Applied Mathematical Modelling 38 (2014) 1052–1063

Contents lists available at ScienceDirect

Applied Mathematical Modelling

journal homepage: www.elsevier.com/locate/apm

Application of fuzzy compromise solution method for fit concept selection

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ARTICLE INFO

Article history:
Received 2 August 2012
Received in revised form 16 June 2013
Accepted 16 July 2013
Available online 31 July 2013

Keywords:
Fit manufacturing
Lean manufacturing
Agile manufacturing
Multi Criteria Decision Making
Vlsekriterijumska Optimizacija I Kompromisno Resenje (VIKOR)

ABSTRACT

The modern manufacturing environment is highly turbulent so as to satisfy the dynamic needs of customers'. To enable the achievement of competitiveness in this complex business environment, newer manufacturing strategies have been introduced for enabling waste elimination and enhancing flexibility and responsiveness of systems. Fit manufacturing is a competitive manufacturing paradigm which includes lean and agile systems coupled with sustainable benefits. This article presents a study in which the concept selection in fit environment was formulated as Multi Criteria Decision Making (MCDM) problem and solved using fuzzy based compromise solution method, Vlsekriterijumska Optimizacija I Kompromisno Resenje (VIKOR). The selected concept design of automotive component was subjected to implementation in the case organisation.

1. Introduction

The increasing competition and dynamic customer demands forces the manufacturing systems to exhibit transition. The manufacturing systems witnessed a transition from craft-mass-lean-agile-fit era. Fit manufacturing [1] encompasses lean, agile and sustainable principles. Lean system focuses on waste elimination thereby enabling cost reduction. Agile system enables the production of variety of products within a short period of time in a cost effective manner [2]. Sustainability focuses on minimization of environmental impact and thereby developing environmentally friendlier products [3]. Fit system encompasses these principles for developing customised products. In the present study, there existed a need to select the best concept design of an automotive product. Since the concept design selection in the context of fit system is a typical Multi Criterion Decision Making problem, fuzzy based compromise solution method, Vlsekriterijumska Optimizacija I Kompromisno Resenje (VIKOR) [4] was used. The details of the study are presented in the following subsections.

2. Literature review

Fit manufacturing is an advanced manufacturing concept which includes the integration of principles of lean, agile and sustainable manufacturing [2]. Pham et al. [1] introduced a new manufacturing strategy by integrating lean and agile principles in order to achieve economic sustainability. This makes them ready to compete and survive in continuously changing market conditions and to attain product flexibility.

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http://dx.doi.org/10.1016/j.apm.2013.07.027

Pham et al. [5] proposed concepts for the company to find ways for achieving economic sustainability in competitive market. Fit manufacturing is achieved by integrating the principles of lean manufacturing, agile manufacturing and sustainability.

Pham et al. [6] proposed a principle by making interlinks between lean manufacturing, agile manufacturing in order to achieve sustainability. Then the relations between those concepts are grouped into four categories and proposed as the fundamental aspects of manufacturing system.

Pham and Thomas [3] proposed a concept to achieve economic sustainability and proceeded on the initial work made on fit manufacturing and proposed Fit Manufacturing framework and developed a model which is capable of managing all modern manufacturing challenges. Fitness of an organisation links in four major manufacturing themes which are: strategy, leadership, process and technology into a cohesive framework to deliver sustainability solution for industry.

Pham et al. [2] developed a fit paradigm. Using that paradigm, they proposed a new manufacturing management strategy which helps them to create an economically sustainable manufacturing organization. The general aims of integration, the different levels and types of integration, and the potential benefits and drawbacks are also being explained in this article.

Jeya Girubha and Vinodh [7] applied fuzzy VIKOR in material selection of an automobile component. Several criteria are selected for material selection along with weights for selection of proper criteria with various environmental considerations. MCDM technique is used for material selection. The main objective of this study is to provide an efficient method for selection of best material for an automobile component based on the application and material requirement. They demonstrated that fuzzy VIKOR could be used for effective material selection considering multiple criteria.

Shemshadi et al. [8] applied fuzzy VIKOR for supplier selection. In business environment efficient supplier plays a key role in the supply chain management. Hence proper and efficient decision making is required. Shannon entropy concept is used for selecting the proper weights suggested by decision makers. These weights are converted in form of linguistic terms and then transformed into trapezoidal fuzzy numbers. Then final result was obtained by fuzzy VIKOR and Shannon entropy concept.

Opricovic [4] applied fuzzy VIKOR in water resource planning. Fuzzy VIKOR was developed in order to prevent the problem with criteria having different units. Thus both weights and criteria are converted in terms of fuzzy numbers. Thus fuzzy VIKOR provides proper solution for multi criteria problem. Fuzzy VIKOR was applied in water resource planning for developing water harvesting system from Mlava River for enhancing the drinking water supply.

Devi [9] extended VIKOR method into fuzzy environment in order to solve Multi criteria Decision Making in which weights of criteria and alternatives are taken as triangular fuzzy set. This study enabled the selection of robot for material handling process.

Sanayei [10] proposed group decision making process for supplier selection with VIKOR under fuzzy environment. Selection of supplier is the major key in supply chain. The selection of supplier is considered to be a complex Multi- Criteria Decision Making method. In this paper linguistic values are used to represent the ratings and weights, and these linguistic values are expressed as trapezoidal or triangular fuzzy numbers. Then Multi criteria Decision Making model based on fuzzy set and VIKOR is proposed for supplier selection.

Vinodh et al. [11] presented the application of fuzzy VIKOR for concept selection in the context of agile systems. The best concept design was identified in the context of agility. The results derived from fuzzy VIKOR were compared with fuzzy TOPSIS.

2.1. Research gap

Only very few researchers concentrated on fit manufacturing paradigm; fit manufacturing research has been reported from the perspectives of development of concept model, and identification of enablers/criteria. There exists a vital need for exploring various research avenues in fit manufacturing. In this context, this case study reports the formulation of fit concept selection as a typical MCDM problem. Based on the prior studies, fuzzy VIKOR was found to derive compromise solution for several applications. Hence, fuzzy VIKOR was selected as solution methodology in the present study.

3. Methodology

The methodology followed during this case study is explained as follows: The first stage is the literature was reviewed on fit manufacturing and application of fuzzy VIKOR. Then it is followed by the concept model creation for selecting the best fit concept. After this, the input data are obtained from the experts of the case organisation in terms of linguistic variables followed by the conversion of these linguistic variables into trapezoidal fuzzy numbers. Next stage include processing these values and determining the utility, regret and VIKOR indices for the organisation followed by ranking of the fit concepts based on these indices. Finally, a compromise solution will be derived. The methodology is shown in Fig. 1.

4. Case study

The details about the case study are presented in the following subsections.

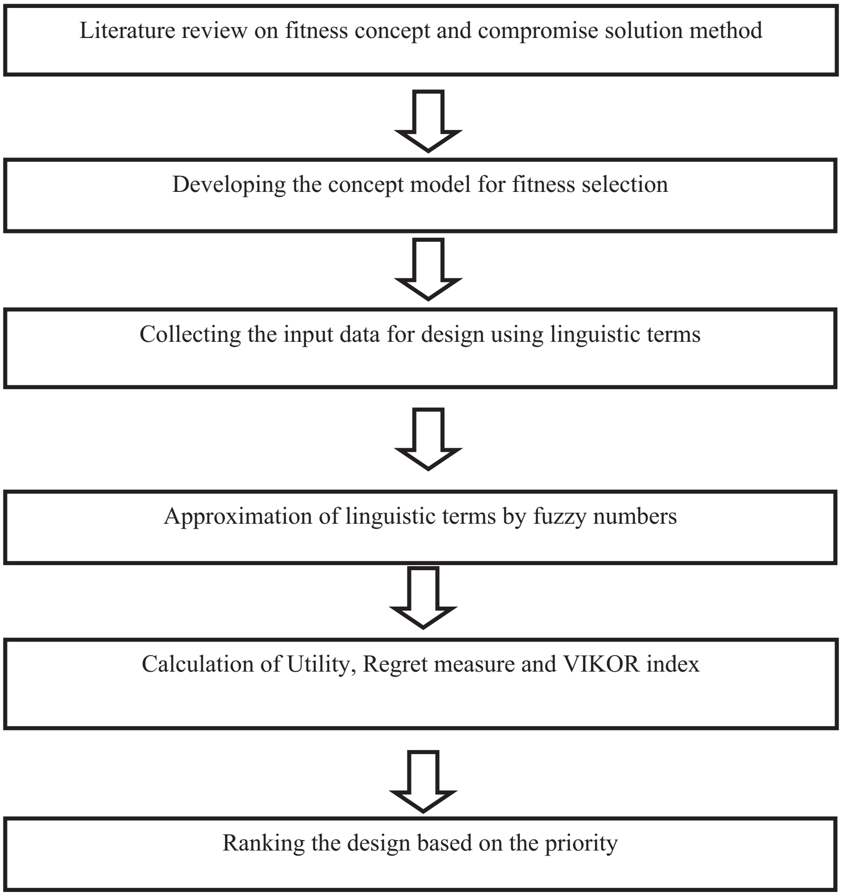

Fig. 1. Methodology.

