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## Superiority of fuzzy AHP-VIKOR approach in an agile environment

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K. Jayakrishna and S. Aravind Raj\*

Department of Manufacturing Engineering,  
School of Mechanical Engineering,  
Vellore Institute of Technology,  
Vellore, Tamil Nadu, India  
Email: mail2jaikrish@gmail.com  
Email: aravindsakthivel@hotmail.com  
\*Corresponding author

S. Vinodh

Department of Production Engineering,  
National Institute of Technology,  
Tiruchirappalli, Tamil Nadu, India  
Email: vinodh\_sekar84@yahoo.com

G. Rajyalakshmi and Sanchitha Sharma

Department of Manufacturing Engineering,  
School of Mechanical Engineering,  
Vellore Institute of Technology,  
Vellore, Tamil Nadu, India  
Email: rajyalakshmed@gmail.com  
Email: sanchita.sharma2015@vit.ac.in

**Abstract:** Agile manufacturing (AM) system focuses on the customised production with shorter lead time in a cost effective manner. Conceptual design is a vital phase of product development and AM obliges towards it. Selecting appropriate conceptual design often involves consideration of multiple factors, multi criteria decision making (MCDM) techniques facilitates in resolving this problem. In this study, hybrid fuzzy analytical hierarchical process (AHP) and fuzzy VIKOR approach was used for selecting the best conceptual design of instrument panel (IP). The article focuses on development of various concept designs for IP considering the recent manufacturing and technological aspects. Appropriate agile criteria were identified through several brainstorming sessions conducted among the stakeholders of the organisation. Fuzzy AHP model was used to compute the weights of the proposed conceptual designs and fuzzy VIKOR was used to select the best suited conceptual design. The case study was also practically validated in a manufacturing scenario.

**Keywords:** agile manufacturing; multi criteria decision making; MCDM; analytical hierarchical process; AHP; VIKOR; concept design.

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**Biographical notes:** K. Jayakrishna is working as an Associate Professor in the School of Mechanical Engineering at the VIT University at Vellore. He received his Doctorate in Production Engineering from the National Institute of Technology, Tiruchirappalli in 2014, Master in Production Engineering from P.S.G College of Technology, Coimbatore in 2009 and Bachelor in Mechanical Engineering from Anna University, in 2006. His research is focused on sustainable manufacturing processes and their applications in automotive industries. His current work at VIT University investigates on imbibing sustainable manufacturing practices into ERP systems for Industry 4.0, developing hybrid composites for aerospace applications. He has published 23 international journals papers in leading SCI/SCOPUS indexed journals and more than 60 papers in International conferences. He has also published and edited two books, authored six book chapters. He is an editorial board member and reviewer of reputed international journals. He has received several awards including MHRD Postgraduate and Doctoral scholarships.

S. Aravind Raj is currently working as an Assistant Professor – Senior in the School of Mechanical Engineering at the VIT University at Vellore. He received his Doctorate in Industrial Engineering from the National Institute of Technology, Tiruchirappalli in 2014 and Master in Production Engineering from P.S.G College of Technology, Coimbatore in 2009 and Bachelor in Mechanical Engineering from Jayaram College of Engineering and Technology, in 2007. He has published 16 international journals papers in leading SCI/SCOPUS indexed journals and 31 papers in international conferences. He is co-author for four book chapters. He is a reviewer of reputed international journals. He has received several awards including Doctoral scholarship and Best Paper Award.

S. Vinodh is an Associate Professor in the Production Engineering Department of National Institute of Technology, Tiruchirappalli, India. He completed his PhD from PSG College of Technology, Coimbatore, India. He was a gold medallist in his undergraduate and postgraduate studies. He has been awarded Highly Commended Paper Award and Outstanding Paper Award by EmeraldPublishers, UK for the year 2009 and 2011. He has published over 100 papers in international journals and in proceedings of the leading national and international conferences. His research interests include agile, lean and sustainable systems and multi-criteria decision making

G. Rajyalakshmi is working as an Associate Professor in School of Mechanical Engineering, Vellore Institute of Technology, Vellore, Tamilnadu, India. He obtained his Doctorate degree from Sri Venkateswara University, Tirupati, in the area of 'process parameters optimisation of WEDM process on superalloys'. Currently he is working in the area of composite materials, smart materials for aerospace, marine applications, laser peening, advanced machining process, optimisation and industrial engineering.

Sanchitha Sharma is an undergraduate student in the School of Mechanical Engineering, Vellore Institute of Technology, Vellore, India. Her area of interest includes industrial engineering and multi-criteria decision making.

