_4^L; w_{\tilde{\tilde{A}}^L}\right), \left(a_1^U, a_2^U, a_3^U, a_4^U; w_{\tilde{\tilde{A}}^U}\right)\right] \oplus \left[\left(b_1^L, b_2^L, b_3^L, b_4^L; w_{\tilde{\tilde{B}}^L}\right), \left(b_1^U, b_2^U, b_3^U, b_4^U; w_{\tilde{\tilde{B}}^U}\right)\right]$$

$$= \left[\left(a_1^L + b_1^L, a_2^L + b_2^L, a_3^L + b_3^L, a_4^L + b_4^L; \min\left(w_{\tilde{\tilde{A}}^L}, w_{\tilde{\tilde{B}}^L}\right)\right), \left(a_1^U + b_1^U, a_2^U + b_2^U, a_3^U + b_3^U, a_4^U + b_4^U; \min\left(w_{\tilde{\tilde{A}}^U}, w_{\tilde{\tilde{B}}^U}\right)\right)\right] \tag{1}$$

2.The difference of two interval-valued trapezoidal fuzzy numbers $\tilde{\tilde{A}} - \tilde{\tilde{B}}$:

$$\tilde{\tilde{A}} - \tilde{\tilde{B}} = \left[\left(a_1^L, a_2^L, a_3^L, a_4^L; w_{\tilde{\tilde{A}}^L}\right), \left(a_1^U, a_2^U, a_3^U, a_4^U; w_{\tilde{\tilde{A}}^U}\right)\right] - \left[\left(b_1^L, b_2^L, b_3^L, b_4^L; w_{\tilde{\tilde{B}}^L}\right), \left(b_1^U, b_2^U, b_3^U, b_4^U; w_{\tilde{\tilde{B}}^U}\right)\right]$$

$$= \left[\left(a_1^L - b_4^L, a_2^L - b_3^L, a_3^L - b_2^L, a_4^L - b_1^L; \min\left(w_{\tilde{\tilde{A}}^L}, w_{\tilde{\tilde{B}}^L}\right)\right), \left(a_1^U - b_4^U, a_2^U - b_3^U, a_3^U - b_2^U, a_4^U - b_1^U; \min\left(w_{\tilde{\tilde{A}}^U}, w_{\tilde{\tilde{B}}^U}\right)\right)\right] \tag{2}$$

3.The product of two interval-valued trapezoidal fuzzy numbers $\tilde{\tilde{A}} \otimes \tilde{\tilde{B}}$:

$$\tilde{\tilde{A}} \otimes \tilde{\tilde{B}} = \left[\left(a_1^L, a_2^L, a_3^L, a_4^L; w_{\tilde{\tilde{A}}^L}\right), \left(a_1^U, a_2^U, a_3^U, a_4^U; w_{\tilde{\tilde{A}}^U}\right)\right] \otimes \left[\left(b_1^L, b_2^L, b_3^L, b_4^L; w_{\tilde{\tilde{B}}^L}\right), \left(b_1^U, b_2^U, b_3^U, b_4^U; w_{\tilde{\tilde{B}}^U}\right)\right]$$

$$= \left[\left(a_1^L \times b_1^L, a_2^L \times b_2^L, a_3^L \times b_3^L, a_4^L \times b_4^L; \min\left(w_{\tilde{\tilde{A}}^L}, w_{\tilde{\tilde{B}}^L}\right)\right), \left(a_1^U \times b_1^U, a_2^U \times b_2^U, a_3^U \times b_3^U, a_4^U \times b_4^U; \min\left(w_{\tilde{\tilde{A}}^U}, w_{\tilde{\tilde{B}}^U}\right)\right)\right] \tag{3}$$

4.The product between an interval-valued trapezoidal fuzzy number and a constant $\lambda\tilde{\tilde{A}}$:

$$\lambda\tilde{\tilde{A}} = \lambda \times \left[\left(a_1^L, a_2^L, a_3^L, a_4^L; w_{\tilde{\tilde{A}}^L}\right), \left(a_1^U, a_2^U, a_3^U, a_4^U; w_{\tilde{\tilde{A}}^U}\right)\right]$$

$$= \left[\left(\lambda a_1^L, \lambda a_2^L, \lambda a_3^L, \lambda a_4^L; w_{\tilde{\tilde{A}}^L}\right), \left(\lambda a_1^U, \lambda a_2^U, \lambda a_3^U, \lambda a_4^U; w_{\tilde{\tilde{A}}^U}\right)\right], \quad \lambda > 0. \tag{4}$$

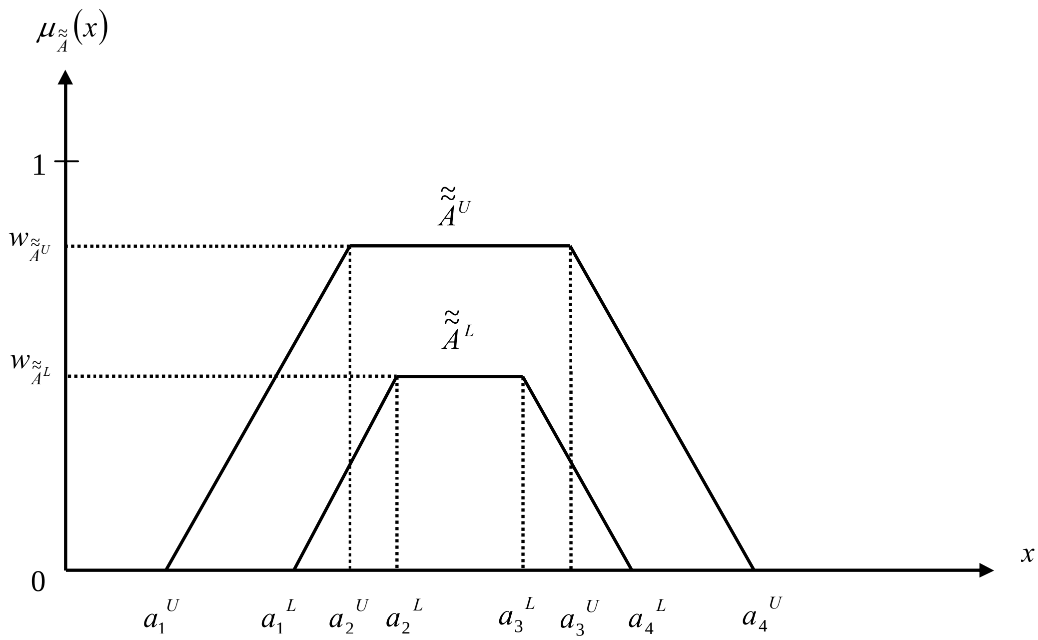

Fig. 1 Interval-valued trapezoidal fuzzy numbers (Liu and Wang, 2011)

Wei and Chen (2009) proposed a new division operator for interval-valued trapezoidal fuzzy numbers for fuzzy risk analysis. According to them, given for two fuzzy numbers:

Let $\tilde{\tilde{A}} = \left[\left(a_1^L, a_2^L, a_3^L, a_4^L; w_{\tilde{\tilde{A}}}^L\right), \left(a_1^U, a_2^U, a_3^U, a_4^U; w_{\tilde{\tilde{A}}}^U\right)\right]$, $\tilde{\tilde{B}} = \left[\left(b_1^L, b_2^L, b_3^L, b_4^L; w_{\tilde{\tilde{B}}}^L\right), \left(b_1^U, b_2^U, b_3^U, b_4^U; w_{\tilde{\tilde{B}}}^U\right)\right]$,

$$U^L = \left\{ a_1^L / b_1^L, a_2^L / b_2^L, a_3^L / b_3^L, a_4^L / b_4^L \right\}, U^U = \left\{ a_1^U / b_1^U, a_2^U / b_2^U, a_3^U / b_3^U, a_4^U / b_4^U \right\}, \tag{5}$$

$x^L = \min\left(U^L\right), x^U = \min\left(U^U\right), y^L = \max\left(U^L\right), y^U = \max\left(U^U\right)$, where

$0 \le a_1^L \le a_2^L \le a_3^L \le a_4^L \le 1,$
$0 \le a_1^U \le a_2^U \le a_3^U \le a_4^U \le 1,$

$0 \le b_1^L \le b_2^L \le b_3^L \le b_4^L \le 1,$
$0 \le b_1^U \le b_2^U \le b_3^U \le b_4^U \le 1.$

