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An integrated Fuzzy MCDM approach for modelling and prioritising the enablers of responsiveness in automotive supply chain using Fuzzy DEMATEL, Fuzzy AHP and Fuzzy TOPSIS

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Abstract

In this dynamic environment with unexpected changes and high market rivalry, supply chains focus more on executing responsive strategies with minimum costs. This research paper aims to identify the crucial enablers of responsiveness of the Indian automotive supply chain. Seventeen enablers were identified from the extensive literature and expert interview for supply chain responsiveness and an integrated methodology of Fuzzy multi-criteria decision-making (MCDM) using Fuzzy DEMATEL, Fuzzy AHP and Fuzzy TOPSIS is applied for modelling and prioritising the enablers. The proposed model revealed the most crucial responsiveness enablers for the supply chain. The top three significant causal enablers derived from Fuzzy DEMATEL are Commitment of management and Strategy decision making, Demand forecasting and Continuous improvement. The Fuzzy AHP–Fuzzy TOPSIS result imply that automotive manufacturer should pay close attention towards Commitment of management and Strategy decision making, Waiting period for vehicle's delivery and Demand forecasting. The proposed framework suggests strategic goals to guide different supply chain members and automotive industry decision-makers towards improved supply chain responsiveness.

Keywords Supply chain responsiveness · Fuzzy DEMATEL · Fuzzy AHP · Fuzzy TOPSIS

1 Introduction

Responsiveness in the supply chain is becoming significant nowadays, because of increasing diversity and customisation requirements. Responsiveness is a concept that overturns many conventional business practices of product development, manufacturing, and logistics planning. Kritchanchai and MacCarthy (1999) stated responsiveness as the capability to deliver or sustain competitive advantage promptly against customer demands and market changes. The primary objective of any supply chain is to ensure that the required product is delivered to the consumer at the required time. To make them more efficient, companies need quicker and more versatile supply chains (Gunasekaran et al. 2008). The capability to respond to orders on time can offer a critical competitive advantage of rising product volatility and customisation. Responsiveness makes it possible for businesses to quickly detect changes in the marketplace, reset their processes in order to meet new business demands (Singh 2015). Researchers have performed several studies to build models to improve responsiveness in the supply chain. Holweg (2005a, b) developed a conceptual model to identify the factors influencing Supply chain responsiveness. Singh (2015) identified the critical factors for responsiveness in the supply chain. Reichhart and Holweg (2007, Gunasekaran et al. (2008) have researched a flexible supply chain, which better copes with the demand gap of our times, as an alternative to the efficiency-based supply chain. A significant competitive advantage is to consider and be able to serve the changing customer needs. The impact on the efficiency of an organisation of a sensitive supply chain policy must still be empirically checked. This paper explored the impact of various factors influencing the

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responsiveness of the supply chain in the Indian automotive industry.

The Indian automobile market is the fourth largest in the world with sales rapidly increasing every year and is relied upon to rise as the world's third-biggest passenger car market by 2021 (Shivanshu Gupta, Neeraj Huddar, Balaji Iyer 2018) (Foundation 2019). The automotive industry is one of the powerhouses of the Indian economy, augmenting about 49% to the country's production Gross Domestic Product. The Indian automotive industry has shown continuity in market growth despite economic liberalisation. The Indian automotive supply chain is expected to grow dramatically, due to the evolving market and new capabilities, as this gives the sector competitive advantage. Implementing appropriate supply chain management practice in the current situation will improve responsiveness and efficiency. The automobile market somewhat impacts the country's economy. Vehicle sales regularly go the same way as the economy. The Indian automotive industry has shown a steady market growth since economic liberalisation, significant development has taken place in the technology sector, in communications and transport because of globalisations and rapid change in the government's GST and e-Way bills. Automotive manufacturers are now thinking about techniques to build their responsiveness to market needs by offering a wide variety of vehicles and less lead time. Automobile manufacturing is complex, includes various substructures and uses multiple techniques of production [7]. Sales forecasting and collaboration are contributing to improved organisational performance (Feizabadi 2020). Customers are focussed on the entire automotive supply chain ecosystem with an increased level of product awareness, fast-developing standards and demand for individual products and services. A responsive supply chain aims to deliver the item using sales data and increasing flexibility to respond to evolving consumer demands by streamlining and centralising supply chain planning processes like product creation and business growth (Roh et al. 2014).