4.1. Need

The case organization has implemented certain lean and agile principles in their manufacturing practice in order to achieve sustainable benefits. This study contributes the concept design selection from fitment perspective with multiple criteria. In order to select the best fitment concept, the decision makers of the case organization and the authors felt the application of compromise MCDM approach as solution methodology.

4.2. Description about the FIT criteria

The criteria considered in our study include organisational structure ($\mathbf{C}_1$), customer response ($\mathbf{C}_2$), waste reduction ($\mathbf{C}_3$), JIT production and delivery ($\mathbf{C}_4$), value maximization ($\mathbf{C}_5$), resource utilization ($\mathbf{C}_6$), responsiveness, adaptability, flexibility ($\mathbf{C}_7$), integration of functions ($\mathbf{C}_8$), manufacturing flexibility ($\mathbf{C}_9$), high technology ($\mathbf{C}_{10}$), product variety ($\mathbf{C}_{11}$), team management ($\mathbf{C}_{12}$), qualitative and quantitative growth ($\mathbf{C}_{13}$), competitive position of a company ($\mathbf{C}_{14}$), performance and growth ($\mathbf{C}_{15}$), long term growth of a company ($\mathbf{C}_{16}$), economic stability ($\mathbf{C}_{17}$), continuous improvement ($\mathbf{C}_{18}$), production methodology ($\mathbf{C}_{19}$) and manufacturing steps ($\mathbf{C}_{20}$).

The organizational structure [12] will function well if it has smooth information flow and time required for decision making can be reduced to a considerable level so as to increase the efficiency and flexibility of an organization. Customer response adoption [12] is responsible for increase in quality of the product, performance of an organization and continuous steady growth rate. Waste reduction [1] is directly linked with the manufacturing cost. Waste reduction can be achieved by simple design of component so that manufacture of component will be easier, decreasing the lead time, manufacturing and assembly time, proper management of human talent, production of quality product. JIT production and delivery [6] helps to reduce the lead time and inventory cost of the organisation. Value maximization involves increasing the value of the product without changing the production cost. Value analysis and evaluation of worth are the aspects to achieve value maximization. Resource utilization [6] involves minimal usage of resources in order to reduce the overall production cost. During the resource utilization, there should not be any emission of toxic gases. Responsiveness, adaptability, flexibility [6] involves the ability of the employees to be capable to adapting themselves to the continuously changing technological advances and should possess flexibility skills (i.e., they should be quick in response to change). Flexibility in customization of products based on customer needs can be achieved by customized production process incorporated with software packages including Computer Aided Manufacturing. Integration of functions [2] involves integration of marketing, sales, finance, knowledge and skills. This integration helps in efficient material movement which is very important for easy flow of things to the market at correct time. Manufacturing flexibility [1] can be achieved by using flexible Assembly systems, Retro fitting of machine tools and Workforce flexibility. High technology [6] means usage of small and adaptable automation in places where it is required. Automation can be achieved using modern manufacturing systems like FMS (Flexible Manufacturing Systems) & CIM (Computer Integrated Manufacturing) and using new and appropriate technology. Product variety [6] is very important to sustain in the competitive market. Trend analysis is vital in selecting the product variety by the organisation. For each organisation, Team management [6] is important in order to obtain high productivity. Team management involves fully utilizing the ideas and knowledge of employees which is susceptible to change and improvements. Qualitative and quantitative growth [1] is the next criterion. Qualitative growth involves zero defects and product life cycle analysis whereas quantitative growth can be obtained using multi-functional teams. Competitive position of a company [2] is the position of the company among the total manufacturers of that product. By using market tracking, competitor analysis and trade analysis, a company can find their market position. Performance and growth [3] of an organisation is the major criteria for any organisation to withstand in the market. Flexibility and quality of a product helps in high performance and productivity and sustainability help in the steady growth of an organization. Product variety and application of Fit principles will lead to long term growth of a company [6]. Economic stability [6]is determined by the Quality & productivity of products, goals and policies of the organization in the field of manufacturing, marketing. In present day competitive market, continuous improvement [6] is required in technology, productivity and marketing strategies. Production methodology [12] and manufacturing steps [12] should be planned so as to reduce lead time, waste and production cost. This can be achieved by simple product layout process and automation of various production processes.

4.3. Application steps of fuzzy VIKOR

The steps involved in applying fuzzy VIKOR for the best fit concept selection is presented as follows:

4.3.1. Input data collection

Opricovic et al. [13] developed VIKOR method. Using this method, from a set of alternatives a compromise solution can be determined. Compromise solution is a feasible solution which is closest to the ideal solution [14]. The inputs taken from the decision makers of the case organisation are shown in Tables 1 and 2. The inputs consist of linguistic terms and corresponding fuzzy numbers for each criterion and fit concept. Linguistic variables are used to calculate the importance of the criteria and the ratings of alternatives with respect to various criteria. Here trapezoidal fuzzy numbers are used. A trapezoidal fuzzy number can be defined as $\{(n_1, n_2, n_3, n_4) | n_1, n_2, n_3, n_4 \in R; n_1 \leqslant n_2 \leqslant n_3 \leqslant n_4\}$ which respectively, denotes the smallest possible, most promising, and largest possible values [8] and the membership function is defined using Eq. (1).

Table 1
Linguistic terms and corresponding fuzzy numbers for each criterion.

Linguistic variable	Fuzzy number
Very poor (VP)	(0.0,0.0,0.1,0.2)
Poor (P)	(0.1,0.2,0.2,0.3)
Medium poor (MP)	(0.2,0.3,0.4,0.5)
Fair (F)	(0.4,0.5,0.5,0.6)
Medium good (MG)	(0.5,0.6,0.7,0.8)
Good (G)	(0.7,0.8,0.8,0.9)
Very good (VG)	(0.8,0.9,1.0,1.0)

Table 2
Linguistic terms and corresponding fuzzy numbers for each fitment concept.

Linguistic variable	Fuzzy number
Very low (VL)	(0.0,0.0,0.1,0.2)
Low (L)	(0.1,0.2,0.2,0.3)
Fairly low (FL)	(0.2,0.3,0.4,0.5)
Medium (M)	(0.4,0.5,0.5,0.6)
Fairly high (FH)	(0.5,0.6,0.7,0.8)
High (H)	(0.7,0.8,0.8,0.9)
Very high (VH)	(0.8,0.9,1.0,1.0)

Table 3
Importance weight of criteria assessed by decision makers (linguistic variable).

	D1	D2	D3	D4	D5
C1 (Organisational structure)	MG	G	G	MG	G
C2 (Customer response adoption)	MG	MG	F	MG	F
C3 (Waste reduction)	MG	G	G	MG	G
C4 (JIT production and delivery)	MG	G	MG	G	G
C5 (Value maximization)	G	MG	G	MG	G
C6 (Resource utilisation)	G	MG	G	MG	G
C7 (Responsiveness, adaptability, flexibility)	MG	MG	G	MG	MG
C8 (Time to market)	G	MG	F	MG	G
C9 (Manufacturing flexibility)	MG	G	MG	G	MG
C10 (High technology)	G	MG	G	MG	G
C11 (Product variety)	MG	G	MG	G	MG
C12 (Team management)	F	G	MG	G	F
C13 (Quality and quantitative growth)	G	MG	G	MG	G
C14 (Competitive position)	G	MG	MG	G	MG
C15 (Performance and growth)	G	MG	MG	G	MG
C16 (Long term company growth)	MG	MG	F	F	MG
C17 (Economic stability)	MG	F	MG	F	MG
C18 (Continuous improvement)	G	MG	G	MG	G
C19 (Production methodology)	G	MG	F	MG	G
C20 (Manufacturing steps)	G	MG	F	F	MG

Table 4
Importance weight of criteria assessed by decision makers (fuzzy set).