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## **1 Introduction**

Recent manufacturing scenario strives to cope up with dynamic customer needs; which can be easily handled using agile manufacturing (AM) strategies (Gunasekaran, 1999; Gunasekaran et al., 2008). AM strategies are used to handle unexpected market changes and to develop and launch any product with short lead time to market. The term agility plays a vital role in the competitive market, which forces the manufacturers to develop new products in a faster manner; by responding to the customer requirements and to retain them (Vinodh et al., 2008a; Alexopoulos et al., 2007; Brown and Bessant, 2003). Significant studies were reported on AM and agility assessment of the organisation by researchers.

A new concept model was developed for agile concept design selection to make the design selection easy and well informed. The new model developed consists of ten vital agile criteria. This article focuses on the development of various concept designs of instrument panel and to select the best design. Fuzzy AHP is an appropriate methodology to select the various types of alternate designs and has the ability to be used as a decision-making analysis tool since it handles uncertain and imprecise data. But this advantage makes fuzzy AHP a highly complex methodology that requires more numerical calculations in assessing composite priorities than the traditional AHP and in return increases the efforts as well. Fuzzy VIKOR on the other hand can handle multiple criteria associated with the selection process. But in certain situations, fuzzy VIKOR ends up with more than one solution and then based on the acceptable advantage and acceptable stability conditions, the compromise solution needs to be derived which increases the number of steps performed to make a decision. Concept model design criteria weightage was identified using fuzzy AHP and the suitable design out of the various concept designs in a fuzzy environment selected using fuzzy VIKOR.

## **2 Literature review**

Literature review was conducted from the viewpoints of concept selection and applications of fuzzy AHP and VIKOR.

Lu et al. (2008) have done their work related to methodology selection using fuzzy logic approach; to select the best suited concept with respect to customer needs. This work was the combined approach of utility scoring and Pugh matrix, using linguistic fuzzy values. Okudan and Shirwaiker (2006) have done their work related to concept selection as multi stage decision problem. This innovative model was used in potential decision making in critical environment. Ayag (2005) have done their work in a product development environment, where alternates were selected using AHP which is commonly used in a MCDM problem. The advantage of this approach was selection of concept design by ranking them respective to their scores. Vinodh et al. (2011) have done concept selection using fuzzy analytical network process (ANP). The authors applied a total agile design system (TADS) model which was used to generate new product according to customers' aspirations. Peyman Babashamsi, Amin Golzadfar, Nur Izzi Md Yusoff, Halil Ceylan and Nor Ghani Md Nor have addressed the prioritisation of pavement maintenance alternatives by integrating the fuzzy analytic hierarchy process (AHP) with the VIKOR method for the process of multi-criteria decision analysis (MCDA) by

considering various pavement network indices. The indices selected include the pavement condition index (PCI), traffic congestion, pavement width, improvement and maintenance costs and the time required to operate. In order to determine the weights of the indices, the fuzzy AHP is used. Following that, the alternatives' priorities are ranked according to the indices weighted with the VIKOR model. The choice of these two independent methods was motivated by the fact that integrating fuzzy AHP with the VIKOR model can assist decision makers with solving MCDA problems. Kaya and Kahraman (2011) have done work related to forecasting using AHP and VIKOR. The authors have developed MCDA model. They have computed the weights using pair wise comparison and further used VIKOR for best concept selection. Fu et al. (2011) have done their work related using fuzzy AHP and VIKOR for hotel industry. This study focuses on the selection of best suited benchmarking principles from the survey. Weights were identified using fuzzy AHP and best suited tool selected using VIKOR. Shemshadi et al. (2011) have done supplier selection using fuzzy VIKOR. The inputs were gathered in linguistic format as trapezoidal values and further used as numerical values for computation. Mohammady and Amid (2011) have explored their work in integrating fuzzy AHP and fuzzy VIKOR for supplier selection. This work mainly focuses about outsourcing and a framework to handle complex situations across the supply chain. This work provides a best decision making model in critical situations and during turbulent market condition. Concept design selection is a typical MCDM problem; integrated MCDM methods prove to be effective than single MCDM methods. In this context integrated Fuzzy AHP-VIKOR approach was used to select best design considering agile factors to fulfil existing research gap.

Research objectives addressed in the present study include:

- How to formulate agile concept design case as a typical MCDM problem?
- How to systematically apply the integrated MCDM methods for concept design selection in a typical agile environment?