The objective of this paper is to identify and analyse the enablers of responsiveness in supply chain management (ReSCM) of Indian automotive industry using a Fuzzy Multi-Criteria Decision Making (MCDM) approach. A comprehensive review of the literature and expert opinion, seventeen enablers of responsiveness were identified. The degree of prominence and cause–effect relation between each enabler is derived using Fuzzy Decision-making Trial and Evaluation Laboratory (DEMATEL) technique and prioritised using Fuzzy Analytic Hierarchy Process (AHP)–Fuzzy Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) approach.

The remainder of this paper is organised as follows. Relevant literature to this work is described in Sect. 2. In Sect. 3, the methodology adopted for this work is explained. Section 4 provides a brief description of the case organisation. Data analysis and results are presented in Sect. 5 and Sect. 6. Conclusions and future scope are proposed.

2 Review of related literature

Responsiveness in supply chain management has attained prominence in the last few years due to its importance in long-term strategic benefits. In the field of supply chain management, the principle of responsiveness in the business enterprises received considerable attention, and it has been introduced as one of the significant aspects of modern supply chain research. This section addresses the literature on responsiveness and its enablers in the Automotive supply chain. It also gives an overview of Fuzzy DEMATEL, Fuzzy AHP, and Fuzzy TOPSIS techniques that are used in this research.

2.1 Enablers of supply chain responsiveness in the automotive industry

The enablers of responsiveness in the supply chain are identified from various works of literature. We used the Web of Science, Google Scholar, Science Direct, Springer and Emerald databases for literature review: The literature has been searched by using combined keywords like "Supply chain Responsiveness" AND "enablers"; "Responsiveness" AND "Supply chain Management"; "Supply chain responsiveness" AND "factors". From the comprehensive literature review and the Brainstorming section with experts from the case company, seventeen enablers relevant to the Automotive supply chain were identified.

Gunasekaran et al. (2008) reported that the enablers of responsiveness in the supply chain are value chain, information technology, and knowledge management. Dubey et al. (2015) established a network for responsive, sustainable supply chain under risk. Management involvement is necessary to provide sustenance for implementing a responsive supply chain. This represents all the management aspects, their policies, attitude, culture, and decisions from the top-level managers. The culture and trust development among the employees will help to create a self-willingness towards putting efforts to meet the market requirement (Colwell and Joshi 2013). The risk management approach of management can build a barrier to the agile supply chain (Ahmed and Huma 2021) (Faisal et al. 2006). Minimum risk mitigation costs will be assessed based on the supply chain development planning for each supply chain where a demand risk or a supply risk exists

(Nooraie et al. 2019). Various supply chain approaches are ideal for specific environmental concerns. Towards the strategic decision, how much efforts are management putting to align the operational and tactical decisions with the strategic one is another enabler for supply chain responsiveness (Kannabiran and Bhaumik 2005). It is observed that continuous improvement is a significant sustainability measure for the automotive industry (Gopal and Thakkar 2016). These can be checked over a period to boost supply chain practices continuously.

The attention paid to quick changes and small part generation enables the company to respond to requests without having large stocks. The demand of customers is more sensitive to a complex set of conditions. The primary apprehension of a supply chain is how its stakeholders are organised to maintain market demand responsiveness (Singh 2015). The situations that make the demand fluctuate and that make it difficult to predict the forecast is referred to as demand uncertainty and variation (Byoungho 2004). Gunasekaran et al. (2008) argued that the resilience of the supply chain must be improved to better respond to dynamic demand and thus to enhance the responsiveness of the supply chain. Customers' mentality on purchasing a vehicle, their priority, waiting period, etc., depends on the responsiveness. Menon (2018) developed a modelling approach to buy passenger cars to test customer expectations, which inevitably trigger car owners' buying behaviour. Purchase decisions initiate when the unique vehicle features attract a customer. Product architecture is the mechanism by which physical components are allocated to the purpose of the system (Ulrich 1995). Challenges of reducing lead time, the supply chain needs to be responsive. More specifically, the lead time will play an essential role in gaining competitive advantages by responding quickly to market demands. Ye and Xu (2010) reported that lead time reduction could altogether diminish the bullwhip impact all through the supply chain.