		D2	D3	D4	D5
C1 (Organisational structure)	(0.5,0.6,0.7,0.8)	(0.7,0.8,0.8,0.9)	(0.7,0.8,0.8,0.9)	(0.5,0.6,0.7,0.8)	(0.7,0.8,0.8,0.9)
C2 (Customer response adoption)	(0.5,0.6,0.7,0.8)	(0.5,0.6,0.7,0.8)	(0.4,0.5,0.5,0.6)	(0.5,0.6,0.7,0.8)	(0.4,0.5,0.5,0.6)
C3 (Waste reduction)	(0.5,0.6,0.7,0.8)	(0.7,0.8,0.8,0.9)	(0.7,0.8,0.8,0.9)	(0.5,0.6,0.7,0.8)	(0.7,0.8,0.8,0.9)
C4 (JIT production and delivery)	(0.5,0.6,0.7,0.8)	(0.7,0.8,0.8,0.9)	(0.5,0.6,0.7,0.8)	(0.7,0.8,0.8,0.9)	(0.7,0.8,0.8,0.9)
C5 (Value minimization)	(0.7,0.8,0.8,0.9)	(0.5,0.6,0.7,0.8)	(0.7,0.8,0.8,0.9)	(0.5,0.6,0.7,0.8)	(0.7,0.8,0.8,0.9)
C6 (Resource utilisation)	(0.7,0.8,0.8,0.9)	(0.5,0.6,0.7,0.8)	(0.7,0.8,0.8,0.9)	(0.5,0.6,0.7,0.8)	(0.7,0.8,0.8,0.9)
C7 (Responsiveness, adaptability, flexibility)	(0.5,0.6,0.7,0.8)	(0.5,0.6,0.7,0.8)	(0.7,0.8,0.8,0.9)	(0.5,0.6,0.7,0.8)	(0.5,0.6,0.7,0.8)
C8 (Time to market)	(0.7,0.8,0.8,0.9)	(0.5,0.6,0.7,0.8)	(0.4,0.5,0.5,0.6)	(0.5,0.6,0.7,0.8)	(0.7,0.8,0.8,0.9)
C9 (Manufacturing flexibility)	(0.5,0.6,0.7,0.8)	(0.7,0.8,0.8,0.9)	(0.5,0.6,0.7,0.8)	(0.7,0.8,0.8,0.9)	(0.5,0.6,0.7,0.8)
C10 (High technology)	(0.7,0.8,0.8,0.9)	(0.5,0.6,0.7,0.8)	(0.7,0.8,0.8,0.9)	(0.5,0.6,0.7,0.8)	(0.7,0.8,0.8,0.9)
C11 (Product variety)	(0.5,0.6,0.7,0.8)	(0.7,0.8,0.8,0.9)	(0.5,0.6,0.7,0.8)	(0.7,0.8,0.8,0.9)	(0.5,0.6,0.7,0.8)
C12 (Team management)	(0.4,0.5,0.5,0.6)	(0.7,0.8,0.8,0.9)	(0.5,0.6,0.7,0.8)	(0.7,0.8,0.8,0.9)	(0.4,0.5,0.5,0.6)
C13 (Quality and quantitative growth)	(0.7,0.8,0.8,0.9)	(0.5,0.6,0.7,0.8)	(0.7,0.8,0.8,0.9)	(0.5,0.6,0.7,0.8)	(0.7,0.8,0.8,0.9)
C14 (Competitive position)	(0.7,0.8,0.8,0.9)	(0.5,0.6,0.7,0.8)	(0.5,0.6,0.7,0.8)	(0.7,0.8,0.8,0.9)	(0.5,0.6,0.7,0.8)
C15 (Performance and growth)	(0.7,0.8,0.8,0.9)	(0.5,0.6,0.7,0.8)	(0.5,0.6,0.7,0.8)	(0.7,0.8,0.8,0.9)	(0.5,0.6,0.7,0.8)
C16 (Long term company growth)	(0.5,0.6,0.7,0.8)	(0.5,0.6,0.7,0.8)	(0.4,0.5,0.5,0.6)	(0.4,0.5,0.5,0.6)	(0.5,0.6,0.7,0.8)
C17 (Economic stability)	(0.5,0.6,0.7,0.8)	(0.4,0.5,0.5,0.6)	(0.5,0.6,0.7,0.8)	(0.4,0.5,0.5,0.6)	(0.5,0.6,0.7,0.8)
C18 (Continuous improvement)	(0.7,0.8,0.8,0.9)	(0.5,0.6,0.7,0.8)	(0.7,0.8,0.8,0.9)	(0.5,0.6,0.7,0.8)	(0.7,0.8,0.8,0.9)
C19 (Production methodology)	(0.7,0.8,0.8,0.9)	(0.5,0.6,0.7,0.8)	(0.4,0.5,0.5,0.6)	(0.5,0.6,0.7,0.8)	(0.7,0.8,0.8,0.9)
C20 (Manufacturing steps)	(0.7,0.8,0.8,0.9)	(0.5,0.6,0.7,0.8)	(0.4,0.5,0.5,0.6)	(0.4,0.5,0.5,0.6)	(0.5,0.6,0.7,0.8)

$$\mu_{\tilde{A}}(x) = \begin{cases} \frac{x-n_1}{n_2-n_1}, & x_\epsilon[n_1, n_2], \\ 1, & x_\epsilon[n_2, n_3], \\ \frac{n_4-x}{n_4-n_3}, & x_\epsilon[n_3, n_4], \\ 0 & \text{Otherwise}. \end{cases} \tag{1}$$

The linguistic variables for each criterion are shown in Table 3. The corresponding fuzzy numbers for each linguistic variable is shown in Table 4. The linguistic variables and corresponding fuzzy set values for describing the importance of fitment concept with respect to criteria assessed by decision makers are shown in Tables 5 and 6. Let the fuzzy rating for the criterion and importance weight of the kth decision maker be $X_{ijk}\{X_{ijk1}; X_{ijk2}; X_{ijk3}; X_{ijk4}\}$ and $W_{jk}\{W_{jk1}; W_{jk2}; W_{jk3}; W_{jk4}\}$ respectively.

4.3.2. Aggregation

With respect to each criterion, the aggregated fuzzy ratings X_{ij} of alternatives is calculated using Eq. (2) [15]

$$X_{ij} = \{X_{ij1}; X_{ij2}; X_{ij3}; X_{ij4}\}, \tag{2}$$

where

Table 5
Importance of fitment concept with respect to criteria assessed by makers (linguistic variable).

		C1	C2	C3	C4	C5	C6	C7	C8	C9	C10
D1	**F1**	H	H	FH	FH	FH	FH	FH	H	M	FH
	F2	FH	H	M	M	H	H	FH	M	H	H
	F3	H	FH	M	FH	FH	FH	M	H	H	FH
	F4	FH	H	FH	M	M	M	FH	FH	FH	M
D2	**F1**	H	H	HFH	FH	H	M	FH	FH	FH	M
	F2	H	FH	M	M	H	H	M	M	M	FH
	F3	FH	H	FH	M	FH	FH	FH	M	H	M
	F4	H	H	M	H	H	H	H	FH	FH	VH
D3	**F1**	H	VH	H	H	VH	VH	VH	VH	VH	VH
	F2	VH	H	FH	VH	H	H	H	H	H	H
	F3	H	H	H	H	H	VH	H	H	M	H
	F4	VH	VH	VH	FH	VH	H	VH	VH	H	VH
D4	**F1**	H	H	H	H	H	H	H	H	VH	VH
	F2	VH	VH	FH	FH	FH	FH	FH	VH	H	H
	F3	H	H	H	H	H	H	H	H	M	M
	F4	H	FH	M	H	FH	FH	FH	VH	FH	FH
D5	**F1**	H	FH	H	H	H	H	H	H	FH	FH
	F2	VH	H	FH	FH	FH	FH	M	M	H	H
	F3	H	FH	FH	H	FH	H	FH	FH	FH	M
	F4	H	H	H	H	H	FH	H	M	H	FH