### **3 Methodology**

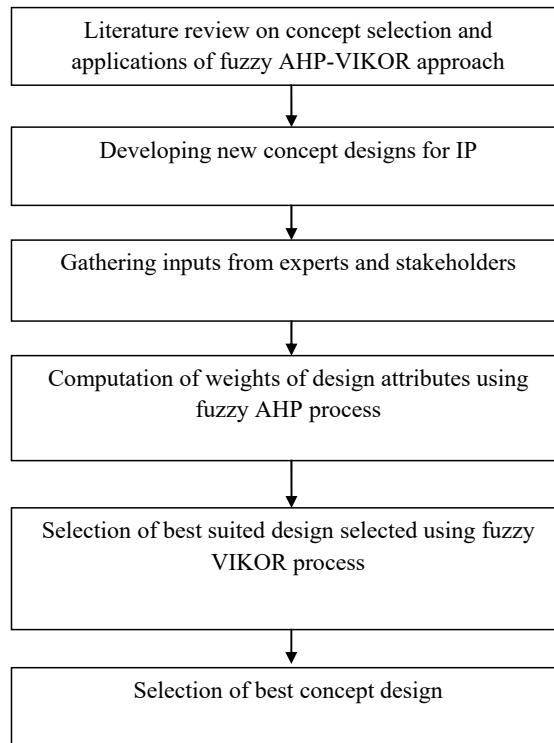
The study was initiated with the development of concept designs for instrument panel, identification of agile criteria and selection of suitable integrated MCDM methods. Primarily based on the stakeholders' inputs, weights of agile criteria were calculated using AHP. In continuation to that secondary computations were carried out using Fuzzy VIKOR to select the best conceptual design. The selected best conceptual design of the IP was adopted by the case organisation.

### **4 Case study**

The inspiration for this research came from the observation that most of the organisations are in the process of agile transformation. Further, it was found that understanding the customer requirements is important and to convert those needs into a desirable design, acceptable and appreciated by the customer, is a very tedious and lengthy task. Thus, to find an alternative of this difficulty, this research was carried out. The study reported in this article was carried out in Tier1 automotive supplier firm located in Bengaluru, India.

This forces the organisation to be more agile to respond to various needs of customers. This study focuses towards the development of customised concept design for IP and to select the best design. An expert team was formulated with professionals across the organisation. The inputs were collected from the expert team and stake holders who possess rich knowledge on designing and manufacturing of IP.

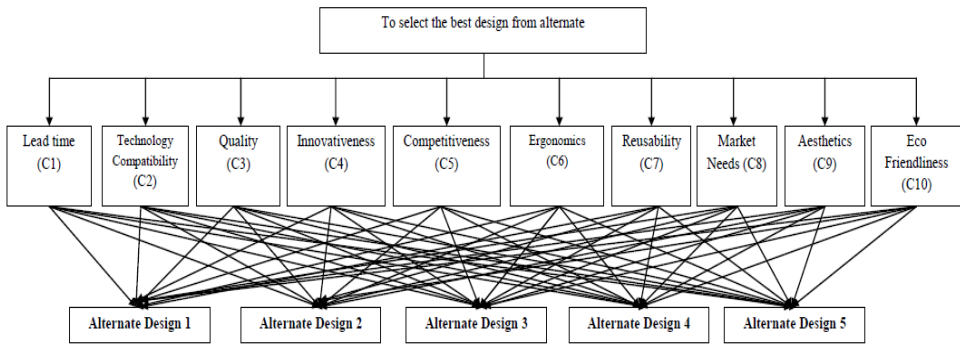
**Figure 1** Methodology



#### 4.1 Concept model

The newly developed concept model mainly consists of ten criteria such as lead time (CR1) (Vinodh et al., 2008a), technology compatibility (CR2) (Tang et al., 2000), quality (CR3) (Vinodh et al., 2008b), innovativeness (CR4) (Hsiao and Chou, 2004), competitiveness (CR5) (Vinodh et al., 2008a), ergonomics (CR6) (Hsiao and Chou, 2004), reusability (CR7) (Girubha and Vinodh, 2012), market needs (CR8) (Vinodh et al., 2008b), aesthetics (CR9) (Hsiao and Chou, 2004) and eco-friendliness (CR10) (Girubha and Vinodh, 2012). These ten criteria mainly focus on the development of newer concept design from the base design of the IP. Considering the market needs and customers' expectations the manufacturer decided to adopt new design and also to increase the product variety by improving functionalities of the existing product to next level. Figure 2 shows the AHP concept model and Table 1 defined the ten agile criteria and their correlation with the concept selection.

**Figure 2** Concept model



**Table 1** Importance of the design criterion

<i>Design criterion</i>	<i>Importance of the criterion</i>
Lead time (CR1)	Lead time reduction is a key aspect in new product development which tends the launch of new product in short span of time.
Technology compatibility (CR2)	Adopting newer technology in a newly developing product is necessary to be updated in the market.
Quality (CR3)	Improvising the quality of the product by enhancing the maintenance across its life cycle.
Innovativeness (CR4)	Implementing new concepts and features in a newly developing product.
Competitiveness (CR5)	Highly competitive in performance compared with the competitors' product.
Ergonomics (CR6)	Ease of handling and operating by assigning values to the human factors in engineering.
Reusability (CR7)	Providing avenue for updating the existing version to be updated with minor modifications leading to minimisation of various wastages across manufacturing.
Market needs (CR8)	Customer voice has to be captured rightly and implemented while developing a new product.
Aesthetics (CR9)	Appearance of the product plays a vital role in market, which mainly focuses on the sales of the product next to its technical competitiveness.
Eco-friendliness (CR10)	Using environmentally friendly materials design and manufacturing processes.