The business landscape today is characterised by a wide range of consumer tastes and preferences, rapid technological advances, and global management. The use of responsiveness in the supply chain needs an overall effect on consumer conditions when preparing a regular production program. Nowadays, Built-to-order and quickened request satisfaction have been portrayed as a possible key way to deal with improve the responsiveness to demand variability (Gunasekaran and Ngai 2005)(Holweg 2005a). Hill (2009) focussed on that the motivation behind production strategy ought not to be restricted to operational effectiveness in any case, instead, ought to be reached out to the formation of vital favourable circumstances by thinking about market unpredictability and patterns. To accomplish supply chain responsiveness, many production companies depend on interests in cutting edge producing innovation. Manufacturing firms met responsiveness through keeping up high procedure ability to diminish dismissal and improve efficiency to defeat ceaseless increment in inventory and assets cost (Birasnav and Bienstock 2019) (Kim et al. 2013).

Coordination among the supply chain individuals additionally relies on shared trust among supply chain accomplices. The use of information technology makes the data flow across the supply chain smooth and clear. Members in the supply chain should contribute to a single structure and organise coordinated works on information transmission (K. 2013) (Mehrjerdi 2009) (Kumar et al. 2014). A manufacturing firm can pact with market changes better when its supply chain members accompaniment it (Roh et al. 2014). Long-term relationship with the supply chain member will give priority to the manufacturer. It also creates trust between members, and these will help in faster response (Tejpal et al. 2013).Hendricks and Singhal (2009) observed that instead of taking the managing and control of all the inventory by the manufacturer if the responsibility is distributed among the supply chain members, it helps to improve the responsiveness.

Information technology competences and data distribution both have substantial effects on logistics integration (Prajogo and Olhager 2012). Nooraie et al. (2019) propose that the availability of point of sales data is a part of supply chain visibility. Furthermore, Francesca (2008) has stated that sale point data quality for a responsive supply chain is critical. The identified enablers of supply chain responsiveness were summarised and are presented in Table 1.

2.2 Fuzzy multi-criteria decision making (MCDM) method

Multi-Criteria Decision Making was developed as part of operational research to model computational and mathematical methods to enable subjective assessment by decision makers of success parameters (Zavadskas et al. 2014). Many researchers were used the application of fuzzy logic into MCDM technique to solve supply chain problems (Rajak et al. 2016; Chen et al. 2019; Mirzamohammadi et al. 2019; Mohammadfam et al. 2019; Nilashi et al. 2019; Ocampo 2019; Digalwar et al. 2020). Fuzzy logic offers a valuable method for eliminating inconveniences such as imprecision, vagueness, complexity, and uncertainty. Tirkolaee et al. (2020) proposed a fuzzy decision making and multi-objective programming for sustainable supplier selection. A combined fuzzy rule-based maturity model with Monte Carlo simulation is introduced by Caiado et al. (2021) to develop new strategy for Industry 4.0. The strong increase in Markov jump systems(MJS) has been increasingly researched over the last few years for stability analysis and control synthesis and significant feedback control