		C11	C12	C13	C14	C15	C16	C17	C18	C19	C20
D1	**F1**	FH	FH	M	FH	H	H	H	H	H	FH
	F2	M	M	H	H	FH	H	H	FH	FH	H
	F3	FH	FH	FH	M	M	FH	FH	M	M	FH
	F4	M	M	M	M	H	H	M	FH	H	M
D2	**F1**	FH	M	FH	H	H	FH	M	M	M	FH
	F2	H	FH	H	H	FH	M	H	H	FH	H
	F3	FH	FH	FH	FH	FH	FH	FH	H	M	H
	F4	M	M	M	H	M	H	H	FH	FH	M
D3	**F1**	VH	VH	H	VH	H	H	H	H	H	H
	F2	H	H	VH	H	VH	VH	VH	VH	VH	VH
	F3	H	H	H	H	H	H	H	VH	VH	H
	F4	VH	VH	VH	VH	H	VH	H	H	H	H
D4	**F1**	H	M	H	H	FH	H	H	H	FH	FH
	F2	FH	FH	FH	FH	H	FH	M	M	H	H
	F3	FH	H	M	H	M	H	FH	H	H	FH
	F4	H	VH	FH	FH	FH	H	M	FH	FH	M
D5	**F1**	H	VH	H	FH	H	M	M	M	M	FH
	F2	M	H	FH	H	FH	FH	FH	FH	H	VH
	F3	FH	M	M	M	H	H	H	H	H	VH
	F4	H	FH	FH	FH	M	FH	H	M	FH	FH

$$X_{ij1} = \min\{X_{ijk1}\},$$

$$X_{ij2} = \frac{1}{k}\sum X_{ijk2},$$

$$X_{ij3} = \frac{1}{k}\sum X_{ijk3},$$

$$X_{ij4} = \min\{X_{ijk4}\}.$$

The aggregated fuzzy weight W_j of each criterion is calculated using Eq. (3) [7]

$$W_j = \{W_{j1}; W_{j2}; W_{j3}; W_{j4}\}, \quad (3)$$

where

$$W_{j1} = \min\{W_{jk1}\},$$

$$W_{j2} = \frac{1}{k}\sum W_{jk2},$$

Table 6
Importance of fitment concept with respect to criteria assessed by decision makers (fuzzy set).

		C1	C2	C3	C4	C5
D1	**F1**	(0.7,0.8,0.8,0.9)	(0.7,0.8,0.8,0.9)	(0.5,0.6,0.7,0.8)	(0.5,0.6,0.7,0.8)	(0.5,0.6,0.7,0.8)
	F2	(0.5,0.6,0.7,0.8)	(0.7,0.8,0.8,0.9)	(0.4,0.5,0.5,0.6)	(0.4,0.5,0.5,0.6)	(0.7,0.8,0.8,0.9)
	F3	(0.7,0.8,0.8,0.9)	(0.5,0.6,0.7,0.8)	(0.4,0.5,0.5,0.6)	(0.5,0.6,0.7,0.8)	(0.5,0.6,0.7,0.8)
	F4	(0.5,0.6,0.7,0.8)	(0.7,0.8,0.8,0.9)	(0.5,0.6,0.7,0.8)	(0.4,0.5,0.5,0.6)	(0.4,0.5,0.5,0.6)
D2	**F5**	(0.7,0.8,0.8,0.9)	(0.7,0.8,0.8,0.9)	(0.5,0.6,0.7,0.8)	(0.5,0.6,0.7,0.8)	(0.7,0.8,0.8,0.9)
	F2	(0.7,0.8,0.8,0.9)	(0.5,0.6,0.7,0.8)	(0.4,0.5,0.5,0.6)	(0.4,0.5,0.5,0.6)	(0.7,0.8,0.8,0.9)
	F3	(0.5,0.6,0.7,0.8)	(0.7,0.8,0.8,0.9)	(0.5,0.6,0.7,0.8)	(0.4,0.5,0.5,0.6)	(0.5,0.6,0.7,0.8)
	F4	(0.7,0.8,0.8,0.9)	(0.7,0.8,0.8,0.9)	(0.4,0.5,0.5,0.6)	(0.7,0.8,0.8,0.9)	(0.7,0.8,0.8,0.9)
D3	**F1**	(0.7,0.8,0.8,0.9)	(0.8,0.9,1.0,1.0)	(0.7,0.8,0.8,0.9)	(0.7,0.8,0.8,0.9)	(0.8,0.9,1.0,1.0)
	F2	(0.8,0.9,1.0,1.0)	(0.7,0.8,0.8,0.9)	(0.5,0.6,0.7,0.8)	(0.8,0.9,1.0,1.0)	(0.7,0.8,0.8,0.9)
	F3	(0.7,0.8,0.8,0.9)	(0.7,0.8,0.8,0.9)	(0.7,0.8,0.8,0.9)	(0.7,0.8,0.8,0.9)	(0.7,0.8,0.8,0.9)
	F4	(0.8,0.9,1.0,1.0)	(0.8,0.9,1.0,1.0)	(0.8,0.9,1.0,1.0)	(0.5,0.6,0.7,0.8)	(0.8,0.9,1.0,1.0)
D4	**F1**	(0.7,0.8,0.8,0.9)	(0.7,0.8,0.8,0.9)	(0.7,0.8,0.8,0.9)	(0.7,0.8,0.8,0.9)	(0.7,0.8,0.8,0.9)
	F2	(0.8,0.9,1.0,1.0)	(0.8,0.9,1.0,1.0)	(0.5,0.6,0.7,0.8)	(0.5,0.6,0.7,0.8)	(0.5,0.6,0.7,0.8)
	F3	(0.7,0.8,0.8,0.9)	(0.7,0.8,0.8,0.9)	(0.7,0.8,0.8,0.9)	(0.7,0.8,0.8,0.9)	(0.7,0.8,0.8,0.9)
	F4	(0.7,0.8,0.8,0.9)	(0.5,0.6,0.7,0.8)	(0.4,0.5,0.5,0.6)	(0.7,0.8,0.8,0.9)	(0.5,0.6,0.7,0.8)
D5	**F1**	(0.7,0.8,0.8,0.9)	(0.5,0.6,0.7,0.8)	(0.7,0.8,0.8,0.9)	(0.7,0.8,0.8,0.9)	(0.7,0.8,0.8,0.9)
	F2	(0.8,0.9,1.0,1.0)	(0.7,0.8,0.8,0.9)	(0.5,0.6,0.7,0.8)	(0.5,0.6,0.7,0.8)	(0.5,0.6,0.7,0.8)
	F3	(0.7,0.8,0.8,0.9)	(0.5,0.6,0.7,0.8)	(0.5,0.6,0.7,0.8)	(0.7,0.8,0.8,0.9)	(0.5,0.6,0.7,0.8)
	F4	(0.7,0.8,0.8,0.9)	(0.7,0.8,0.8,0.9)	(0.7,0.8,0.8,0.9)	(0.7,0.8,0.8,0.9)	(0.7,0.8,0.8,0.9)

		C6	C7	C8	C9	C10
D1	**F1**	(0.5,0.6,0.7,0.8)	(0.5,0.6,0.7,0.8)	(0.7,0.8,0.8,0.9)	(0.4,0.5,0.5,0.6)	(0.5,0.6,0.7,0.8)
	F2	(0.7,0.8,0.8,0.9)	(0.5,0.6,0.7,0.8)	(0.4,0.5,0.5,0.6)	(0.7,0.8,0.8,0.9)	(0.7,0.8,0.8,0.9)
	F3	(0.5,0.6,0.7,0.8)	(0.4,0.5,0.5,0.6)	(0.7,0.8,0.8,0.9)	(0.7,0.8,0.8,0.9)	(0.5,0.6,0.7,0.8)
	F4	(0.4,0.5,0.5,0.6)	(0.5,0.6,0.7,0.8)	(0.5,0.6,0.7,0.8)	(0.5,0.6,0.7,0.8)	(0.4,0.5,0.5,0.6)
D2	**F5**	(0.4,0.5,0.5,0.6)	(0.5,0.6,0.7,0.8)	(0.5,0.6,0.7,0.8)	(0.5,0.6,0.7,0.8)	(0.4,0.5,0.5,0.6)
	F2	(0.7,0.8,0.8,0.9)	(0.4,0.5,0.5,0.6)	(0.4,0.5,0.5,0.6)	(0.4,0.5,0.5,0.6)	(0.5,0.6,0.7,0.8)
	F3	(0.5,0.6,0.7,0.8)	(0.5,0.6,0.7,0.8)	(0.4,0.5,0.5,0.6)	(0.7,0.8,0.8,0.9)	(0.4,0.5,0.5,0.6)
	F4	(0.7,0.8,0.8,0.9)	(0.7,0.8,0.8,0.9)	(0.5,0.6,0.7,0.8)	(0.5,0.6,0.7,0.8)	(0.8,0.9,1.0,1.0)
D3	**F1**	(0.8,0.9,1.0,1.0)	(0.8,0.9,1.0,1.0)	(0.8,0.9,1.0,1.0)	(0.8,0.9,1.0,1.0)	(0.8,0.9,1.0,1.0)
	F2	(0.7,0.8,0.8,0.9)	(0.7,0.8,0.8,0.9)	(0.7,0.8,0.8,0.9)	(0.7,0.8,0.8,0.9)	(0.7,0.8,0.8,0.9)
	F3	(0.8,0.9,1.0,1.0)	(0.7,0.8,0.8,0.9)	(0.7,0.8,0.8,0.9)	(0.4,0.5,0.5,0.6)	(0.7,0.8,0.8,0.9)
	F4	(0.7,0.8,0.8,0.9)	(0.8,0.9,1.0,1.0)	(0.8,0.9,1.0,1.0)	(0.7,0.8,0.8,0.9)	(0.8,0.9,1.0,1.0)
D4	**F1**	(0.7,0.8,0.8,0.9)	(0.7,0.8,0.8,0.9)	(0.7,0.8,0.8,0.9)	(0.8,0.9,1.0,1.0)	(0.8,0.9,1.0,1.0)
	F2	(0.5,0.6,0.7,0.8)	(0.5,0.6,0.7,0.8)	(0.8,0.9,1.0,1.0)	(0.7,0.8,0.8,0.9)	(0.7,0.8,0.8,0.9)
	F3	(0.7,0.8,0.8,0.9)	(0.7,0.8,0.8,0.9)	(0.7,0.8,0.8,0.9)	(0.4,0.5,0.5,0.6)	(0.4,0.5,0.5,0.6)
	F4	(0.5,0.6,0.7,0.8)	(0.5,0.6,0.7,0.8)	(0.8,0.9,1.0,1.0)	(0.5,0.6,0.7,0.8)	(0.5,0.6,0.7,0.8)
D5	**F1**	(0.7,0.8,0.8,0.9)	(0.7,0.8,0.8,0.9)	(0.7,0.8,0.8,0.9)	(0.5,0.6,0.7,0.8)	(0.5,0.6,0.7,0.8)
	F2	(0.5,0.6,0.7,0.8)	(0.4,0.5,0.5,0.6)	(0.4,0.5,0.5,0.6)	(0.7,0.8,0.8,0.9)	(0.7,0.8,0.8,0.9)
	F3	(0.7,0.8,0.8,0.9)	(0.5,0.6,0.7,0.8)	(0.5,0.6,0.7,0.8)	(0.5,0.6,0.7,0.8)	(0.4,0.5,0.5,0.6)
	F4	(0.5,0.6,0.7,0.8)	(0.7,0.8,0.8,0.9)	(0.4,0.5,0.5,0.6)	(0.7,0.8,0.8,0.9)	(0.5,0.6,0.7,0.8)