*4.2 Application of fuzzy AHP for generation of agile criteria weights*

AHP is a MCDM technique used to find the interdependency between the criteria (Saaty, 1989, 2005). In this study fuzzy AHP was used to compute the weights of the agile concept design criteria with the inputs from the expert team (ET). Table 2 shows the pair wise comparison matrix. Fuzzy AHP is a complex methodology which requires more numerical calculations in assessing the key design parameters, desirable by the customer, than the traditional AHP and hence it increases the effort. But in addition with this complexity, fuzzy methodology can be extended with the other multi-criteria

decision-making (MCDM) methods such as analytical network process (ANP), TOPSIS, ELECTRE and DEA techniques in solving any problem and hence, due to its versatility, fuzzy AHP methodology is used instead of the traditional AHP method.

**Table 2** Pair wise comparison of design criteria

	<i>CR1</i>	<i>CR2</i>	<i>CR3</i>	<i>CR4</i>	<i>CR5</i>	<i>CR6</i>	<i>CR7</i>	<i>CR8</i>	<i>CR9</i>	<i>CR10</i>
CR1	1	1.5	1.5	3	3	5	5	7	7	9
CR2	0.75	1	1.5	1.5	3	3	5	5	7	7
CR3	0.75	0.75	1	1.5	1.5	3	3	5	5	7
CR4	0.375	0.75	0.75	1	1.5	1.5	3	3	5	5
CR5	0.375	0.375	0.75	0.75	1	1.5	1.5	3	3	5
CR6	0.204	0.375	0.375	0.75	0.75	1	1.5	1.5	3	3
CR7	0.204	0.204	0.375	0.375	0.75	0.75	1	1.5	1.5	3
CR8	0.146	0.204	0.204	0.375	0.375	0.75	0.75	1	1.5	1.5
CR9	0.146	0.146	0.204	0.204	0.375	0.375	0.75	0.75	1	1.5
CR10	0.11	0.146	0.146	0.204	0.204	0.375	0.375	0.75	0.75	1

The upper triangular values were filled with values using the Saaty scale (Saaty, 1989) and the lower triangular values were generated from their inverse values. The consistency index and the consistency ratio were computed using equation (1) and equation (2) (Dagdeviren et al., 2009).

$$CI = \frac{\lambda_{max} - n}{n - 1} \tag{1}$$

$$CR = \frac{CI}{RI} \tag{2}$$

where *RI*, random index which was considered as ‘1.24’ (Dagdeviren et al., 2009). Based on the computation, the weights of the agile concept design criteria were computed which were used as input to Fuzzy VIKOR technique to compute the best suited concept design alternative.

**Table 3** Weights of concept design criteria

<i>Criteria</i>	<i>Weights</i>
CR1	0.247967797
CR2	0.192981085
CR3	0.153548538
CR4	0.115210255
CR5	0.088791621
CR6	0.064678756
CR7	0.049437236
CR8	0.036345162
CR9	0.028841645
CR10	0.022197905

Note:  $D_{max} = 10.5166$ ,  $CI = 0.0574$ ,  $RI = 1.24$  and  $CR = 0.0458$ .

4.3 Application of fuzzy VIKOR for prioritising the concept design

4.3.1 Data collection

VIKOR was used to compute the compromise solutions from the group of alternates; compromising solution means the most possible nearer solution from the group of alternates. In this research, fuzzy VIKOR methodology has been used because it gives one or more solutions as the end result and based on the acceptable advantages and acceptable stability conditions, the compromise solution needs to be derived. The solution thus derived from the study, needs to be checked for practical feasibility by the decision makers in order to obtain a well studied and interpreted decision. The inputs collected from stakeholders are gathered in the form of trapezoidal fuzzy values and further converted into numerical values presented in Table 3 and Table 4 respectively. Table 5 presents the input values for various design criteria provided by stakeholders.