The division operator Ø proposed by (Wei and Chen, 2009) between interval-valued trapezoidal fuzzy numbers has been presented follows:

$$\tilde{\tilde{A}} \varnothing \tilde{\tilde{B}} = \left[\left(a_1^L, a_2^L, a_3^L, a_4^L; w_{\tilde{\tilde{A}}}^L\right), \left(a_1^U, a_2^U, a_3^U, a_4^U; w_{\tilde{\tilde{A}}}^U\right)\right] \varnothing \left[\left(b_1^L, b_2^L, b_3^L, b_4^L; w_{\tilde{\tilde{B}}}^L\right), \left(b_1^U, b_2^U, b_3^U, b_4^U; w_{\tilde{\tilde{B}}}^U\right)\right]$$

$$= \begin{bmatrix} \left(\min\left(U^{L}\right), \min\left(U^{L} - x^{L}\right), \max\left(U^{L} - y^{L}\right), \max\left(U^{L}\right); \min\left(w_{\tilde{\tilde{A}}}^{L}, w_{\tilde{\tilde{B}}}^{L}\right)\right), \\ \left(\min\left(U^{U}\right), \min\left(U^{U} - x^{U}\right), \max\left(U^{U} - y^{U}\right), \max\left(U^{U}\right); \min\left(w_{\tilde{\tilde{A}}}^{U}, w_{\tilde{\tilde{B}}}^{U}\right)\right) \end{bmatrix} \tag{6}$$

Here $\left(U^{L} - x^{L}\right)$ denotes deleting the element x^{L} from the set U^{L}, $\left(U^{U} - x^{U}\right)$ denotes deleting the element x^{U} from the set U^{U}, $\left(U^{L} - y^{L}\right)$ denotes deleting the element y^{L} from the set U^{L}, $\left(U^{U} - y^{U}\right)$ denotes deleting the element y^{U} from the set U^{U}.

2.4 Degree of Similarity between Two Trapezoidal IVFNs

Combining the concepts of geometric distance, the perimeter, the height and the COG points, the degree of similarity between interval-valued trapezoidal fuzzy numbers can be calculated (Wei and Chen, 2009). Assuming that there are two interval-valued trapezoidal fuzzy numbers:

$\tilde{\tilde{A}} = \left[\tilde{\tilde{A}}^{L}, \tilde{\tilde{A}}^{U}\right] = \left[\left(a_1^{L}, a_2^{L}, a_3^{L}, a_4^{L}; w_{\tilde{\tilde{A}}}^{L}\right), \left(a_1^{U}, a_2^{U}, a_3^{U}, a_4^{U}; w_{\tilde{\tilde{A}}}^{U}\right)\right]$ and

$\tilde{\tilde{B}} = \left[\tilde{\tilde{B}}^{L}, \tilde{\tilde{B}}^{U}\right] = \left[\left(b_1^{L}, b_2^{L}, b_3^{L}, b_4^{L}; w_{\tilde{\tilde{B}}}^{L}\right), \left(b_1^{U}, b_2^{U}, b_3^{U}, b_4^{U}; w_{\tilde{\tilde{B}}}^{U}\right)\right]$

Here, $0 \le a_1^{L} \le a_2^{L} \le a_3^{L} \le a_4^{L} \le 1$, $\quad 0 \le a_1^{U} \le a_2^{U} \le a_3^{U} \le a_4^{U} \le 1$,

$0 \le w_{\tilde{\tilde{A}}}^{L} \le w_{\tilde{\tilde{A}}}^{U} \le 1$, $\tilde{\tilde{A}}^{L} \subset \tilde{\tilde{A}}^{U}$.

$0 \le b_1^{L} \le b_2^{L} \le b_3^{L} \le b_4^{L} \le 1$, $\quad 0 \le b_1^{U} \le b_2^{U} \le b_3^{U} \le b_4^{U} \le 1$,

$0 \le w_{\tilde{\tilde{B}}}^{L} \le w_{\tilde{\tilde{B}}}^{U} \le 1$, $\tilde{\tilde{B}}^{L} \subset \tilde{\tilde{B}}^{U}$.

The procedural steps for calculating the degree of similarity between interval-valued trapezoidal fuzzy numbers $\tilde{\tilde{A}}$ and $\tilde{\tilde{B}}$ are summarized below (Wei and Chen, 2009).

<u>Step 1:</u> Calculate the areas $A\left(\tilde{\tilde{A}}^{L}\right)$ and $A\left(\tilde{\tilde{A}}^{U}\right)$ of the lower trapezoidal fuzzy number $\tilde{\tilde{A}}^{L}$ and the upper trapezoidal fuzzy number $\tilde{\tilde{A}}^{U}$, respectively, shown as follows:

$$A\left(\tilde{\tilde{A}}^{L}\right) = \frac{\left(a_4^{L} + a_3^{L} - a_2^{L} - a_1^{L}\right) \times w_{\tilde{\tilde{A}}^{L}}}{2}, \tag{7}$$

$$A\left(\tilde{\tilde{A}}^U\right)=\frac{\left(a_4^U+a_3^U-a_2^U-a_1^U\right)\times w_{\tilde{\tilde{A}}^U}}{2}. \tag{8}$$

In the same way, calculate the areas $A\left(\tilde{\tilde{B}}^L\right)$ and $A\left(\tilde{\tilde{B}}^U\right)$ of the lower trapezoidal fuzzy number $\tilde{\tilde{B}}^L$ and the upper trapezoidal fuzzy number $\tilde{\tilde{B}}^U$, respectively, shown as follows:

$$A\left(\tilde{\tilde{B}}^L\right)=\frac{\left(b_4^L+b_3^L-b_2^L-b_1^L\right)\times w_{\tilde{\tilde{B}}^L}}{2}, \tag{9}$$

$$A\left(\tilde{\tilde{B}}^U\right)=\frac{\left(b_4^U+b_3^U-b_2^U-b_1^U\right)\times w_{\tilde{\tilde{B}}^U}}{2}. \tag{10}$$

<u>Step 2:</u> Calculate the COG points $\left(x^*_{\tilde{\tilde{A}}^L}, y^*_{\tilde{\tilde{A}}^L}\right)$, $\left(x^*_{\tilde{\tilde{A}}^U}, y^*_{\tilde{\tilde{A}}^U}\right)$, $\left(x^*_{\tilde{\tilde{B}}^L}, y^*_{\tilde{\tilde{B}}^L}\right)$, $\left(x^*_{\tilde{\tilde{B}}^U}, y^*_{\tilde{\tilde{B}}^U}\right)$ of $\tilde{\tilde{A}}^L, \tilde{\tilde{A}}^U$ and $\tilde{\tilde{B}}^L, \tilde{\tilde{B}}^U$, respectively, by Eqs.17-24.

$$x^*_{\tilde{\tilde{A}}^L}=\frac{y^*_{\tilde{\tilde{A}}^L}\left(a_3^L+a_2^L\right)+\left(a_4^L+a_1^L\right)\left(w_{\tilde{\tilde{A}}^L}-y^*_{\tilde{\tilde{A}}^L}\right)}{2w_{\tilde{\tilde{A}}^L}} \tag{11}$$

$$y^*_{\tilde{\tilde{A}}^L}=\begin{cases}\dfrac{w_{\tilde{\tilde{A}}^L}\left(\dfrac{a_3^L-a_2^L}{a_4^L-a_1^L}+2\right)}{6}, & if\ \ a_1^L\neq a_4^L\ \ and\ 0<w_{\tilde{\tilde{A}}^L}\leq 1,\\ \dfrac{w_{\tilde{\tilde{A}}^L}}{2}, & if\ \ a_1^L=a_4^L\ \ and\ 0<w_{\tilde{\tilde{A}}^L}\leq 1.\end{cases} \tag{12}$$

$$x^*_{\tilde{\tilde{A}}^U}=\frac{y^*_{\tilde{\tilde{A}}^U}\left(a_3^U+a_2^U\right)+\left(a_4^U+a_1^U\right)\left(w_{\tilde{\tilde{A}}^U}-y^*_{\tilde{\tilde{A}}^U}\right)}{2w_{\tilde{\tilde{A}}^U}} \tag{13}$$

$$y^*_{\tilde{\tilde{A}}^U}=\begin{cases}\dfrac{w_{\tilde{\tilde{A}}^U}\left(\dfrac{a_3^U-a_2^U}{a_4^U-a_1^U}+2\right)}{6}, & if\ \ a_1^U\neq a_4^U\ \ and\ 0<w_{\tilde{\tilde{A}}^U}\leq 1,\\ \dfrac{w_{\tilde{\tilde{A}}^U}}{2}, & if\ \ a_1^U=a_4^U\ \ and\ 0<w_{\tilde{\tilde{A}}^U}\leq 1.\end{cases} \tag{14}$$