Table 1 Enablers of supply chain responsiveness

Code	Enablers	References
E1	Culture, trust, and involvement of people in the organisation	(Singh and Sharma 2014b; Salimian et al. 2020)
E2	Managing the supply chain risk	(Mohammaddust et al. 2017; Vanalle et al. 2019)
E3	Commitment of management and strategy decision making	(Power et al. 2001; Kannabiran and Bhaumik 2005; Jesus et al. 2020)
E4	Continuous improvement	Expert opinion, (Gopal and Thakkar 2016)(Araceli et al. 2020)
E5	Demand forecasting	(Holweg 2005a; Gunasekaran et al. 2008; Moyano-Fuentes et al. 2016; Feizabadi 2020)
E6	Purchase behaviour of customer	(Chang and Hsiao 2011; Gupta et al. 2017; David and Banumathi 2018)
E7	Vehicle architecture	(Ulrich 1995; Holweg 2005a)
E8	Waiting period for vehicle's delivery	(Reichhart and Holweg 2007; Roh et al. 2014; Singh 2015)
E9	Production strategy	(Power et al. 2001; Holweg 2005a; Kim et al. 2013; Roh et al. 2014; Fatorachian and Kazemi 2021)
E10	Material and warehouse management	(Holweg 2005b; Singh and Sharma 2014b)
E11	Advanced manufacturing system and plant capacity	(Storey et al. 2005; Kim et al. 2013; Roh et al. 2014; Moyano-Fuentes et al. 2016)
E12	Coordination between supply chain members	(Arshinder and Deshmukh 2008; Roh et al. 2014; Dubey et al. 2018)
E13	Organisational integration	(K. 2013; Kumar et al. 2014; Lu et al. 2019)
E14	Integrated inventory management	(B.S. 2003; Hendricks and Singhal 2009; Fatorachian and Kazemi 2021)
E15	Accessibility of data	(Francesca 2008; Marek 2008; Prajogo and Olhager 2012; Fatorachian and Kazemi 2021)
E16	Data integration tools	(Bhattacharya 2014; Chandak 2019; Martinelli and Tunisini 2019; Tigga et al. 2021)
E17	Data visibility and visualisation	(Bhattacharya 2014; Zhong et al. 2016; Moktadir et al. 2018; Fatorachian and Kazemi 2021)

and filtering results were gathered (Zhuang et al. 2021). The H$\propto$ control theory has currently gained considerable interest and made considerable progress (Zhuang et al. 2020b). For instance, asynchronous mixed passivity and H$\propto$ filter design for fuzzy jump systems with time-varying delays was investigated by (Zhao et al. 2021). In contrast, feedback controls of different complex systems will guarantee system reliability and increase system efficiency (Zhuang et al. 2020a). The next sections discuss in detail about the Fuzzy DEMATEL, Fuzzy AHP and Fuzzy TOPSIS techniques.

2.2.1 Fuzzy DEMATEL

Decision Making Trial and Evaluation Laboratory (DEMATEL) technique is a powerful technique to recognise the cause–effect relationship among the enablers. It manages to assess associated connections among the factors and finding the most influencing factor through a visual structure mode (Gedam et al. 2021; Bacudio et al. 2016; Kaur et al. 2018; Mahmoudi et al. 2019; Mirzamohammadi et al. 2019; Nilashi et al. 2019). Implementing the fuzzy logic to traditional DEMATEL will enhance the process of establishing interactions between enablers. Arasteh (2020) measured the supply chain planning decision under uncertainty with the combination of fuzzy multi-objective planning and market uncertainty. Yazdani et al. (2020) developed a combined decision support model based on DEMATEL, QFD and Fuzzy values. In fuzzy DEMATEL, the interrelationship among the enablers was stated in linguistic terms and their corresponding fuzzy numbers. The following steps are required throughout the Fuzzy DEMATEL analysis (Xu et al. 2020; J. et al. 2021;Mentes et al. 2015; Khompatraporn and Somboonwiwat 2017; Seker and Zavadskas 2017; Han and Deng 2018; Pandey et al. 2019; Vardopoulos 2019).