**Table 4** Trapezoidal fuzzy inputs gathered from decision makers

		<i>C1</i>	<i>C2</i>	<i>C3</i>	<i>C4</i>	<i>C5</i>	<i>C6</i>	<i>C7</i>	<i>C8</i>	<i>C9</i>	<i>C10</i>
Expert 1	Design 1	FH	M	VH	H	H	FH	H	M	FH	H
	Design 2	M	FH	H	H	H	FH	H	FH	H	FH
	Design 3	VH	H	VH	H	H	VH	H	VH	H	VH
	Design 4	FH	H	H	H	H	H	H	H	FH	H
	Design 5	FH	H	FH	H	H	H	FH	H	FH	H
Expert 2	Design 1	FH	VH	M	H	VH	H	H	H	M	H
	Design 2	FH	M	FH	M	FH	M	M	M	M	M
	Design 3	H	VH	H	VH	H	VH	H	H	H	H
	Design 4	H	H	FH	H	FH	H	FH	FH	FH	M
	Design 5	FH	M	FH	M	FH	M	H	H	H	H
Expert 3	Design 1	M	FH	H	H	FH	H	H	VH	H	H
	Design 2	FH	FH	H	H	H	H	FH	H	FH	H
	Design 3	M	H	M	M	H	FH	FH	FH	FH	H
	Design 4	FH	FH	M	M	H	FH	FH	M	M	M
	Design 5	FH	M	M	FH	FH	M	H	M	M	H
Expert 4	Design 1	FH	H	H	M	FH	H	VH	H	H	VH
	Design 2	FH	FH	H	H	H	H	FH	H	FH	H
	Design 3	M	M	FH	FH	FH	H	FH	M	H	M
	Design 4	FH	H	FH	FH	M	M	H	M	FH	M
	Design 5	FH	FH	H	H	H	FH	H	FH	H	FH
Expert 5	Design 1	H	H	H	M	H	VH	H	M	FH	M
	Design 2	M	FH	H	H	H	H	FH	H	FH	H
	Design 3	M	M	H	FH	FH	H	M	M	M	H
	Design 4	FH	FH	H	M	M	FH	FH	FH	M	M
	Design 5	M	FH	FH	M	M	H	H	FH	H	FH



**Table 5** Trapezoidal fuzzy numbers used in this study

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)

Source: Girubha and Vinodh (2012)

### 4.3.2 Aggregation of values

The aggregated fuzzy ratings ( $A_{ij}$ ) of alternates were compared to individual criterion using equation (3); similarly the aggregated fuzzy weight ( $W_j$ ) was computed using equation (4) (Shemshadi et al., 2011; Girubha and Vinodh, 2012).

$$A_{ij} = \{A_{ij1}, A_{ij2}, A_{ij3}, A_{ij4}\} \tag{3}$$

where

$$A_{ij1} = \min \{A_{ijk1}\}$$

$$A_{ij2} = \frac{1}{k} S A_{ijk2}$$

$$A_{ij3} = \frac{1}{k} S A_{ijk3}$$

$$A_{ij4} = \min \{A_{ijk4}\}$$

$$W_j = \{W_{j1}, W_{j2}, W_{j3}, W_{j4}\} \tag{4}$$

where

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

$$W_{j2} = \frac{1}{k} S W_{jk2}$$

$$W_{j3} = \frac{1}{k} S W_{jk3}$$

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

Table 7 depicts the excerpt of computed aggregated matrix computed using equations (3) and (4), which was further used to compute the decision matrix of individual criterion.

**Table 6** Trapezoidal numerical values for design criteria

	CR1	CR2	CR3	CR4	CR5	CR6	CR7	CR8	CR9	CR10
Expert 1	(0.5, 0.6, 0.7, 0.8)	(0.4, 0.5, 0.5, 0.6)	(0.8, 0.9, 1.0, 1.0)	(0.7, 0.8, 0.8, 0.9)	(0.7, 0.8, 0.8, 0.9)	(0.5, 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)	(0.7, 0.8, 0.8, 0.9)
Design 1	(0.5, 0.6, 0.7, 0.8)	(0.4, 0.5, 0.5, 0.6)	(0.8, 0.9, 1.0, 1.0)	(0.7, 0.8, 0.8, 0.9)	(0.7, 0.8, 0.8, 0.9)	(0.5, 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)	(0.7, 0.8, 0.8, 0.9)
Design 2	(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)	(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)	(0.5, 0.6, 0.7, 0.8)
Design 3	(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)	(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)	(0.7, 0.8, 0.8, 0.9)	(0.8, 0.9, 1.0, 1.0)
Design 4	(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)	(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)	(0.7, 0.8, 0.8, 0.9)
Design 5	(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)	(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)

**Table 7** Excerpt of aggregated values by DM1

	CR1	CR2	CR3	CR4	CR5	CR6	CR7	CR8	CR9	CR10
Expert 1										
Design 1	(0.5, 0.6, 0.7, 0.8)	(0.4, 0.5, 0.5, 0.6)	(0.8, 0.9, 1.0, 1.0)	(0.7, 0.8, 0.8, 0.9)	(0.7, 0.8, 0.8, 0.9)	(0.5, 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)	(0.7, 0.8, 0.8, 0.9)
Design 2	(0.5, 0.6, 0.7, 0.8)	(0.8, 0.9, 1.0, 1.0)	(0.4, 0.5, 0.5, 0.6)	(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)	(0.7, 0.8, 0.8, 0.9)	(0.4, 0.5, 0.5, 0.6)	(0.7, 0.8, 0.8, 0.9)
Design 3	(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)	(0.5, 0.6, 0.7, 0.8)	(0.7, 0.8, 0.8, 0.9)	(0.7, 0.8, 0.8, 0.9)	(0.8, 0.9, 1.0, 1.0)	(0.7, 0.8, 0.8, 0.9)	(0.7, 0.8, 0.8, 0.9)
Design 4	(0.5, 0.6, 0.7, 0.8)	(0.7, 0.8, 0.8, 0.9)	(0.7, 0.8, 0.8, 0.9)	(0.4, 0.5, 0.5, 0.6)	(0.5, 0.6, 0.7, 0.8)	(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)
Design 5	(0.4, 0.5, 0.5, 0.6)	(0.7, 0.8, 0.8, 0.9)	(0.7, 0.8, 0.8, 0.9)	(0.8, 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)	(0.4, 0.5, 0.5, 0.6)	(0.5, 0.6, 0.7, 0.8)	(0.4, 0.5, 0.5, 0.6)