		C11	C12	C13	C14	C15
D1	**F1**	(0.5,0.6,0.7,0.8)	(0.5,0.6,0.7,0.8)	(0.4,0.5,0.5,0.6)	(0.5,0.6,0.7,0.8)	(0.7,0.8,0.8,0.9)
	F2	(0.4,0.5,0.5,0.6)	(0.4,0.5,0.5,0.6)	(0.7,0.8,0.8,0.9)	(0.7,0.8,0.8,0.9)	(0.5,0.6,0.7,0.8)
	F3	(0.5,0.6,0.7,0.8)	(0.5,0.6,0.7,0.8)	(0.5,0.6,0.7,0.8)	(0.4,0.5,0.5,0.6)	(0.4,0.5,0.5,0.6)
	F4	(0.4,0.5,0.5,0.6)	(0.4,0.5,0.5,0.6)	(0.4,0.5,0.5,0.6)	(0.4,0.5,0.5,0.6)	(0.7,0.8,0.8,0.9)
D2	**F5**	(0.5,0.6,0.7,0.8)	(0.4,0.5,0.5,0.6)	(0.5,0.6,0.7,0.8)	(0.7,0.8,0.8,0.9)	(0.7,0.8,0.8,0.9)
	F2	(0.7,0.8,0.8,0.9)	(0.5,0.6,0.7,0.8)	(0.7,0.8,0.8,0.9)	(0.7,0.8,0.8,0.9)	(0.5,0.6,0.7,0.8)
	F3	(0.5,0.6,0.7,0.8)	(0.5,0.6,0.7,0.8)	(0.5,0.6,0.7,0.8)	(0.5,0.6,0.7,0.8)	(0.5,0.6,0.7,0.8)
	F4	(0.4,0.5,0.5,0.6)	(0.4,0.5,0.5,0.6)	(0.4,0.5,0.5,0.6)	(0.7,0.8,0.8,0.9)	(0.4,0.5,0.5,0.6)
D3	**F1**	(0.8,0.9,1.0,1.0)	(0.8,0.9,1.0,1.0)	(0.7,0.8,0.8,0.9)	(0.8,0.9,1.0,1.0)	(0.7,0.8,0.8,0.9)
	F2	(0.7,0.8,0.8,0.9)	(0.7,0.8,0.8,0.9)	(0.8,0.9,1.0,1.0)	(0.7,0.8,0.8,0.9)	(0.8,0.9,1.0,1.0)
	F3	(0.7,0.8,0.8,0.9)	(0.7,0.8,0.8,0.9)	(0.7,0.8,0.8,0.9)	(0.7,0.8,0.8,0.9)	(0.7,0.8,0.8,0.9)
	F4	(0.8,0.9,1.0,1.0)	(0.8,0.9,1.0,1.0)	(0.8,0.9,1.0,1.0)	(0.8,0.9,1.0,1.0)	(0.7,0.8,0.8,0.9)
D4	**F1**	(0.7,0.8,0.8,0.9)	(0.4,0.5,0.5,0.6)	(0.7,0.8,0.8,0.9)	(0.7,0.8,0.8,0.9)	(0.5,0.6,0.7,0.8)
	F2	(0.5,0.6,0.7,0.8)	(0.5,0.6,0.7,0.8)	(0.5,0.6,0.7,0.8)	(0.5,0.6,0.7,0.8)	(0.7,0.8,0.8,0.9)
	F3	(0.5,0.6,0.7,0.8)	(0.7,0.8,0.8,0.9)	(0.4,0.5,0.5,0.6)	(0.7,0.8,0.8,0.9)	(0.4,0.5,0.5,0.6)
	F4	(0.7,0.8,0.8,0.9)	(0.8,0.9,1.0,1.0)	(0.5,0.6,0.7,0.8)	(0.5,0.6,0.7,0.8)	(0.5,0.6,0.7,0.8)
D5	**F1**	(0.7,0.8,0.8,0.9)	(0.8,0.9,1.0,1.0)	(0.7,0.8,0.8,0.9)	(0.5,0.6,0.7,0.8)	(0.7,0.8,0.8,0.9)
	F2	(0.4,0.5,0.5,0.6)	(0.7,0.8,0.8,0.9)	(0.5,0.6,0.7,0.8)	(0.7,0.8,0.8,0.9)	(0.5,0.6,0.7,0.8)

Table 6 (*continued*)