$$x^*_{\tilde{\tilde{B}}^L}=\frac{y^*_{\tilde{\tilde{B}}^L}\left(b_3^L+b_2^L\right)+\left(b_4^L+b_1^L\right)\left(w_{\tilde{\tilde{B}}^L}-y^*_{\tilde{\tilde{B}}^L}\right)}{2w_{\tilde{\tilde{B}}^L}} \tag{15}$$

$$y^*_{\tilde{\tilde{B}}^L} = \begin{cases} \dfrac{w_{\tilde{\tilde{B}}^L}\left(\dfrac{b_3^L - b_2^L}{b_4^L - b_1^L} + 2\right)}{6}, & if\ b_1^L \neq b_4^L\ and\ 0 < w_{\tilde{\tilde{B}}^L} \leq 1, \\ \dfrac{w_{\tilde{\tilde{B}}^L}}{2}, & if\ b_1^L = b_4^L\ and\ 0 < w_{\tilde{\tilde{B}}^L} \leq 1. \end{cases} \quad (16)$$

$$x^*_{\tilde{\tilde{B}}^U} = \frac{y^*_{\tilde{\tilde{B}}^U}\left(b_3^U + b_2^U\right) + \left(b_4^U + b_1^U\right)\left(w_{\tilde{\tilde{B}}^U} - y^*_{\tilde{\tilde{B}}^U}\right)}{2w_{\tilde{\tilde{B}}^U}} \quad (17)$$

$$y^*_{\tilde{\tilde{B}}^U} = \begin{cases} \dfrac{w_{\tilde{\tilde{B}}^U}\left(\dfrac{b_3^U - b_2^U}{b_4^U - b_1^U} + 2\right)}{6}, & if\ b_1^U \neq b_4^U\ and\ 0 < w_{\tilde{\tilde{B}}^U} \leq 1, \\ \dfrac{w_{\tilde{\tilde{B}}^U}}{2}, & if\ b_1^U = b_4^U\ and\ 0 < w_{\tilde{\tilde{B}}^U} \leq 1. \end{cases} \quad (18)$$

<u>Step 3:</u> Calculate the COG point $\left(x^*_{\tilde{\tilde{A}}}, y^*_{\tilde{\tilde{A}}}\right)$ of the interval-valued fuzzy number $\tilde{\tilde{A}}$, where

$$x^*_{\tilde{\tilde{A}}} = \begin{cases} \dfrac{A\left(\tilde{\tilde{A}}^U\right) \times x^*_{\tilde{\tilde{A}}^U} - A\left(\tilde{\tilde{A}}^L\right) \times x^*_{\tilde{\tilde{A}}^L}}{A\left(\tilde{\tilde{A}}^U\right) - A\left(\tilde{\tilde{A}}^L\right)}, & if\ A\left(\tilde{\tilde{A}}^U\right) - A\left(\tilde{\tilde{A}}^L\right) \neq 0, \\ 0, & otherwise. \end{cases} \quad (19)$$

$$y^*_{\tilde{\tilde{A}}} = \begin{cases} \dfrac{A\left(\tilde{\tilde{A}}^U\right) \times y^*_{\tilde{\tilde{A}}^U} - A\left(\tilde{\tilde{A}}^L\right) \times y^*_{\tilde{\tilde{A}}^L}}{A\left(\tilde{\tilde{A}}^U\right) - A\left(\tilde{\tilde{A}}^L\right)}, & if\ A\left(\tilde{\tilde{A}}^U\right) - A\left(\tilde{\tilde{A}}^L\right) \neq 0, \\ 0, & otherwise. \end{cases} \quad (20)$$

In the same way, calculate the COG point $\left(x^*_{\tilde{\tilde{B}}}, y^*_{\tilde{\tilde{B}}}\right)$ of the interval-valued fuzzy number $\tilde{\tilde{B}}$, where

$$x^*_{\tilde{\tilde{B}}} = \begin{cases} \dfrac{A\left(\tilde{\tilde{B}}^U\right) \times x^*_{\tilde{\tilde{B}}^U} - A\left(\tilde{\tilde{B}}^L\right) \times x^*_{\tilde{\tilde{B}}^L}}{A\left(\tilde{\tilde{B}}^U\right) - A\left(\tilde{\tilde{B}}^L\right)}, & if\ A\left(\tilde{\tilde{B}}^U\right) - A\left(\tilde{\tilde{B}}^L\right) \neq 0, \\ 0, & otherwise. \end{cases} \quad (21)$$

$$y^*_{\tilde{\tilde{B}}} = \begin{cases} \dfrac{A\left(\tilde{\tilde{B}}^U\right) \times y^*_{\tilde{\tilde{B}}^U} - A\left(\tilde{\tilde{B}}^L\right) \times y^*_{\tilde{\tilde{B}}^L}}{A\left(\tilde{\tilde{B}}^U\right) - A\left(\tilde{\tilde{B}}^L\right)}, & if\ A\left(\tilde{\tilde{B}}^U\right) - A\left(\tilde{\tilde{B}}^L\right) \neq 0, \\ 0, & otherwise. \end{cases} \quad (22)$$

<u>Step 4:</u> Calculate the degree of similarity $S\left(\tilde{\tilde{A}}^L, \tilde{\tilde{B}}^L\right)$ between the lower trapezoidal fuzzy numbers $\tilde{\tilde{A}}^L$ and $\tilde{\tilde{B}}^L$, shown as follows:

$$S\left(\tilde{\tilde{A}}^L, \tilde{\tilde{B}}^L\right) = \begin{cases} \left[1 - \frac{\sum_{i=1}^{4}\left|a_i^L - b_i^L\right|}{4}\right] \times \frac{\min\left(L\left(\tilde{\tilde{A}}^L\right), L\left(\tilde{\tilde{B}}^L\right)\right) + \min\left(w_{\tilde{\tilde{A}}^L}, w_{\tilde{\tilde{B}}^L}\right)}{\max\left(L\left(\tilde{\tilde{A}}^L\right), L\left(\tilde{\tilde{B}}^L\right)\right) + \max\left(w_{\tilde{\tilde{A}}^L}, w_{\tilde{\tilde{B}}^L}\right)}, & if \ \min\left(w_{\tilde{\tilde{A}}^L}, w_{\tilde{\tilde{B}}^L}\right) \neq 0, \\ 0, & otherwise. \end{cases}$$

(23)

Here,

$$L\left(\tilde{\tilde{A}}^L\right) = \sqrt{\left(a_1^L - a_2^L\right)^2 + w_{\tilde{\tilde{A}}^L}^2} + \sqrt{\left(a_3^L - a_4^L\right)^2 + w_{\tilde{\tilde{A}}^L}^2} + \left(a_3^L - a_2^L\right) + \left(a_4^L - a_1^L\right), \quad (24)$$

$$L\left(\tilde{\tilde{B}}^L\right) = \sqrt{\left(b_1^L - b_2^L\right)^2 + w_{\tilde{\tilde{B}}^L}^2} + \sqrt{\left(b_3^L - b_4^L\right)^2 + w_{\tilde{\tilde{B}}^L}^2} + \left(b_3^L - b_2^L\right) + \left(b_4^L - b_1^L\right), \quad (25)$$

Also, $S\left(\tilde{\tilde{A}}^L, \tilde{\tilde{B}}^L\right) \in [0,1]$.

Calculate the degree of similarity $S\left(\tilde{\tilde{A}}^U, \tilde{\tilde{B}}^U\right)$ between the upper trapezoidal fuzzy numbers $\tilde{\tilde{A}}^U$ and $\tilde{\tilde{B}}^U$, shown as follows:

$$S\left(\tilde{\tilde{A}}^U, \tilde{\tilde{B}}^U\right) = \begin{cases} \left[1 - \frac{\sum_{i=1}^{4}\left|a_i^U - b_i^U\right|}{4}\right] \times \frac{\min\left(L\left(\tilde{\tilde{A}}^U\right), L\left(\tilde{\tilde{B}}^U\right)\right) + \min\left(w_{\tilde{\tilde{A}}^U}, w_{\tilde{\tilde{B}}^U}\right)}{\max\left(L\left(\tilde{\tilde{A}}^U\right), L\left(\tilde{\tilde{B}}^U\right)\right) + \max\left(w_{\tilde{\tilde{A}}^U}, w_{\tilde{\tilde{B}}^U}\right)}, & if \ \min\left(w_{\tilde{\tilde{A}}^U}, w_{\tilde{\tilde{B}}^U}\right) \neq 0, \\ 0, & otherwise. \end{cases}$$

(26)

Here,

$$L\left(\tilde{\tilde{A}}^U\right) = \sqrt{\left(a_1^U - a_2^U\right)^2 + w_{\tilde{\tilde{A}}^U}^2} + \sqrt{\left(a_3^U - a_4^U\right)^2 + w_{\tilde{\tilde{A}}^U}^2} + \left(a_3^U - a_2^U\right) + \left(a_4^U - a_1^U\right), \quad (27)$$

$$L\left(\tilde{\tilde{B}}^U\right) = \sqrt{\left(b_1^U - b_2^U\right)^2 + w_{\tilde{\tilde{B}}^U}^2} + \sqrt{\left(b_3^U - b_4^U\right)^2 + w_{\tilde{\tilde{B}}^U}^2} + \left(b_3^U - b_2^U\right) + \left(b_4^U - b_1^U\right), \quad (28)$$

Also, $S\left(\tilde{\tilde{A}}^U, \tilde{\tilde{B}}^U\right) \in [0,1]$.