**Table 8** Excerpt of normalized matrix using DM1

	CR1	CR2	CR3	CR4	CR5	CR6	CR7	CR8	CR9	CR10
Expert 1										
Design 1	(0.4, 0.62, 0.68, 0.9)	(0.4, 0.72, 0.76, 1)	(0.4, 0.76, 0.78, 1)	(0.7, 0.82, 0.84, 1)	(0.5, 0.74, 0.8, 1)	(0.5, 0.78, 0.82, 1)	(0.7, 0.82, 0.84, 1)	(0.4, 0.7, 0.72, 1)	(0.4, 0.66, 0.7, 0.9)	(0.4, 0.76, 0.78, 1)
Design 2	(0.4, 0.56, 0.62, 0.8)	(0.4, 0.58, 0.66, 0.8)	(0.5, 0.76, 0.78, 0.9)	(0.4, 0.74, 0.74, 0.9)	(0.5, 0.76, 0.78, 0.9)	(0.4, 0.7, 0.72, 0.9)	(0.4, 0.62, 0.68, 0.9)	(0.4, 0.7, 0.72, 0.9)	(0.4, 0.62, 0.68, 0.9)	(0.4, 0.7, 0.72, 0.9)
Design 3	(0.4, 0.64, 0.66, 1)	(0.4, 0.7, 0.72, 1)	(0.4, 0.72, 0.76, 1)	(0.4, 0.68, 0.74, 1)	(0.5, 0.72, 0.76, 0.9)	(0.5, 0.8, 0.86, 1)	(0.4, 0.66, 0.7, 0.9)	(0.4, 0.66, 0.7, 1)	(0.4, 0.7, 0.72, 0.9)	(0.4, 0.76, 0.78, 1)
Design 4	(0.5, 0.64, 0.72, 0.9)	(0.5, 0.72, 0.76, 0.9)	(0.4, 0.66, 0.7, 0.9)	(0.4, 0.64, 0.66, 0.9)	(0.4, 0.64, 0.66, 0.9)	(0.4, 0.66, 0.7, 0.9)	(0.5, 0.68, 0.74, 0.9)	(0.4, 0.6, 0.64, 0.9)	(0.4, 0.56, 0.62, 0.8)	(0.4, 0.56, 0.56, 0.9)
Design 5	(0.4, 0.58, 0.66, 0.8)	(0.4, 0.6, 0.64, 0.9)	(0.4, 0.62, 0.68, 0.9)	(0.4, 0.64, 0.66, 0.9)	(0.4, 0.66, 0.7, 0.9)	(0.4, 0.64, 0.66, 0.9)	(0.5, 0.76, 0.78, 0.9)	(0.4, 0.66, 0.7, 0.9)	(0.4, 0.7, 0.72, 0.9)	(0.5, 0.72, 0.76, 0.9)

### 4.3.3 Normalisation

Normalisation is the process of converting dimensional criterion values into dimensionless values. Normalisation was carried out to eliminate the process dimensions. VIKOR uses linear normalisation (Opricovic, 1998). The properties which possess maximum value are known as positive criterion or beneficiary attributes while properties possessing minimum value are to be negative or cost criterion (Opricovic, 2011). Normalised values are computed by the ratio between cost criterions to minimum value and benefit criterion to maximum value using equations (5) and (6) (Shemshadi et al., 2011; Girubha and Vinodh, 2012). Table 8 shows the excerpt of normalised values.

$$u_{ij} = \left( \frac{x_{ij1}}{x_{ij4}^+}, \frac{x_{ij2}}{x_{ij4}^+}, \frac{x_{ij3}}{x_{ij4}^+}, \frac{x_{ij4}}{x_{ij4}^+} \right), C_j \in B \tag{5}$$

$$u_{ij} = \left( \frac{x_{ij1}}{x_{ij1}^-}, \frac{x_{ij2}}{x_{ij1}^-}, \frac{x_{ij3}}{x_{ij1}^-}, \frac{x_{ij4}}{x_{ij1}^-} \right), C_j \in C \tag{6}$$

where

$C_j$  denotes the  $j^{\text{th}}$  criterion

$$x_{ij4}^+ = \max_i \{\text{decision matrix}\}, C_j \in B \tag{7}$$

$$x_{ij1}^- = \min_i \{\text{decision matrix}\}, C_j \in C \tag{8}$$

### 4.3.4 Defuzzification

Fuzzy weights and importance rating pertaining to design criteria were defuzzified using equation (9) to obtain crisp values (Shemshadi et al., 2011; Girubha and Vinodh, 2012). The crisp values obtained are shown in Table 9.