		C1	C2	C3	C4	C5
	F3	(0.5, 0.6, 0.7, 0.8)	(0.4, 0.5, 0.5, 0.6)	(0.4, 0.5, 0.5, 0.6)	(0.4, 0.5, 0.5, 0.6)	(0.7, 0.8, 0.8, 0.9)
	F4	(0.7, 0.8, 0.8, 0.9)	(0.5, 0.6, 0.7, 0.8)	(0.5, 0.6, 0.7, 0.8)	(0.5, 0.6, 0.7, 0.8)	(0.4, 0.5, 0.5, 0.6)
		C16	**C17**	**C18**	**C19**	**C20**
D1	**F1**	(0.7, 0.8, 0.8, 0.9)	(0.7, 0.8, 0.8, 0.9)	(0.7, 0.8, 0.8, 0.9)	(0.7, 0.8, 0.8, 0.9)	(0.5, 0.6, 0.7, 0.8)
	F2	(0.7, 0.8, 0.8, 0.9)	(0.7, 0.8, 0.8, 0.9)	(0.5, 0.6, 0.7, 0.8)	(0.5, 0.6, 0.7, 0.8)	(0.7, 0.8, 0.8, 0.9)
	F3	(0.5, 0.6, 0.7, 0.8)	(0.5, 0.6, 0.7, 0.8)	(0.4, 0.5, 0.5, 0.6)	(0.4, 0.5, 0.5, 0.6)	(0.5, 0.6, 0.7, 0.8)
	F4	(0.7, 0.8, 0.8, 0.9)	(0.4, 0.5, 0.5, 0.6)	(0.5, 0.6, 0.7, 0.8)	(0.7, 0.8, 0.8, 0.9)	(0.4, 0.5, 0.5, 0.6)
D2	**F5**	(0.5, 0.6, 0.7, 0.8)	(0.4, 0.5, 0.5, 0.6)	(0.4, 0.5, 0.5, 0.6)	(0.4, 0.5, 0.5, 0.6)	(0.5, 0.6, 0.7, 0.8)
	F2	(0.4, 0.5, 0.5, 0.6)	(0.7, 0.8, 0.8, 0.9)	(0.7, 0.8, 0.8, 0.9)	(0.5, 0.6, 0.7, 0.8)	(0.7, 0.8, 0.8, 0.9)
	F3	(0.5, 0.6, 0.7, 0.8)	(0.5, 0.6, 0.7, 0.8)	(0.7, 0.8, 0.8, 0.9)	(0.4, 0.5, 0.5, 0.6)	(0.7, 0.8, 0.8, 0.9)
	F4	(0.7, 0.8, 0.8, 0.9)	(0.7, 0.8, 0.8, 0.9)	(0.5, 0.6, 0.7, 0.8)	(0.5, 0.6, 0.7, 0.8)	(0.4, 0.5, 0.5, 0.6)
D3	**F1**	(0.7, 0.8, 0.8, 0.9)	(0.7, 0.8, 0.8, 0.9)	(0.7, 0.8, 0.8, 0.9)	(0.7, 0.8, 0.8, 0.9)	(0.7, 0.8, 0.8, 0.9)
	F2	(0.8, 0.9, 1.0, 1.0)	(0.8, 0.9, 1.0, 1.0)	(0.8, 0.9, 1.0, 1.0)	(0.8, 0.9, 1.0, 1.0)	(0.8, 0.9, 1.0, 1.0)
	F3	(0.7, 0.8, 0.8, 0.9)	(0.7, 0.8, 0.8, 0.9)	(0.8, 0.9, 1.0, 1.0)	(0.8, 0.9, 1.0, 1.0)	(0.7, 0.8, 0.8, 0.9)
	F4	(0.8, 0.9, 1.0, 1.0)	(0.7, 0.8, 0.8, 0.9)	(0.7, 0.8, 0.8, 0.9)	(0.7, 0.8, 0.8, 0.9)	(0.7, 0.8, 0.8, 0.9)
D4	**F1**	(0.7, 0.8, 0.8, 0.9)	(0.7, 0.8, 0.8, 0.9)	(0.7, 0.8, 0.8, 0.9)	(0.5, 0.6, 0.7, 0.8)	(0.5, 0.6, 0.7, 0.8)
	F2	(0.5, 0.6, 0.7, 0.8)	(0.4, 0.5, 0.5, 0.6)	(0.4, 0.5, 0.5, 0.6)	(0.7, 0.8, 0.8, 0.9)	(0.7, 0.8, 0.8, 0.9)
	F3	(0.7, 0.8, 0.8, 0.9)	(0.5, 0.6, 0.7, 0.8)	(0.7, 0.8, 0.8, 0.9)	(0.7, 0.8, 0.8, 0.9)	(0.5, 0.6, 0.7, 0.8)
	F4	(0.7, 0.8, 0.8, 0.9)	(0.4, 0.5, 0.5, 0.6)	(0.5, 0.6, 0.7, 0.8)	(0.5, 0.6, 0.7, 0.8)	(0.4, 0.5, 0.5, 0.6)
D5	**F1**	(0.4, 0.5, 0.5, 0.6)	(0.4, 0.5, 0.5, 0.6)	(0.4, 0.5, 0.5, 0.6)	(0.4, 0.5, 0.5, 0.6)	(0.5, 0.6, 0.7, 0.8)
	F2	(0.5, 0.6, 0.7, 0.8)	(0.5, 0.6, 0.7, 0.8)	(0.5, 0.6, 0.7, 0.8)	(0.7, 0.8, 0.8, 0.9)	(0.8, 0.9, 1.0, 1.0)
	F3	(0.7, 0.8, 0.8, 0.9)	(0.7, 0.8, 0.8, 0.9)	(0.7, 0.8, 0.8, 0.9)	(0.7, 0.8, 0.8, 0.9)	(0.8, 0.9, 1.0, 1.0)
	F4	(0.5, 0.6, 0.7, 0.8)	(0.7, 0.8, 0.8, 0.9)	(0.4, 0.5, 0.5, 0.6)	(0.5, 0.6, 0.7, 0.8)	(0.5, 0.6, 0.7, 0.8)

$$W_{j3} = \frac{1}{k}\sum W_{jk3},$$

$$W_{j4} = \min\{W_{jk4}\}.$$

The aggregated matrix for criterion weights and fit concept are calculated by using Eqs. (2) and (3) [8] and are shown in Table 7.

4.3.3. Normalisation

In order to have common set of values for fit concept and criterion selection, all non-commensurable criteria should be converted into the dimensionless criteria. Normalisation is method which can be used to remove the dimensions of all criteria. Usually linear normalization is employed within VIKOR method [16].The properties whose higher values are desirable, called positive criteria or beneficial attributes and those properties whose smaller values are favourable, named negative criteria or cost criteria [4]. In this normalisation method, the cost criterion (C) is divided by minimum value and the benefit criterion (B) is divided by the maximum value of the decision matrix using Eqs. (4) and (5) [8] and the normalised values are shown in Table 8.

$$u_{ij} = \left(\frac{x_{ij1}}{x^{+}_{ij4}}, \frac{x_{ij2}}{x^{+}_{ij4}}, \frac{x_{ij3}}{x^{+}_{ij4}}, \frac{x_{ij4}}{x^{+}_{ij4}}\right), \quad C_j \in B, \tag{4}$$

$$u_{ij} = \left(\frac{x_{ij1}}{x^{-}_{ij1}}, \frac{x_{ij2}}{x^{-}_{ij1}}, \frac{x_{ij3}}{x^{-}_{ij1}}, \frac{x_{ij4}}{x^{-}_{ij1}}\right), \quad C_j \in C, \tag{5}$$

where C_j denotes the jth criterion

$$x^{+}_{ij4} = \max_{i\{decision\,matrix\}}, \quad C_j \in B,$$

$$x^{-}_{ij1} = \min_{i\{decision\,matrix\}}, \quad C_j \in C.$$

4.3.4. Defuzzification

The criterion fuzzy weights and importance of the criterion with fit concept selection are defuzzified by taking the average of the normalised trapezoidal fuzzy numbers to get the crisp values. The attained crisp values are shown in Table 9.

$$Defuzz(X_{ij}) = \left(\frac{x_{ij1} + x_{ij2} + x_{ij3} + x_{ij4}}{4}\right). \tag{6}$$

Table 7
Aggregated fuzzy values of fitment concepts and criterion weights.