Step 5: Calculate the difference Δx on the x- axis and the difference Δy on the y- axis of the COG points of the interval-valued trapezoidal fuzzy numbers $\tilde{\tilde{A}}$ and $\tilde{\tilde{B}}$ shown as follows:

$$\Delta x = \begin{cases} \left|x^*_{\tilde{\tilde{A}}} - x^*_{\tilde{\tilde{B}}}\right|, & if \ A\left(\tilde{\tilde{A}}^U\right) - A\left(\tilde{\tilde{A}}^L\right) \neq 0 \ and \ A\left(\tilde{\tilde{B}}^U\right) - A\left(\tilde{\tilde{B}}^L\right) \neq 0, \\ 0, & otherwise. \end{cases} \quad (29)$$

$$\Delta y = \begin{cases} \left| y^*_{\tilde{\tilde{A}}} - y^*_{\tilde{\tilde{B}}} \right|, & \text{if } A\left(\tilde{\tilde{A}}^U\right) - A\left(\tilde{\tilde{A}}^L\right) \neq 0 \text{ and } A\left(\tilde{\tilde{B}}^U\right) - A\left(\tilde{\tilde{B}}^L\right) \neq 0, \\ 0, & \text{otherwise.} \end{cases} \tag{30}$$

Step 6: Calculate the degree of similarity $S\left(\tilde{\tilde{A}}, \tilde{\tilde{B}}\right)$ between the interval-valued trapezoidal fuzzy numbers $\tilde{\tilde{A}}$ and $\tilde{\tilde{B}}$ as follows:

$$S\left(\tilde{\tilde{A}}, \tilde{\tilde{B}}\right) = \left[\frac{S\left(\tilde{\tilde{A}}^L, \tilde{\tilde{B}}^L\right) + S\left(\tilde{\tilde{A}}^U, \tilde{\tilde{B}}^U\right)}{2} \times (1 - \Delta x) \times (1 - \Delta y) \right]^{\left(\frac{1}{1+2t}\right)} \times \left(1 - \left| w^U_{\tilde{\tilde{A}}} - w^U_{\tilde{\tilde{B}}} - w^L_{\tilde{\tilde{A}}} + w^L_{\tilde{\tilde{B}}} \right| \right)^{\frac{u}{2}}, \tag{31}$$

Here,

$$t = \begin{cases} 1, & \text{if } A\left(\tilde{\tilde{A}}^U\right) - A\left(\tilde{\tilde{A}}^L\right) \neq 0 \text{ and } A\left(\tilde{\tilde{B}}^U\right) - A\left(\tilde{\tilde{B}}^L\right) \neq 0, \\ 0, & \text{otherwise.} \end{cases} \tag{32}$$

$$u = \begin{cases} 1, & \text{if } a_1^U = a_4^U \text{ and } b_1^U = b_4^U, \\ 0, & \text{otherwise.} \end{cases} \tag{33}$$

Also, $S\left(\tilde{\tilde{A}}, \tilde{\tilde{B}}\right) \in [0,1]$. The larger the value of $S\left(\tilde{\tilde{A}}, \tilde{\tilde{B}}\right)$, the more the similarity between the interval-valued trapezoidal fuzzy numbers $\tilde{\tilde{A}}$ and $\tilde{\tilde{B}}$.

3. Implementation of Proposed Appraisement Module: Case Study

Agility evaluation has been made by the procedural framework as described as follows. The evaluation framework is based on an agile capabler-attribute-criterion hierarchy adapted from the work by (Seyedhoseini et al., 2010).

3.1 Determination of the appropriate linguistic scale for assessing the performance ratings and importance weights of agile attributes

The linguistic terms are used to assess the performance ratings and priority weights of agile attributes since vagueness is associated with individualsô subjective opinion, it is difficult for the decision-makers to determine the exact numeric score against an attribute. In order to assess the performance rating of the agile criterions from Table 1 (3^{rd} level indices), the nine linguistic variables {***Absolutely Poor (AP), Very Poor (VP), Poor (P), Medium Poor (MP), Medium (M), Medium Good (MG), Good (G), Very Good (VG) and Absolutely Good (AG)***} have been used (Table 2). Similarly, to assign importance weights (priority degree) of the agile capabilities-attributes and criterions, the linguistic variables {***Absolutely Low (AL), Very Low (VL), Low (L), Medium Low (ML), Medium (M), Medium High (MH), High (H), Very High (VH), Absolutely High (AH)***} have been utilized (Table 2). The linguistic variables have been accepted among the DMs of the enterprise taking into consideration the company policy, company characteristics, business changes and competitive situation.

3.2 Measurement of performance ratings and importance weights of agile attributes using linguistic terms

After the linguistic variables for assessing the performance ratings and importance weights of agile parameters has been accepted by the decision-makers (DMs), the decision-makers have been asked to use aforesaid linguistic scales to assess the performance rating as well as to assign importance weights (Tables 3-6).

3.3 Approximation of the linguistic terms by generalized IV trapezoidal fuzzy numbers

Using the concept of generalized IV trapezoidal fuzzy numbers in fuzzy set theory, the linguistic variables have been be approximated by trapezoidal fuzzy numbers (shown in Table 2). Next, the aggregated decision-making cum evaluation matrix has been constructed. The aggregated fuzzy appropriateness rating against each agile criterions (3rd level indices) attribute has been shown in Table 7 with corresponding fuzzy importance weight. Aggregated fuzzy priority weight of agile attributes (2nd level indices) as well as enablers/capabilities (1st level indices) given by decision-makers has been furnished in Table 8-9.

3.4 Determination of FPI

FPI represents the *Fuzzy Performance Index*. The fuzzy index has been calculated at the attribute level and then extended to enabler level. Fuzzy index system (at 2nd level) encompasses several agile attributes (Table 1).

The fuzzy index (appropriateness rating) of each agile attribute (at 2nd level) has been calculated as follows:

$$U_{i,j} = \frac{\sum_{k=1}^{n}\left(w_{i,j,k} \otimes U_{i,j,k}\right)}{\sum_{k=1}^{n} w_{i,j,k}} \tag{34}$$

Here $U_{i,j,k}$ represent aggregated fuzzy performance measure (rating) and $w_{i,j,k}$ represent aggregated fuzzy weight corresponding to agile criterion $C_{i,j,k}$ which is under j_{th} agile attribute (at 2nd level) and i_{th} agile capability (at 1st level).

The fuzzy index of each agile capability/enabler (at 1st level) has been calculated as follows:

$$U_{i} = \frac{\sum_{j=1}^{n}\left(w_{i,j} \otimes U_{i,j}\right)}{\sum_{j=1}^{n} w_{i,j}} \tag{35}$$

Here $U_{i,j}$ represent computed fuzzy performance measure (rating) obtained using Eq. (34) and $w_{i,j}$ represent aggregated fuzzy weight for priority importance corresponding to j_{th} agile attribute $C_{i,j}$ which is under i_{th} agile capability (at 1st level).

Thus, fuzzy performance index $U(FPI)$ has been calculated as follows:

$$U(FPI) = \frac{\sum_{i=1}^{n} (w_i \otimes U_i)}{\sum_{i=1}^{n} w_i} \quad (36)$$

Here U_i =Computed fuzzy performance rating of i^{th} agile capability C_i (computed by Eq. (35); w_i =Aggregated fuzzy weight of i^{th} agile capability, and $i = 1, 2, 3, \ldots n$.

Computed fuzzy appropriateness ratings of different agile attributes (at 2nd level) as well as agile enablers (at 1st level) have been furnished in Table 8 and 9, respectively. Finally, Eq. (36) has been explored to calculate overall agile estimate.