**Table 9** Defuzzified crisp values

	CR1	CR2	CR3	CR4	CR5	CR6	CR7	CR8	CR9	CR10
Design 1	0.65	0.72	1.8375	0.84	0.76	1.9375	0.84	0.705	0.738889	0.735
Design 2	0.595	0.61	1.8375	0.695	0.735	1.7	0.65	0.68	0.722222	0.68
Design 3	0.675	0.705	1.8	0.705	0.72	1.975	0.665	0.69	0.755556	0.735
Design 4	0.69	0.72	1.6625	0.65	0.65	1.6625	0.705	0.635	0.661111	0.605
Design 5	0.61	0.635	1.625	0.65	0.665	1.625	0.735	0.665	0.755556	0.72

$$Defuzz(X_{ij}) = \frac{\int \mu(x).xdx}{\int \mu(x)dx} = \frac{-x_{ij1}x_{ij2} + x_{ij3}x_{ij4} + \frac{1}{3}(x_{ij4} - x_{ij3}) - \frac{1}{3}(x_{ij2} - x_{ij1})^2}{-x_{ij1} - x_{ij2} + x_{ij3} + x_{ij4}} \tag{9}$$

The best ( $f_i^*$ ) and worst ( $f_i^-$ ) value of the design concepts were identified from the crisp values and presented in Table 10.

**Table 10** Best and worst values of crisp values

Max value	0.69	0.72	1.8375	0.84	0.76	1.975	0.84	0.705	0.755556	0.735
Min value	0.595	0.61	1.625	0.65	0.65	1.625	0.65	0.635	0.661111	0.605

4.3.5 Measurement of utility, regret and VIKOR indices

The utility ( $S_i$ ), regret ( $R_i$ ) and VIKOR index ( $Q_i$ ) was computed using equations (10–12) respectively (Vinodh et al., 2011, 2008a), (Shemshadi et al., 2011; Girubha and Vinodh, 2012) and the values are shown in Table 11.

$$S_i = \sum_{j=1}^n \frac{w_j (f_i^* - f_{ij})}{(f_i^* - f_i^-)} \tag{10}$$

$$R_i = \max_i \left( \frac{w_j (f_i^* - f_{ij})}{(f_i^* - f_i^-)} \right) \tag{11}$$

$$Q_i = \frac{v(S_i - S^*)}{S^- - S^*} + \frac{(1-v)(R_i - R^*)}{R^- - R^*} \tag{12}$$

where,  $Q_i$  represents the  $i^{th}$  alternative VIKOR value,  $i = 1, 2, \dots, m$ .

**Table 11** Utility, regret measure and VIKOR indices for concept designs

	Design 1	Design 2	Design 3	Design 4	Design 5
S	0.116	0.681	0.260	0.510	0.818
R	0.104	0.247	0.081	0.126	0.208
Q (v = 0.8)	0.027	0.844	0.217	0.502	0.952

5 Results and discussion

The parameter ‘v’ was introduced to know the weight strategy of the major criteria, i.e., the maximum utilised group, also ‘1 – v’ is used to compute the individual regret. The alternate which has least VIKOR value is said to be the best suited concept (Girubha and Vinodh, 2012). By arranging the  $S_i$ ,  $R_i$  and  $Q_i$  values in ascending order the ranking order is shown in Table 12. It is clear that design 1 (D1) possess the least value in  $Q_i$  and further compromise solution was used to refine the ranking.

**Table 12** Ranking order of concept designs

	1	2	3	4	5
S	D1	D3	D4	D2	D5
R	D3	D1	D4	D5	D2
Q	D1	D3	D4	D2	D5

5.1 Proposing compromise solution

The compromise solution is used for the selection of alternates in a refined way. The alternate design D1 which has highest rank while arranging  $S_i$ ,  $R_i$  and  $Q_i$  in ascending order is said to be the compromised solution, when the following two conditions C1 and C2 are satisfied (Shemshadi et al., 2011; Girubha and Vinodh, 2012).

Condition 1 (C1) *Acceptable advantage*:  $Q(D2) - Q(D1) \geq 1/(m - 1)$ , where D2 is in second position of the alternates ranked according to  $Q$ .

If the condition C1 is not satisfied, check the below condition i.e., condition C2.