	C1	C2	C3	C4	C5
W	(0.5,0.72,0.76,0.9)	(0.4,0.56,0.62,0.9)	(0.5,0.72,0.76,0.9)	(0.5,0.72,0.76,0.9)	(0.5,0.72,0.76,0.9)
F1	(0.5,0.78,0.82,1)	(0.5,0.78,0.82,1)	(0.5,0.72,0.76,0.9)	(0.4,0.7,0.72,0.9)	(0.5,0.78,0.82,1)
F2	(0.5,0.76,0.78,0.9)	(0.5,0.72,0.76,0.9)	(0.4,0.56,0.62,0.8)	(0.4,0.7,0.72,0.9)	(0.5,0.72,0.76,0.9)
F3	(0.5,0.82,0.9,1)	(0.5,0.78,0.82,1)	(0.4,0.66,0.7,0.9)	(0.4,0.62,0.68,1)	(0.5,0.68,0.74,0.9)
F4	(0.7,0.8,0.8,0.9)	(0.5,0.78,0.82,1)	(0.4,0.66,0.7,1)	(0.5,0.72,0.76,0.9)	(0.4,0.72,0.76,1)
	C6	**C7**	**C8**	**C9**	**C10**
W	(0.5,0.72,0.76,0.9)	(0.5,0.64,0.72,0.9)	(0.4,0.66,0.7,0.9)	(0.5,0.68,0.74,0.9)	(0.5,0.72,0.76,0.9)
F1	(0.4,0.66,0.7,0.9)	(0.5,0.74,0.8,1)	(0.5,0.78,0.82,1)	(0.5,0.68,0.74,0.9)	(0.4,0.7,0.78,1)
F2	(0.5,0.74,0.8,1)	(0.4,0.66,0.7,0.9)	(0.4,0.64,0.66,1)	(0.4,0.64,0.66,0.9)	(0.4,0.58,0.6,0.9)
F3	(0.5,0.72,0.76,0.9)	(0.4,0.6,0.34,0.9)	(0.4,0.7,0.68,0.9)	(0.4,0.74,0.74,0.9)	(0.5,0.76,0.78,0.9)
F4	(0.4,0.72,0.76,1)	(0.5,0.74,0.8,1)	(0.4,0.7,0.78,1)	(0.4,0.7,0.78,1)	(0.4,0.7,0.78,1)
	C11	**C12**	**C13**	**C14**	**C15**
W	(0.5,0.68,0.74,0.9)	(0.4,0.64,0.72,0.9)	(0.5,0.68,0.74,0.9)	(0.5,0.68,0.74,0.9)	(0.5,0.68,0.74,0.9)
F1	(0.4,0.7,0.72,1)	(0.4,0.68,0.74,1)	(0.4,0.62,0.68,1)	(0.5,0.68,0.74,1)	(0.5,0.64,0.66,0.9)
F2	(0.5,0.64,0.72,0.9)	(0.4,0.66,0.7,0.9)	(0.4,0.6,0.64,0.9)	(0.4,0.64,0.66,0.9)	(0.4,0.64,0.66,0.9)
F3	(0.4,0.64,0.66,0.9)	(0.4,0.66,0.7,0.9)	(0.5,0.74,0.8,1)	(0.5,0.76,0.78,0.9)	(0.5,0.7,0.78,1)
F4	(0.5,0.74,0.8,1)	(0.4,0.68,0.74,1)	(0.4,0.7,0.78,0.9)	(0.5,0.72,0.76,1)	(0.5,0.76,0.78,0.9)
	C16	**C17**	**C18**	**C19**	**C20**
W	(0.4,0.56,0.62,0.8)	(0.4,0.56,0.62,0.8)	(0.5,0.72,0.76,0.9)	(0.4,0.66,0.7,0.9)	(0.4,0.6,0.64,0.9)
F1	(0.5,0.78,0.82,1)	(0.4,0.68,0.68,0.9)	(0.5,0.62,0.68,0.9)	(0.4,0.64,0.7,0.9)	(0.5,0.64,0.7,0.9)
F2	(0.5,0.72,0.76,0.9)	(0.5,0.68,0.74,0.9)	(0.4,0.76,0.78,1)	(0.5,0.74,0.8,1)	(0.7,0.84,0.88,1)
F3	(0.4,0.68,0.78,1)	(0.4,0.72,0.76,1)	(0.4,0.68,0.74,1)	(0.4,0.7,0.72,1)	(0.5,0.74,0.8,1)
F4	(0.4,0.7,0.78,0.9)	(0.4,0.68,0.74,0.9)	(0.4,0.68,0.74,0.9)	(0.5,0.68,0.74,0.9)	(0.4,0.58,0.6,0.9)

Table 8
Normalised matrix.

	C1	C2	C3	C4	C5
W	(0.5,0.72,0.76,0.9)	(0.4,0.56,0.62,0.9)	(0.5,0.72,0.76,0.9)	(0.5,0.72,0.76,0.9)	(0.5,0.72,0.76,0.9)
F1	(0.5,0.78,0.82,1)	(0.5,0.78,0.82,1)	(1,1.65,1.75,2.5)	(0.4,0.7,0.72,0.9)	(1,1.8,1.9,2.5)
F2	(0.5,0.76,0.78,0.9)	(0.5,0.72,0.76,0.9)	(1,1.65,1.75,2.25)	(0.4,0.7,0.72,0.9)	(1.25,1.7,185,2.25)
F3	(0.5,0.82,0.9,1)	(0.5,0.78,0.82,1)	(1,1.4,1.55,2)	(0.4,0.62,0.68,1)	(1.25,1.8,1.9,2.25)
F4	(0.7,0.8,0.8,0.9)	(0.5,0.78,0.82,1)	(1.25,1.81.9,2.25)	(0.5,0.72,0.76,0.9)	(1.25,1.95,2.05,2.5)
	C6	**C7**	**C8**	**C9**	**C10**
W	(0.5,0.72,0.76,0.9)	(0.5,0.64,0.72,0.9)	(0.4,0.66,0.7,0.9)	(0.5,0.68,0.74,0.9)	(0.5,0.72,0.76,0.9)
F1	(0.4,0.66,0.7,0.9)	(0.5,0.74,0.8,1)	(1,1.75,1.95,2.5)	(0.5,0.68,0.74,0.9)	(0.4,0.7,0.78,1)
F2	(0.5,0.74,0.8,1)	(0.4,0.66,0.7,0.9)	(1,1.75,1.7,2.25)	(0.4,0.64,0.66,0.9)	(0.4,0.58, 0.6,0.9)
F3	(0.5,0.72,0.76,0.9)	(0.4,0.6,0.34,0.9)	(1,1.6,1.65,2.5)	(0.4,0.74,0.74,0.9)	(0.5,0.76,0.78,0.9)
F4	(0.4,0.72,0.76,1)	(0.5,0.74,0.8,1)	(1.25,1.95,2.05,2.5)	(0.4,0.7,0.78,1)	(0.4,0.7,0.78,1)
	C11	**C12**	**C13**	**C14**	**C15**
W	(0.5,0.68,0.74,0.9)	(0.4,0.64,0.72,0.9)	(0.5,0.68,0.74,0.9)	(0.5,0.68,0.74,0.9)	(0.5,0.68,0.74,0.9)
F1	(0.4,0.7,0.72,1)	(0.4,0.68,0.74,1)	(0.4,0.62,0.68,1)	(0.5,0.68, 0.74,1)	(0.5,0.64,0.66,0.9)
F2	(0.5,0.64,0.72,0.9)	(0.4,0.66,0.7,0.9)	(0.4,0.6,0.64,0.9)	(0.4,0.64,0.66,0.9)	(0.4,0.64,0.66,0.9)
F3	(0.4,0.64,0.66,0.9)	(0.4,0.66,0.7,0.9)	(0.5,0.74,0.8,1)	(0.5,0.76,0.78,0.9)	(0.5,0.7,0.78,1)
F4	(0.5,0.74,0.8,1)	(0.4,0.68,0.74,1)	(0.4,0.7,0.78,0.9)	(0.5,0.72,0.76,1)	(0.5,0.76,0.78,0.9)
	C16	**C17**	**C18**	**C19**	**C20**
W	(0.4,0.56,0.62,0.8)	(0.4,0.56,0.62,0.8)	(0.5,0.72,0.76,0.9)	(0.4,0.66,0.7,0.9)	(0.4,0.6,0.64,0.9)
F1	(0.5,0.78,0.82,1)	(0.4,0.68,0.68,0.9)	(0.5,0.62,0.68,0.9)	(1.25,1.7,1.85,2.25_)	(1,1.45,1.5,2.25)
F2	(0.5,0.72,0.76,0.9)	(0.5,0.68,0.74,0.9)	(0.4,0.76,0.78,1)	(1,1.75,1.8,2.5)	(1.25,1.85,2,2.5)
F3	(0.4,0.68,0.78,1)	(0.4,0.72,0.76,1)	(0.4,0.68,0.74,1)	(1.25,1.85,2,2.5)	(1.75,2.1,2.2,2.5)
F4	(0.4,0.7,0.78,0.9)	(0.4,0.68,0.74,0.9)	(0.4,0.68,0.74,0.9)	(1,1.6,1.75,2.25)	(1.25,1.6,1.75,2.25)

The best value (f_i^*) and worst value (f_i^-) of crisp fit concept values are identified and it is shown in Table 10.

5. Result

The results derived from the study are presented in this subsection.

Table 9
Crisp values for weights and design ratings.

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10
W	0.72	0.595	1.8	0.72	1.8	0.72	0.69	1.6625	0.705	0.72
F1	0.8	0.775	1.8	0.72	1.9375	0.72	0.76	1.9375	0.72	0.72
F2	0.805	0.775	1.4875	0.675	1.8	0.72	0.56	1.6875	0.695	0.735
F3	0.735	0.72	1.6625	0.68	1.7625	0.76	0.665	1.675	0.65	0.62
F4	0.775	0.775	1.725	0.68	1.8	0.665	0.76	1.8	0.705	0.72
	C11	**C12**	**C13**	**C14**	**C15**	**C16**	**C17**	**C18**	**C19**	**C20**
W	0.705	0.665	0.705	0.705	0.705	0.595	0.595	0.72	1.6625	1.5875
F1	0.76	0.705	0.695	0.745	0.735	0.695	0.68	0.68	1.65	1.9125
F2	0.65	0.665	0.76	0.735	0.745	0.705	0.72	0.705	1.9	2.1375
F3	0.69	0.665	0.635	0.65	0.65	0.72	0.705	0.735	1.7625	1.9
F4	0.705	0.705	0.675	0.73	0.675	0.775	0.665	0.675	1.7625	1.55

Table 10
Calculated best and worst values.