Fuzzy Performance Index becomes: (035, 0.52, 1.25, 1.79; 0.80), (035, 0.52, 1.25, 1.79; 1.00)

4. Identification of Agile Barriers

After evaluating FPI and the organizational existing agility extent, simultaneously it is also felt indeed necessary to identify and analyze the obstacles (ill-performing areas) for agility improvement. Fuzzy Performance Importance Index (FPII) may be used to identify these obstacles. FPII combines the performance rating and importance weight of agile criterions. The higher the FPII of a factor, the higher is the contribution. The FPII can be calculated as follows (Lin et al., 2006):

$$FPII_{i,j,k} = w'_{i,j,k} \otimes U_{i,j,k} \quad (37)$$

Here, $w'_{i,j,k} = [(1,1,1,1;1) - w_{i,j,k}]$ (38)

In this formulation, $U_{i,j,k}$ represent aggregated fuzzy performance measure (rating) and $w_{i,j,k}$ represent aggregated fuzzy weight corresponding to agile criterion $C_{i,j,k}$ which is under j_{th} agile attribute (at 2nd level) and i_{th} agile capability (at 1st level).

FPII need to be ranked to identify individual criterion performance level. Based on that poorly performing criterions are identified and in future, attention must be given to improve those criteria aspects in order to boost up overall agility degree.

Computed FPII against each agile criterions has been tabulated (Table 10). Ranking scores based on ‗degree of similarity' (between individual FPIIs with respect to ideal FPII) have been furnished in Table 11, Fig. 2. Ranking provides necessary information about comparative performance picture of existing agile criterions. By this way, ill-performing areas can be sorted out. Industry should find feasible means to improve performance in those areas to boost up overall agility degree in future.

5. Managerial Implications and Conclusions

Agile paradigm has become an important avenue in recent times. Many organizations around the world have been attempting to implement agile concepts in their supply chain. The agility metric is an important indicator in agile performance measure. Aforesaid study aimed to develop a quantitative analysis framework and a simulation methodology to evaluate the efficacy of agile practices by exploring the concept of Interval-Valued Fuzzy numbers. The procedural hierarchy presented here could help the industries to assess their existing agile performance extent, to compare and to identify week-performing areas towards implementing agility successfully.

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Table 1: The conceptual model for agility appraisement

Goal	1st Grade (Agile capabilities)	2nd Grade (Agile attributes)	3rd Grade (Agile criterions)
Supply Chain Agility 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}	Flexible manufacturing system C_{121}
			CAM based manufacturing C_{122}
			Variety and volume of productions C_{123}
		Delivery Flexibility C_{13}	Variety of supply schedules for meeting customersô needs C_{131}
			Flexibility in volume of product C_{132}
			Provision of after-sales service C_{133}
	Responsiveness C_2	Sourcing Responsiveness C_{21}	Adaptability of delivery time by suppliers C_{211}
			Suppliersô 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}	Achievement of advised delivery C_{231}
			New product-to-market time C_{232}
			Customer service C_{233}
	Competency C_3	Cooperation and Internal-External Balance C_{31}	Cooperation and Internal-External Balance C_{311}
		Manufacturing Competency C_{32}	New product introduce C_{321}
			Quality of products and services C_{322}
			Integration C_{323}
			Time of new product development C_{324}
		Capabilities of human resources C_{33}	Capabilities 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_{4222}
			The cost of changing parts C_{423}
		Delivery Cost C_{43}	Delivery Cost C_{431}

Table 2: Definitions of linguistic variables for criteria ratings (A-9 member interval linguistic term set)

Linguistic terms (Attribute/criteria ratings)	Linguistic terms (Priority weights)	Generalized interval-valued trapezoidal fuzzy numbers
Absolutely Poor (AP)	Absolutely Low (AL)	[(0, 0, 0, 0; 0.8), (0, 0, 0, 0; 1)]
Very Poor (VP)	Very Low (VL)	[(0, 0, 0.02, 0.07; 0.8), (0, 0, 0.02, 0.07; 1)]
Poor (P)	Low (L)	[(0.04, 0.10, 0.18, 0.23; 0.8), (0.04, 0.10, 0.18, 0.23; 1)]
Medium Poor (MP)	Medium Low (ML)	[(0.17, 0.22, 0.36, 0.42; 0.8), (0.17, 0.22, 0.36, 0.42; 1)]
Medium (M)	Medium (M)	[(0.32, 0.41, 0.58, 0.65; 0.8), (0.32, 0.41, 0.58, 0.65; 1)]
Medium Good (MG)	Medium High (MH)	[(0.58, 0.63, 0.80, 0.86; 0.8), (0.58, 0.63, 0.80, 0.86; 1)]
Good (G)	High (H)	[(0.72, 0.78, 0.92, 0.97; 0.8), (0.72, 0.78, 0.92, 0.97; 1)]
Very Good (VG)	Very High (VH)	[(0.93, 0.98, 1, 1; 0.8), (0.93, 0.98, 1, 1; 1)]
Absolutely Good (AG)	Absolutely High (AH)	[(1, 1, 1, 1; 0.8), (1, 1, 1, 1; 1)]

Table 3: Appropriateness rating of agile criterions given by decision-makers

Agile criterions C_{ijk}	Appropriateness rating (In Linguistic terms) as given by decision-makers				
	DM1	DM2	DM3	DM4	DM5
C_{111}	VG	VG	G	AG	VG
C_{112}	G	G	G	G	G
C_{113}	G	VG	G	VG	VG
C_{121}	MG	MG	G	MG	MG
C_{122}	M	M	G	M	M
C_{123}	VG	VG	G	VG	VG
C_{131}	MG	G	G	G	MG
C_{132}	G	G	G	G	G
C_{133}	G	G	G	G	G
C_{211}	VG	VG	G	G	G
C_{212}	M	MG	G	G	M
C_{213}	MG	MG	MG	MG	MG
C_{221}	G	G	G	G	G
C_{222}	VG	AG	AG	AG	VG
C_{231}	G	G	G	G	G
C_{232}	G	VG	VG	G	VG
C_{233}	MG	M	M	M	M
C_{311}	MP	M	M	M	MP
C_{321}	G	G	G	G	G
C_{322}	G	G	G	G	G
C_{323}	VG	AG	AG	AG	AG
C_{324}	VG	VG	G	G	G
C_{331}	G	G	G	G	VG
C_{411}	AG	G	VG	VG	G
C_{421}	M	M	MG	MG	MG
C_{4222}	G	G	G	G	G
C_{423}	G	G	G	G	MG
C_{431}	VG	G	G	G	G

Table 4: Priority weight of agile criterions given by decision-makers

Agile criterions C_{ijk}	Priority Weight (In Linguistic terms) as given by decision-makers				
	DM1	DM2	DM3	DM4	DM5
C_{111}	AH	AH	AH	VH	VH
C_{112}	H	H	H	H	H
C_{113}	MH	H	H	H	H
C_{121}	MH	H	MH	H	H
C_{122}	VH	VH	VH	VH	VH
C_{123}	H	H	H	H	H
C_{131}	MH	MH	H	H	MH
C_{132}	AH	AH	AH	AH	AH
C_{133}	H	H	H	H	H
C_{211}	M	ML	M	MH	MH
C_{212}	H	VH	H	VH	H
C_{213}	H	H	H	H	H
C_{221}	VH	AH	VH	H	H
C_{222}	MH	H	H	H	H
C_{231}	VH	H	VH	H	VH
C_{232}	H	H	H	H	H
C_{233}	H	H	H	H	H
C_{311}	H	H	H	VH	VH
C_{321}	MH	MH	H	H	MH
C_{322}	H	H	H	H	H
C_{323}	H	H	H	H	H
C_{324}	VH	AH	VH	H	H
C_{331}	MH	H	H	H	H
C_{411}	VH	H	VH	H	VH
C_{421}	MH	H	H	H	H
C_{4222}	MH	H	MH	H	H
C_{423}	VH	VH	VH	VH	VH
C_{431}	H	H	H	H	H

Table 5: Priority weight of agile attributes given by decision-makers

Agile attributes C_{ij}	Priority Weight (In Linguistic terms) as given by decision-makers				
	DM1	DM2	DM3	DM4	DM5
C_{11}	H	H	H	H	H
C_{12}	AH	H	H	AH	H
C_{13}	MH	MH	MH	MH	H
C_{21}	MH	H	VH	VH	VH
C_{22}	H	AH	H	H	H
C_{23}	M	MH	MH	MH	H
C_{31}	H	H	H	VH	VH
C_{32}	H	H	H	H	H
C_{33}	MH	H	H	H	H
C_{41}	VH	H	VH	H	VH
C_{42}	H	H	H	H	VH
C_{43}	H	H	H	H	H