Condition 2 (C2) *Acceptable stability in decision making*: alternate design D1 also ranked considering  $S$  and  $R$ .

If any one of the conditions given is not satisfied, then compromise solution is selected. The set of compromise solutions are composed of:

- 1 Alternate designs D1 and D2 if only condition C2 was not satisfied (or)
- 2 Alternate designs D1, D2, ..., Dm if condition C1 is not satisfied.

$D_m$  was calculated using the relation  $Q(D_m) - Q(D1) < 1/(m - 1)$  for maximum  $m$ .

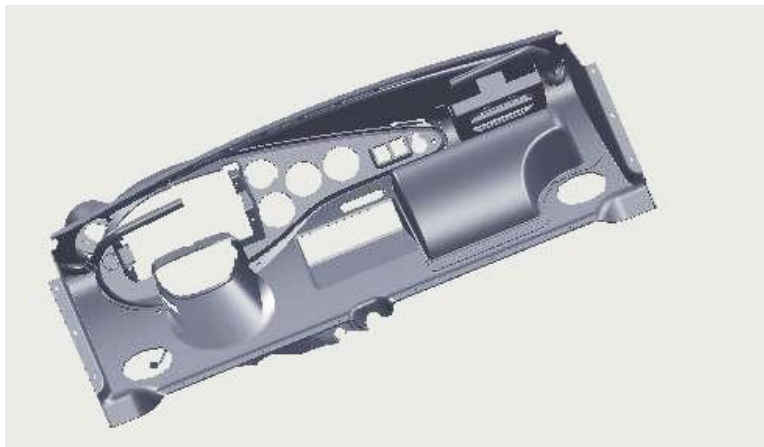
In this study, C2 was satisfied and the best suited design alternates are D1 and D3.

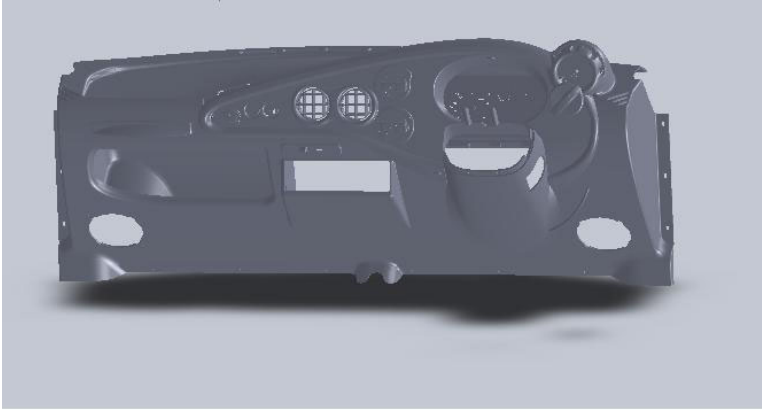
The compromise solution, closest to the ideal was achieved for design 1 and design 3, satisfying conditions C1 and C2 with low VIKOR index value ( $v = 0.8$ ). The ranking order based compromise solution obtained is shown in Table 13, which shows the two best concepts selected from five alternate designs using compromising solution. The selected design alternates are designs 1 and 3 and are shown in Figure 3 and 4.

**Table 13** Ranking order based on compromise solution

Rank	1	2	3	4
Q	D1, D3	D4	D2	D5

**Figure 3** Concept design 1 for instrument panel (see online version for colours)



**Figure 4** Concept design 3 for instrument panel (see online version for colours)

## 6 Conclusions

AM environment is highly unpredictable with dynamic market changes and to keep up with these changes, use of integrated methodologies like fuzzy AHP – VIKOR helps in searching for the appropriate alternate design by keeping the customer requirements in mind easily. The selection of best concept design, in this research, was carried out by considering the multiple agile criteria so as to fulfil the customers varied requirements. The IP is a vital interior part of the automobile which consists of various features related to the user functionality interaction of the vehicle. In this study, the concept selection was done using integrated fuzzy AHP and VIKOR approach. This is a new attempt to integrate both fuzzy AHP and VIKOR for selection of best concept design in an agile environment and was done to benefit from the advantages of both the methodologies equally. The weights of agile concept design criteria were found using fuzzy AHP and the vital agile criteria are lead time, technology compatibility, quality, innovativeness, competitiveness, ergonomics, reusability, market needs, aesthetics and eco-friendliness. The best concept design was selected after considering the customer requirements and coming up with various alternate designs. Those designs were then ranked based upon the  $S_i$ ,  $R_i$  and  $Q_i$  values in ascending order and then two conditions were developed. Depending upon which alternate design satisfied the particular condition, the final solution was selected. In this case two best alternates were identified using compromising solution approach. The best concept alternate designs were found to be  $D1$  and  $D3$ .

The conduct of this research study leads to an inference that the utilisation of integrated MCDM approaches enables the concept selection facility in a better way, thereby facilitating the agility in product development process.



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