Step 1 Establish the causal relationship between each enabler. In the first step, each participant is requested to give their opinion on the measure of scale. Develop the Direct relation matrix using the linguistic scale and the corresponding fuzzy numbers as given in Table 2. Let us consider there are "E" experts, and then Eq. (1) shows the obtained Fuzzy Initial direct relation matrix.

$$D^E = \begin{bmatrix} 0 & D_{12}^{-E} & \cdots & D_{1n}^{-E} \\ D_{21}^{-E} & 0 & \cdots & D_{2n}^{-E} \\ \vdots & \vdots & \ddots & \vdots \\ D_{n1}^{-E} & D_{n2}^{-E} & \cdots & 0 \end{bmatrix} \quad (1)$$

Table 2 The fuzzy linguistic scale for the experts' evaluations

Linguistic terms	Corresponding fuzzy number
No influence (NO)	(0, 0, 0.25)
Very low influence (VL)	(0, 0.25, 0.5)
Low influence (L)	(0.25, 0.5, 0.75)
High influence (H)	(0.5, 0.75, 1)
Very high influence (VH)	(0.75, 1, 1)

Step 2 Combining all fuzzy direct relation matrices established by the experts using Eq. (2)

$$D = \frac{\left(\sum_{i=1}^{E} E\right)}{E} \tag{2}$$

Step 3 Normalising the Direct relation matrix using the following method,

Let,

$$\sum_{j=1}^{n} \breve{D}_{ij} = \left(\sum_{j=1}^{n} \breve{D}_{ij(1)}, \sum_{j=1}^{n} D_{ij(2)}, \sum_{j=1}^{n} \breve{D}_{ij(3)}\right) \tag{3}$$

apply and

$$r = \max_{1 \le i \le n}\left(\sum_{j=1}^{n} \breve{D}_{ij(3)}\right)$$

Now, the fuzzy normalised direct-relation matrix, N, is

$N = r^{-1}.D,$

where $\tilde{g}_{ij} = \left(\tilde{D}_{ij}/_r\right) = \left(\tilde{D}_{ij(1)}/_r, \tilde{D}_{ij(2)}/_r, \tilde{D}_{ij(3)}/_r\right).$

Step 4 Develop the Fuzzy Total relation matrix M_f using Eqn

$$M_f = N(1 - N)^{-1} \tag{4}$$

$Where \tilde{t}_{ij} = \left(\tilde{t}_{ij(1)}, \tilde{t}_{ij(2)}, \tilde{t}_{ij(3)}\right)$

Step 5 Defuzzify the Total relation matrix, M_f. Wu and Lee (2007) had suggested a modified CFCS (Converting Fuzzy data into Crisp Scores) method for converting a fuzzy number into crisp value as

$$t_{ij(1)} = \frac{t_{ij(1)} - min_i\left(t_{ij(1)}\right)}{\Delta_{min}^{max}} \tag{5}$$

$$t_{ij(2)} = \frac{t_{ij(2)} - min_i\left(t_{ij(1)}\right)}{\Delta_{min}^{max}} \tag{6}$$

$$t_{ij(3)} = \frac{t_{ij(3)} - min_i\left(t_{ij(1)}\right)}{\Delta_{min}^{max}} \tag{7}$$

$where\ \Delta_{min}^{max} = max\left(t_{ij(3)}\right) - min\left(t_{ij(1)}\right)$

$$t_{ij(1)} = \frac{t_{ij(2)}}{1 + t_{ij(2)} - t_{ij(1)}} \tag{8}$$

$$t_{ij(3)} = \frac{t_{ij(3)}}{1 + t_{ij(3)} - t_{ij(2)}} \tag{9}$$

The Defuzzified total relation matrix $M = \left[t_{ij}\right]_{n \times n}$ is obtained by using Eqns

$$t_{ij}^{'} = \frac{t_{ij(1)}\left(1 - t_{ij(1)}\right) + t_{ij(3)}t_{ij(3)}}{1 - t_{ij(1)} + t_{ij(3)}}$$

$$t_{ij} = min_j\left(t_{ij(1)}\right) + t_{ij}^{'}\Delta_{min}^{max} \tag{10}$$

Step 6 Calculate the row sum and column sum from Defuzzified total relation matrix using Eqns

$$d = (d_i)_{n \times 1} = \left[\sum_{j=1}^{n} t_{ij}\right]_{n \times 1} \tag{11}$$

$$r = \left(r_j\right)_{1 \times n} = \left[\sum_{i=1}^{n} t_{ij}\right]_{1 \times n} \tag{12}$$

Step 7 Draw the Cause–Effect Relation diagraph and analyse the results. The (d + r) values signify the effects between enablers and (d − r) values characterises the causal relations between the enablers. The Inner dependency matrix is achieved by discarding values smaller than the threshold value in the total relation matrix. The threshold value is obtained by averaging entries in the total relation matrix (Quezada et al. 2018).