Table 6: Priority weight of agile capabilities/enablers given by decision-makers

Agile enablers C_i	Priority weight (In Linguistic terms) as given by decision-makers				
	DM1	DM2	DM3	DM4	DM5
C_1	VH	VH	H	VH	H
C_2	AH	AH	AH	AH	VH
C_3	H	H	H	H	H
C_4	MH	H	MH	VH	H

Table 7: Aggregated rating and aggregated priority weight of agile criterions

Agile criterions C_{ijk}	Aggregated rating of agile criterions	Aggregated weight of agile criterions
C_{111}	(0.90, 0.94, 0.98, 0.99; 0.80), (0.90, 0.94, 0.98, 0.99; 1.00)	(0.97, 0.99, 1.00, 1.00; 0.80), (0.97, 0.99, 1.00, 1.00; 1.00)
C_{112}	(0.72, 0.78, 0.92, 0.97; 0.80), (0.72, 0.78, 0.92, 0.97; 1.00)	(0.72, 0.78, 0.92, 0.97; 0.80), (0.72, 0.78, 0.92, 0.97; 1.00)
C_{113}	(0.85, 0.90, 0.97, 0.99; 0.80), (0.85, 0.90, 0.97, 0.99; 1.00)	(0.69, 0.75, 0.90, 0.95; 0.80), (0.69, 0.75, 0.90, 0.95; 1.00)
C_{121}	(0.61, 0.66, 0.82, 0.88; 0.80), (0.61, 0.66, 0.82, 0.88; 1.00)	(0.66, 0.72, 0.87, 0.93; 0.80), (0.66, 0.72, 0.87, 0.93; 1.00)
C_{122}	(0.40, 0.48, 0.65, 0.71; 0.80), (0.40, 0.48, 0.65, 0.71; 1.00)	(0.93, 0.98, 1.00, 1.00; 0.80), (0.93, 0.98, 1.00, 1.00; 1.00)
C_{123}	(0.89, 0.94, 0.98, 0.99; 0.80), (0.89, 0.94, 0.98, 0.99; 1.00)	(0.72, 0.78, 0.92, 0.97; 0.80), (0.72, 0.78, 0.92, 0.97; 1.00)
C_{131}	(0.66, 0.72, 0.87, 0.93; 0.80), (0.66, 0.72, 0.87, 0.93; 1.00)	(0.64, 0.69, 0.85, 0.90; 0.80), (0.64, 0.69, 0.85, 0.90; 1.00)
C_{132}	(0.72, 0.78, 0.92, 0.97; 0.80), (0.72, 0.78, 0.92, 0.97; 1.00)	(1.00, 1.00, 1.00, 1.00; 0.80), (1.00, 1.00, 1.00, 1.00; 1.00)
C_{133}	(0.72, 0.78, 0.92, 0.97; 0.80), (0.72, 0.78, 0.92, 0.97; 1.00)	(0.72, 0.78, 0.92, 0.97; 0.80), (0.72, 0.78, 0.92, 0.97; 1.00)
C_{211}	(0.80, 0.86, 0.95, 0.98; 0.80), (0.80, 0.86, 0.95, 0.98; 1.00)	(0.39, 0.46, 0.62, 0.69; 0.80), (0.39, 0.46, 0.62, 0.69; 1.00)
C_{212}	(0.53, 0.60, 0.76, 0.82; 0.80), (0.53, 0.60, 0.76, 0.82; 1.00)	(0.80, 0.86, 0.95, 0.98; 0.80), (0.80, 0.86, 0.95, 0.98; 1.00)
C_{213}	(0.58, 0.63, 0.80, 0.86; 0.80), (0.58, 0.63, 0.80, 0.86; 1.00)	(0.72, 0.78, 0.92, 0.97; 0.80), (0.72, 0.78, 0.92, 0.97; 1.00)
C_{221}	(0.72, 0.78, 0.92, 0.97; 0.80), (0.72, 0.78, 0.92, 0.97; 1.00)	(0.86, 0.90, 0.97, 0.99; 0.80), (0.86, 0.90, 0.97, 0.99; 1.00)
C_{222}	(0.97, 0.99, 1.00, 1.00; 0.80), (0.97, 0.99, 1.00, 1.00; 1.00)	(0.69, 0.75, 0.90, 0.95; 0.80), (0.69, 0.75, 0.90, 0.95; 1.00)
C_{231}	(0.72, 0.78, 0.92, 0.97; 0.80), (0.72, 0.78, 0.92, 0.97; 1.00)	(0.85, 0.90, 0.97, 0.99; 0.80), (0.85, 0.90, 0.97, 0.99; 1.00)
C_{232}	(0.85, 0.90, 0.97, 0.99; 0.80), (0.85, 0.90, 0.97, 0.99; 1.00)	(0.72, 0.78, 0.92, 0.97; 0.80), (0.72, 0.78, 0.92, 0.97; 1.00)
C_{233}	(0.37, 0.45, 0.62, 0.69; 0.80), (0.37, 0.45, 0.62, 0.69; 1.00)	(0.72, 0.78, 0.92, 0.97; 0.80), (0.72, 0.78, 0.92, 0.97; 1.00)
C_{311}	(0.26, 0.33, 0.49, 0.56; 0.80), (0.26, 0.33, 0.49, 0.56; 1.00)	(0.80, 0.86, 0.95, 0.98; 0.80), (0.80, 0.86, 0.95, 0.98; 1.00)
C_{321}	(0.72, 0.78, 0.92, 0.97; 0.80), (0.72, 0.78, 0.92, 0.97; 1.00)	(0.64, 0.69, 0.85, 0.90; 0.80), (0.64, 0.69, 0.85, 0.90; 1.00)
C_{322}	(0.72, 0.78, 0.92, 0.97; 0.80), (0.72, 0.78, 0.92, 0.97; 1.00)	(0.72, 0.78, 0.92, 0.97; 0.80), (0.72, 0.78, 0.92, 0.97; 1.00)
C_{323}	(0.99, 1.00, 1.00, 1.00; 0.80), (0.99, 1.00, 1.00, 1.00; 1.00)	(0.72, 0.78, 0.92, 0.97; 0.80), (0.72, 0.78, 0.92, 0.97; 1.00)
C_{324}	(0.80, 0.86, 0.95, 0.98; 0.80), (0.80, 0.86, 0.95, 0.98; 1.00)	(0.86, 0.90, 0.97, 0.99; 0.80), (0.86, 0.90, 0.97, 0.99; 1.00)
C_{331}	(0.76, 0.82, 0.94, 0.98; 0.80), (0.76, 0.82, 0.94, 0.98; 1.00)	(0.69, 0.75, 0.90, 0.95; 0.80), (0.69, 0.75, 0.90, 0.95; 1.00)
C_{411}	(0.86, 0.90, 0.97, 0.99; 0.80), (0.86, 0.90, 0.97, 0.99; 1.00)	(0.85, 0.90, 0.97, 0.99; 0.80), (0.85, 0.90, 0.97, 0.99; 1.00)
C_{421}	(0.48, 0.54, 0.71, 0.78; 0.80), (0.48, 0.54, 0.71, 0.78; 1.00)	(0.69, 0.75, 0.90, 0.95; 0.80), (0.69, 0.75, 0.90, 0.95; 1.00)
C_{4222}	(0.72, 0.78, 0.92, 0.97; 0.80), (0.72, 0.78, 0.92, 0.97; 1.00)	(0.66, 0.72, 0.87, 0.93; 0.80), (0.66, 0.72, 0.87, 0.93; 1.00)
C_{423}	(0.69, 0.75, 0.90, 0.95; 0.80), (0.69, 0.75, 0.90, 0.95; 1.00)	(0.93, 0.98, 1.00, 1.00; 0.80), (0.93, 0.98, 1.00, 1.00; 1.00)
C_{431}	(0.76, 0.82, 0.94, 0.98; 0.80), (0.76, 0.82, 0.94, 0.98; 1.00)	(0.72, 0.78, 0.92, 0.97; 0.80), (0.72, 0.78, 0.92, 0.97; 1.00)