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10
$\mathbf{f}_i^*$	0.72	0.595	1.4875	0.675	1.7625	0.665	0.56	1.6625	0.65	0.62
$\mathbf{f}_i^-$	0.805	0.775	1.8	0.72	1.9375	0.76	0.76	1.9375	0.72	0.735
	C11	C12	C13	C14	C15	C16	C17	C18	C19	C20
$\mathbf{f}_i^*$	0.65	0.665	0.635	0.65	0.65	0.595	0.595	0.675	1.65	1.55
$\mathbf{f}_i^-$	0.76	0.705	0.76	0.745	0.745	0.775	0.72	0.735	1.9	2.1375

Table 11
Calculation of utility, regret measure and VIKOR index.

	F1	F2	F3	F4
S	4.26556	8.72618	12.3844	8.763
R	1.6625	1.8	1.8	1.5875
Q ($v = 0.2$)	0.070588	0.30988	0.4	0.11079

5.1. Measurement of utility, regret and VIKOR indices

The utility (S_i), regret (R_i) and VIKOR index (Q_i) is calculated using Eqs. (7)–(9) [7] and the values are shown in Table 11.

$$S_i = \sum_{j=1}^{n} \frac{w_j^o (f_i^* - f_{ij})}{(f_i^* - f_i^-)}, \tag{7}$$

$$R_i = \max_i \left(\frac{w_j^o (f_i^* - f_{ij})}{(f_i^* - f_i^-)} \right), \tag{8}$$

$$Q_i = \frac{v(S_i - S^*)}{S^- - S^*} + \frac{(1 - v)(R_i - R^*)}{R^- - R^*}, \tag{9}$$

where Q_i, represents the ith alternative's VIKOR value, $i = 1, 2, \ldots, m$;

Here, v is the weight for the strategy of "the majority of criteria" (or "the maximum group utility"), and $1 - v$ is the weight of the individual regret. Based on the VIKOR value, best solution is determined. (i.e., the alternative having the least VIKOR

Table 12
Ranking of design alternatives.

	1	2	3	4
S	F1	F2	F4	F3
R	F4	F1	F2	F3
Q ($v = 0.2$)	F1	F4	F2	F3

Fig. 2. Selected concept design.

value is the best solution). For determining the rank of the alternatives, S_i, R_i, Q_i values are arranged in increasing order and it is shown in Table 12. It is evident that (F1) fit concept has the least VIKOR (Q_i) value. For finding the compromise solution, the rankings has to be further refined [7].

5.2. Proposing compromise solution

This step deals with improving the alternatives for a compromise solution. The alternative ($A^{(1)}$), i.e., the alternative with highest rank by arranging S_i, R_i, Q_i in increasing order is considered to be the compromise solution if and only two conditions C_1 and C_2 are satisfied [7].

C1. *Acceptable advantage*: $Q\left(A^{(2)}\right) - Q\left(A^{(1)}\right) \geqslant 1/(m-1)$, where $A^{(2)}$ is the second position in the alternatives ranked by Q.

C2. *Acceptable stability in decision making*: Alternative $A^{(1)}$ must also be best ranked by S or/and R. When one of the conditions is not satisfied, a set of compromise solutions is selected.

The set of compromise solutions [7] are composed of:

1. Alternatives $A^{(1)}$ and $A^{(2)}$ if only condition **C2** is not satisfied (or)
2. Alternatives $A^{(1)}, A^{(2)}, \ldots, A^{(m)}$ if condition **C1** is not satisfied. $A^{(M)}$ is calculated using the relation $Q\left(A^{(M)}\right) - Q\left(A^{(1)}\right) < 1/(m-1)$ for maximum M.

In this context, both the conditions are satisfied, therefore the fit concept with least VIKOR index can be selected as the best solution. Hence fit concept (F1) has been selected as the best concept design. The best concept design is shown in Fig. 2.

The concept selection in the context of fit systems is unique. The best compromise solution was derived using Fuzzy VIKOR. The compromise solution derived using Fuzzy VIKOR was found to be effective as the method was found to generate better solution in the context of agile concept selection [11] , material selection in the context of sustainable systems [7].

The selected concept design of the case product is best from fitment perspective, i.e., the concept design possess lean and agile characteristics coupled with sustainable benefits. The best concept design was selected based on the formulated MCDM problem encompassed with multiple criteria and solution derivation using VIKOR. The practicing engineers also agreed with the selected concept design. The conduct of the study enabled the practicing engineers to formulate the concept design as MCDM problem and solution generation using appropriate methodology. The selected concept design was subjected to implementation in the case organisation.

6. Conclusion

Fit manufacturing system is a competitive paradigm enabling manufacturing organisations to sustain global competitiveness. The selection of concept design involves multiple criteria from agile, lean and sustainability perspectives. In the present study, fuzzy VIKOR was used for selecting the best fit concept design by means of computing utility, regret and indices. Based on the computations, concept design (**F1**) was found to be the best design. The selected design was subjected to implementation in the case organisation. The selected concept design was found to possess lean and agile features encompassed with sustainable benefits. The study is unique as it presents concept design selection for fit systems as a typical MCDM problem and solution generation using VIKOR in a fuzzy environment.

In the present study, fuzzy VIKOR was deployed for providing solution for concept selection problem in the context of fit manufacturing. In future, more number of concept design selection problems could be solved using fuzzy VIKOR; also hybrid MCDM methods could be explored for solution generation. Furthermore, variety of application problems in the context of fit manufacturing could be formulated as MCDM problems for effective solution generation.

References

[1] D.T. Pham, O. Adebayo-Williams, A.J. Thomas, R. Barton, Z. Ebrahim, T. Shamsuddin, Fit Manufacturing: A Strategy for Achieving Economic Sustainability, Innovative production machines and systems, 2008.

[2] D.T. Pham, P.T.N. Pham, A. Thomas, Integrated production machines and systems – beyond lean manufacturing, J. Manuf. Technol. Manage. 19 (6) (2008) 695–711.

[3] D.T. Pham, A.J. Thomas, Fit manufacturing: a framework for sustainability, J. Manuf. Technol. Manage. 23 (1) (2012) 103–123.

[4] S. Opricovic, Fuzzy vikor with an application to water resource planning, Expert Syst. Appl. 38 (2011) 12983–12990.

[5] D.T. Pham, R. Barton, A. Thomas, O. Williams, T. Shamsuddin, Ebrahim, Z, Fit Manufacturing, Innovative production machines and systems, 2007.

[6] D.T. Pham, Z. Ebrahim, T. Shamsuddin, R. Barton, O. Williams, Relationship Between Lean Manufacturing, Agile Manufacturing and Sustainability, Innovative production machines and systems, 2008.

[7] R. Jeya Girubha, S. Vinodh, Application of fuzzy VIKOR and environmental impact analysis for material selection of an automotive component, Mater. Des. 37 (2012) (2012) 478–486.

[8] A. Shemshadi, H. Shirazi, M. Toreihi, M.J. Tarokh, A fuzzy VIKOR method for supplier selection based on entropy measure for objective weighting, Expert Syst. Appl. 38 (2011) 12160–12167.

[9] K. Devi, Extension of VIKOR method in intuitionistic fuzzy environment for robot selection, Expert Syst. Appl. 38 (2011) 14163–14168.

[10] A. Sanayei, S.F. Mousavi, A. Yazdankhah, Group decision making process for supplier selection with VIKOR under fuzzy environment, Expert Syst. Appl. 37 (2010) 24–30.

[11] S. Vinodh, A.R. Varadharajan, A. Subramanian, Application of fuzzy VIKOR for concept selection in an agile environment, Vol. 65, Int. J. Adv. Manuf. Technol. 65 (5–8) (2013) 825–832.

[12] S. Vinodh, S.K. Chintha, Leanness assessment using multi-grade fuzzy approach, Int. J. Prod. Res. 49 (2) (2010) 431–445.

[13] S. Opricovic, G.H. Tzeng, Compromise solution by MCDM methods: a comparative analysis of VIKOR and TOPSIS, Eur. J. Oper. Res. 156 (2004) 445–455.

[14] S. Opricovic, G.H. Tzeng, Extended VIKOR method in comparison with outranking methods, Eur. J. Oper. Res. 178 (2007) 514–529.

[15] G. Jung, S.M. Kim, S.Y. Kim, E.S. Jung, S. Park, Effects of design factors of the instrument cluster panel on consumers' affection, in: Proceedings of the International Multiconference of Engineers and Computer Scientists 2010, vol. III, March 17–19, Hong Kong, 2010.

[16] S. Opricovic, Multicriteria optimization of civil engineering systems, Faculty of Civil Engineering, Belgrade, 1998.