2.2.2 Fuzzy AHP

T. Saaty introduced the Analytical Hierarchical Process (AHP) in the year 1977, is a powerful technique for solving complex systems in decision making (Saaty 1977). The fuzzy AHP is built with a combination of Satty's AHP and fuzzy set theory (Jain et al. 2020; Singh and Sharma 2014a; Ocampo 2019; Rajak and Shaw 2019). A fuzzy number is indicated in the fuzzy AHP by a membership function that is a real number from 0 to 1. These membership functions will take different forms. The most used functions are triangular and trapezoidal. Many researchers (Sun 2010; Wang et al. 2019; Lyu et al. 2020; Pilevar et al. 2020) have used a Triangular fuzzy number on Fuzzy AHP for solving industrial problems (Table 3).

In this paper, we took Fuzzy AHP to determine the weights of the criteria. First, we constructed a pairwise evaluation matrix of all the criteria and then assigned linguistic terms shown in Table 4 to the pairwise comparisons by expert opinion as to the following matrix $\hat{A}$.

Table 3 ReSCM evaluation criteria

Criteria	References
Lead time reduction	(Disney and Towill 2003; Reichhart and Holweg 2007)
Meeting the customer expectation	(Holweg 2005a)
Total useful life of vehicle	Expert opinion
Vehicle model variety	Expert opinion
Response capability of supply chain	(Holweg 2005a)
Understanding the demand uncertainty and variability	(Griffiths and Margetts 2000; Krajewski et al. 2005; Reichhart and Holweg 2007; Feizabadi 2020)

Table 4 linguistic term for Pairwise comparison

Linguistic terms	Corresponding fuzzy number
Perfect	(8, 9,10)
Absolute	(7, 8,9)
Very good	(6, 7,8)
Fairly good	(5, 6,7)
Good	(4, 5,6)
Preferable	(3, 4,5)
Not bad	(2, 3,4)
Weak advantage	(1, 2,3)
Equal	(1,1,1)

$$\hat{A} = \begin{bmatrix} 1 & a_{12} & \cdots & a_{1n} \\ a_{21} & 1 & \cdots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ a_{n1} & a_{n2} & \cdots & 1 \end{bmatrix} = \begin{bmatrix} 1 & a_{12} & \cdots & a_{1n} \\ {}^{1}/_{a_{12}} & 1 & \cdots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ {}^{1}/_{a_{n1}} & {}^{1}/_{a_{n2}} & \cdots & 1 \end{bmatrix}$$

The fuzzy geometric mean and fuzzy weights of each criterion were calculated by using the geometric mean Eqn proposed by Hsieh et al. (2004) as follows

$$\tilde{r}_i = \left(\hat{a}_{i1} \otimes \cdots \otimes \hat{a}_{ij} \otimes \cdots \otimes \hat{a}_{in}\right)^{1/n}$$

$$\tilde{w}_i = \tilde{r}_i \otimes [\tilde{r}_1 \oplus \cdots \oplus \tilde{r}_i \oplus \cdots \oplus \tilde{r}_n]^{-1} \tag{13}$$