Table 8: Aggregated priority weight and computed rating of agile attributes

Agile attributes C_{ij}	Aggregated weight of agile attributes	Computed rating of agile attributes
C_{11}	(0.72, 0.78, 0.92, 0.97; 0.80), (0.72, 0.78, 0.92, 0.97; 1.00)	(0.68, 0.79, 1.07, 1.20; 0.80), (0.68, 0.79, 1.07, 1.20; 1.00)
C_{12}	(0.83, 0.87, 0.95, 0.98; 0.80), (0.83, 0.87, 0.95, 0.98; 1.00)	(0.49, 0.60, 0.92, 1.08; 0.80), (0.49, 0.60, 0.92, 1.08; 1.00)
C_{13}	(0.61, 0.66, 0.82, 0.88; 0.80), (0.61, 0.66, 0.82, 0.88; 1.00)	(0.58, 0.68, 1.01, 1.17; 0.80), (0.58, 0.68, 1.01, 1.17; 1.00)
C_{21}	(0.82, 0.87, 0.94, 0.97; 0.80), (0.82, 0.87, 0.94, 0.97; 1.00)	(0.44, 0.56, 0.98, 1.21; 0.80), (0.44, 0.56, 0.98, 1.21; 1.00)
C_{22}	(0.78, 0.82, 0.94, 0.98; 0.80), (0.78, 0.82, 0.94, 0.98; 1.00)	(0.67, 0.78, 1.08, 1.23; 0.80), (0.67, 0.78, 1.08, 1.23; 1.00)
C_{23}	(0.56, 0.62, 0.78, 0.84; 0.80), (0.56, 0.62, 0.78, 0.84; 1.00)	(0.51, 0.63, 0.96, 1.13; 0.80), (0.51, 0.63, 0.96, 1.13; 1.00)
C_{31}	(0.80, 0.86, 0.95, 0.98; 0.80), (0.80, 0.86, 0.95, 0.98; 1.00)	(0.21, 0.30, 0.54, 0.68; 0.80), (0.21, 0.30, 0.54, 0.68; 1.00)
C_{32}	(0.72, 0.78, 0.92, 0.97; 0.80), (0.72, 0.78, 0.92, 0.97; 1.00)	(0.62, 0.74, 1.,10, 1.28; 0.80), (0.62, 0.74, 1.10, 1.28; 1.00)
C_{33}	(0.69, 0.75, 0.90, 0.95; 0.80), (0.69, 0.75, 0.90, 0.95; 1.00)	(0.56, 0.69, 1.12, 1.34; 0.80), (0.56, 0.69, 1.12, 1.34; 1.00)
C_{41}	(0.85, 0.90, 0.97, 0.99; 0.80), (0.85, 0.90, 0.97, 0.99; 1.00)	(0.74, 0.84, 1.04, 1.15; 0.80), (0.74, 0.84, 1.04, 1.15; 1.00)
C_{42}	(0.76, 0.82, 0.94, 0.98; 0.80), (0.76, 0.82, 0.94, 0.98; 1.00)	(0.50, 0.62, 0.95, 1.13; 0.80), (0.50, 0.62, 0.95, 1.13; 1.00)
C_{43}	(0.72, 0.78, 0.92, 0.97; 0.80), (0.72, 0.78, 0.92, 0.97; 1.00)	(0.57, 0.70, 1.10, 1.31; 0.80), (0.57, 0.70, 1.10, 1.31; 1.00)

Table 9: Aggregated priority weight and computed rating of agile enablers

Agile enablers C_i	Aggregated weight of agile capabilities	Computed rating of agile capabilities
C_1	(0.85, 0.90, 0.97, 0.99; 0.80), (0.85, 0.90, 0.97, 0.99; 1.00)	(0.44, 0.59, 1.17, 1.51; 0.80), (0.44, 0.59, 1.17, 1.51; 1.00)
C_2	(0.99, 1.00, 1.00, 1.00; 0.80), (0.99, 1.00, 1.00, 1.00; 1.00)	(0.42, 0.57, 1.16, 1.54; 0.80), (0.42, 0.57, 1.16, 1.54; 1.00)
C_3	(0.72, 0.78, 0.92, 0.97; 0.80), (0.72, 0.78, 0.92, 0.97; 1.00)	(0.35, 0.49, 1.06, 1.43; 0.80), (0.35, 0.49, 1.06, 1.43; 1.00)
C_4	(0.71, 0.76, 0.89, 0.93; 0.80), (0.71, 0.76, 0.89, 0.93; 1.00)	(0.48, 0.64, 1.17, 1.51; 0.80), (0.48, 0.64, 1.17, 1.51; 1.00)

Table 10: Estimation of FPII of agile criterions

Agile criterion C_{ijk}	$w'_{i,j,k} = [(1,1,1,1;1) - w_{i,j,k}]$	Fuzzy Performance Importance Index (FPII) $w'_{i,j,k} \otimes U_{i,j,k}$
C_{111}	(0.000, 0.000, 0.008, 0.028; 0.800), (0.000, 0.000, 0.008, 0.028; 1.000)	(0.000, 0.000, 0.008, 0.028; 0.800), (0.000, 0.000, 0.008, 0.028; 1.000)
C_{112}	(0.030, 0.080, 0.220, 0.280; 0.800), (0.030, 0.080, 0.220, 0.280; 1.000)	(0.022, 0.062, 0.202, 0.272; 0.800), (0.022, 0.062, 0.202, 0.272; 1.000)
C_{113}	(0.052, 0.104, 0.250, 0.308; 0.800), (0.052, 0.104, 0.250, 0.308; 1.000)	(0.044, 0.094, 0.242, 0.304; 0.800), (0.044, 0.094, 0.242, 0.304; 1.000)
C_{121}	(0.074, 0.128, 0.280, 0.336; 0.800), (0.074, 0.128, 0.280, 0.336; 1.000)	(0.045, 0.084, 0.231, 0.296; 0.800), (0.045, 0.084, 0.231, 0.296; 1.000)
C_{122}	(0.000, 0.000, 0.020, 0.070; 0.800), (0.000, 0.000, 0.020, 0.070; 1.000)	(0.000, 0.000, 0.013, 0.050; 0.800), (0.000, 0.000, 0.013, 0.050; 1.000)
C_{123}	(0.030, 0.080, 0.220, 0.280; 0.800), (0.030, 0.080, 0.220, 0.280; 1.000)	(0.027, 0.075, 0.216, 0.278; 0.800), (0.027, 0.075, 0.216, 0.278; 1.000)
C_{131}	(0.096, 0.152, 0.310, 0.364; 0.800), (0.096, 0.152, 0.310, 0.364; 1.000)	(0.064, 0.109, 0.270, 0.337; 0.800), (0.064, 0.109, 0.270, 0.337; 1.000)
C_{132}	(0.000, 0.000, 0.000, 0.000; 0.800), (0.000, 0.000, 0.000, 0.000; 1.000)	(0.000, 0.000, 0.000, 0.000; 0.800), (0.000, 0.000, 0.000, 0.000; 1.000)
C_{133}	(0.030, 0.080, 0.220, 0.280; 0.800), (0.030, 0.080, 0.220, 0.280; 1.000)	(0.022, 0.062, 0.202, 0.272; 0.800), (0.022, 0.062, 0.202, 0.272; 1.000)
C_{211}	(0.312, 0.376, 0.540, 0.606; 0.800), (0.312, 0.376, 0.540, 0.606; 1.000)	(0.251, 0.323, 0.514, 0.595; 0.800), (0.251, 0.323, 0.514, 0.595; 1.000)
C_{212}	(0.018, 0.048, 0.140, 0.196; 0.800), (0.018, 0.048, 0.140, 0.196; 1.000)	(0.010, 0.029, 0.106, 0.161; 0.800), (0.010, 0.029, 0.106, 0.161; 1.000)
C_{213}	(0.030, 0.080, 0.220, 0.280; 0.800), (0.030, 0.080, 0.220, 0.280; 1.000)	(0.017, 0.050, 0.176, 0.241; 0.800), (0.017, 0.050, 0.176, 0.241; 1.000)
C_{221}	(0.012, 0.032, 0.096, 0.140; 0.800), (0.012, 0.032, 0.096, 0.140; 1.000)	(0.009, 0.025, 0.088, 0.136; 0.800), (0.009, 0.025, 0.088, 0.136; 1.000)
C_{222}	(0.052, 0.104, 0.250, 0.308; 0.800), (0.052, 0.104, 0.250, 0.308; 1.000)	(0.051, 0.103, 0.250, 0.308; 0.800), (0.051, 0.103, 0.250, 0.308; 1.000)
C_{231}	(0.012, 0.032, 0.100, 0.154; 0.800), (0.012, 0.032, 0.100, 0.154; 1.000)	(0.009, 0.025, 0.092, 0.149; 0.800), (0.009, 0.025, 0.092, 0.149; 1.000)
C_{232}	(0.030, 0.080, 0.220, 0.280; 0.800), (0.030, 0.080, 0.220, 0.280; 1.000)	(0.025, 0.072, 0.213, 0.277; 0.800), (0.025, 0.072, 0.213, 0.277; 1.000)
C_{233}	(0.030, 0.080, 0.220, 0.280; 0.800), (0.030, 0.080, 0.220, 0.280; 1.000)	(0.011, 0.036, 0.137, 0.194; 0.800), (0.011, 0.036, 0.137, 0.194; 1.000)
C_{311}	(0.018, 0.048, 0.140, 0.196; 0.800), (0.018, 0.048, 0.140, 0.196; 1.000)	(0.005, 0.016, 0.069, 0.109; 0.800), (0.005, 0.016, 0.069, 0.109; 1.000)
C_{321}	(0.096, 0.152, 0.310, 0.364; 0.800), (0.096, 0.152, 0.310, 0.364; 1.000)	(0.069, 0.119, 0.285, 0.353; 0.800), (0.069, 0.119, 0.285, 0.353; 1.000)
C_{322}	(0.030, 0.080, 0.220, 0.280; 0.800), (0.030, 0.080, 0.220, 0.280; 1.000)	(0.022, 0.062, 0.202, 0.272; 0.800), (0.022, 0.062, 0.202, 0.272; 1.000)
C_{323}	(0.030, 0.080, 0.220, 0.280; 0.800), (0.030, 0.080, 0.220, 0.280; 1.000)	(0.030, 0.080, 0.220, 0.280; 0.800), (0.030, 0.080, 0.220, 0.280; 1.000)
C_{324}	(0.012, 0.032, 0.096, 0.140; 0.800), (0.012, 0.032, 0.096, 0.140; 1.000)	(0.010, 0.028, 0.091, 0.137; 0.800), (0.010, 0.028, 0.091, 0.137; 1.000)
C_{331}	(0.052, 0.104, 0.250, 0.308; 0.800), (0.052, 0.104, 0.250, 0.308; 1.000)	(0.040, 0.085, 0.234, 0.301; 0.800), (0.040, 0.085, 0.234, 0.301; 1.000)
C_{411}	(0.012, 0.032, 0.100, 0.154; 0.800), (0.012, 0.032, 0.100, 0.154; 1.000)	(0.010, 0.029, 0.097, 0.152; 0.800), (0.010, 0.029, 0.097, 0.152; 1.000)
C_{421}	(0.052, 0.104, 0.250, 0.308; 0.800), (0.052, 0.104, 0.250, 0.308; 1.000)	(0.025, 0.056, 0.178, 0.239; 0.800), (0.025, 0.056, 0.178, 0.239; 1.000)
C_{4222}	(0.074, 0.128, 0.280, 0.336; 0.800), (0.074, 0.128, 0.280, 0.336; 1.000)	(0.053, 0.100, 0.258, 0.326; 0.800), (0.053, 0.100, 0.258, 0.326; 1.000)
C_{423}	(0.000, 0.000, 0.020, 0.070; 0.800), (0.000, 0.000, 0.020, 0.070; 1.000)	(0.000, 0.000, 0.018, 0.066; 0.800), (0.000, 0.000, 0.018, 0.066; 1.000)
C_{431}	(0.030, 0.080, 0.220, 0.280; 0.800), (0.030, 0.080, 0.220, 0.280; 1.000)	(0.023, 0.066, 0.206, 0.273; 0.800), (0.023, 0.066, 0.206, 0.273; 1.000)

Ideal Fuzzy Performance Importance Index (FPII) = (0.251, 0.323, 0.514, 0.595; 0.800),(0.251, 0.323, 0.514, 0.595; 1.000)

Table 11: Agile criteria ranking based on DOS between two IVFNs

Agile Criterions $C_{i,j,k}$	Degree of Similarity with respect to ideal FPII	Ranking
C_{111}	0.6448	25
C_{112}	0.7896	13
C_{113}	0.8131	6
C_{121}	0.8064	8
C_{122}	0.6507	24
C_{123}	0.7966	10
C_{131}	0.8313	3
C_{132}	0.0652	26
C_{133}	0.7896	13
C_{211}	1.0000	1
C_{212}	0.7268	17
C_{213}	0.7725	15
C_{221}	0.7137	21
C_{222}	0.8176	5
C_{231}	0.7169	19
C_{232}	0.7948	11
C_{233}	0.7478	16
C_{311}	0.7005	22
C_{321}	0.8410	2
C_{322}	0.7896	13
C_{323}	0.7987	9
C_{324}	0.7154	20
C_{331}	0.8089	7
C_{411}	0.7196	18
C_{421}	0.7733	14
C_{4222}	0.8239	4
C_{423}	0.6574	23
C_{431}	0.7914	12

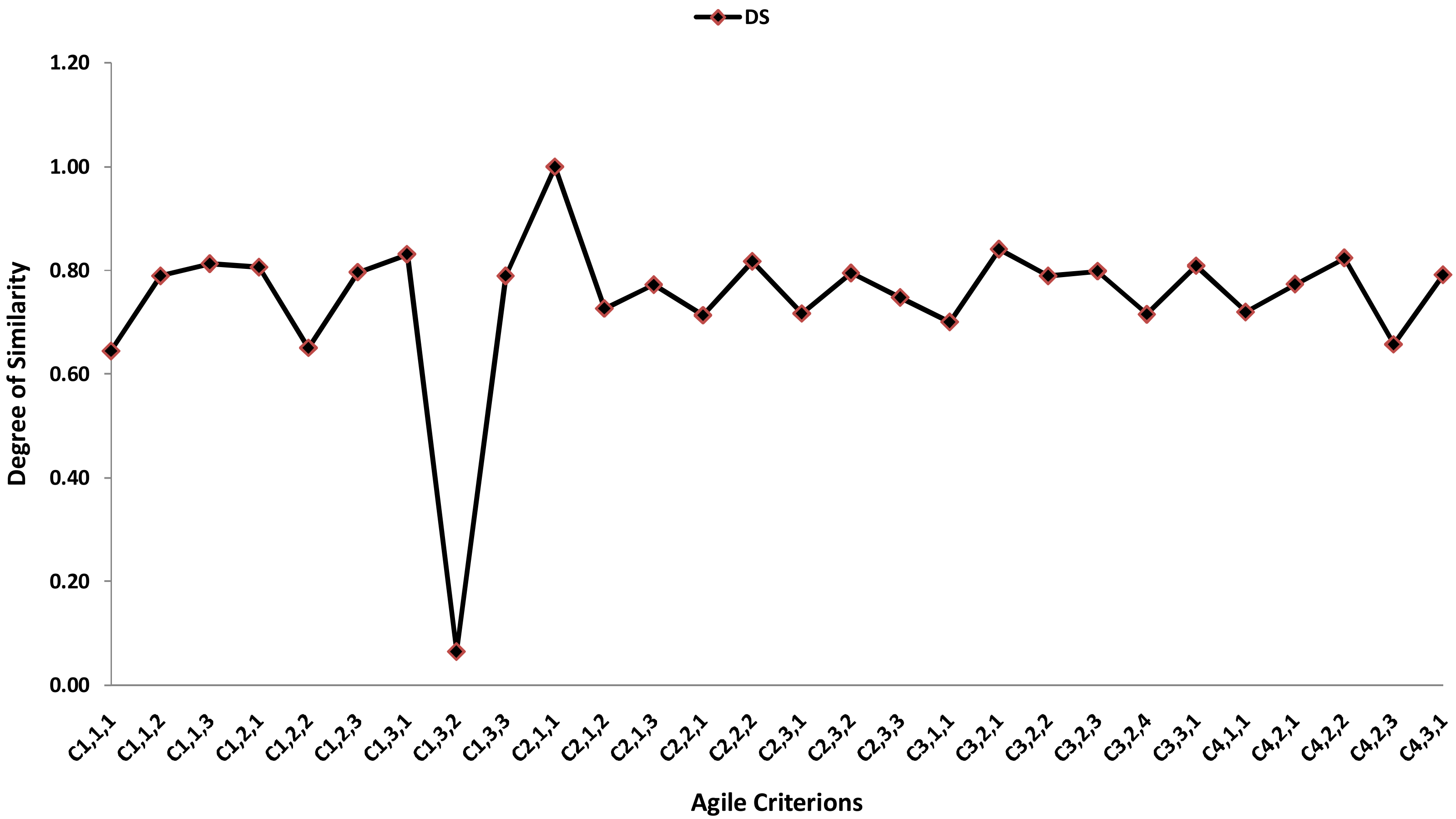

Fig. 2: Ranking of agile criteria based on Degree of Similarity