2.2.3 Fuzzy TOPSIS

Technique for Order Preference by Similarity to ideal Solution (TOPSIS) is a group decision-making process, where a group of experts is being consulted on a matter for their opinion. The concept behind TOPSIS is that the actual outcome will be as near as possible to the optimal choice and to the negative ideal solution as possible (Vinodh et al. 2016). Rubio-Aliaga et al. (2021) developed an integrated AHP and TOPSIS approach for the selection of optimal ground water pumping system. The Fuzzy TOPSIS has successfully found the best solution under uncertainty as a multi-criteria decision-making method (Arpit et al. 2021). Amin et al. (2019)introduced a concept of the trapezoidal cubic hesitant fuzzy TOPSIS method. In this study, along with Fuzzy AHP, we employed the Fuzzy TOPSIS concept to establish an approach to prioritising supply-chain responsiveness enables. The calculation steps of Fuzzy TOPSIS has been used in this paper as follows (Kannan et al. 2009; Sun 2010; Beikkhakhian et al. 2015; Singh et al. 2018; Nilashi et al. 2019; Çalık 2020; Öztürk and Yildizbaşi 2020):

Step 1 Calculate the weights of each criterion by Fuzzy AHP as explained in Sect. 2.4

Step 2 Develop the fuzzy decision matrix and select the relevant linguistic variables for the enablers corresponding to each criterion.

$$\tilde{B} = \begin{bmatrix} \tilde{x}_{11} & \tilde{x}_{12} & \cdots & \tilde{x}_{1n} \\ \tilde{x}_{21} & \tilde{x}_{21} & \cdots & \tilde{x}_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \tilde{x}_{m1} & \tilde{x}_{m1} & \cdots & \tilde{x}_{mn} \end{bmatrix} \tag{14}$$

$i = 1, 2...m$ and $j = 1, 2, ...n$

$$\tilde{x}_i = \frac{1}{K}\left(x_{ij}^{-1} \oplus \cdots \oplus x_{ij}^{-k} \oplus \cdots \oplus x_{ij}^{-K}\right)$$

where x_{ij}^{-k} is the performance rating of alternative Ai with respect to criterion Cj evaluated by kth expert, and $x_{ij}^{-k} = \left(l_{ij}^k, m_{ij}^k, n_{ij}^k\right)$.

Step 3 The next step of Fuzzy TOPSIS is to normalise the fuzzy-decision matrix.

The normalised fuzzy-decision matrix denoted by $\check{F}$ as shown in below formula

$$\check{F} = \left[\tilde{r}_{jk}\right]_{m \times n} \tag{15}$$

$j = 1, 2...m$ and $k = 1, 2, ...n$

The normalisation operation will then be carried out using Eqn:

$$\tilde{r}_{jk} = \left(\frac{l_{jk}}{u_k^+}, \frac{m_{jk}}{u_k^+}, \frac{n_{jk}}{u_k^+}\right) \tag{16}$$

The weighted fuzzy normalised decision matrix is shown as the following matrix $\check{\boldsymbol{W}}$

$$\check{W} = \left[\tilde{v}_{jk}\right]_{m \times n} j = 1, 2, 3...m \text{ and } k = 1, 2, 3...n \tag{17}$$

where $\tilde{v}_{jk} = \tilde{r}_{jk} \otimes \tilde{w}_{jk}$

Step 4 Calculate the fuzzy positive-ideal solution (FPIS) and fuzzy negative-ideal solution (FNIS) using Eqn:

$$H^{+} = \left(\acute{v}_1^{+}, \ldots, \acute{v}_k^{+}, \ldots, \acute{v}_n^{+}\right) \quad (18)$$

$$H^{-} = \left(\acute{v}_1^{-}, \ldots, \acute{v}_k^{-}, \ldots, \acute{v}_n^{-}\right) \quad (19)$$

where $\acute{v}_k^{+} = (1,1,1) \otimes \tilde{w}_{jk} = (lw_k, mw_k, nw_k)$ and $\acute{v}_k^{-} = (0,0,0)$, j = 1,2…..n

Step 5: Compute the distance of each enablers from fuzzy positive-ideal solution and fuzzy negative-ideal solution. The distances $\left(\breve{p}_j^{+}, \breve{p}_j^{-}\right)$ of individual enabler from H^{+} and H^{-} can be now computed by the area compensation method

$$\breve{p}_j^{+} = \sum_{j=1}^{n} d\left(\tilde{v}_{jk}, \acute{v}_k^{+}\right) \; j = 1,2,3\ldots m; k = 1,2,3,\ldots,n \quad (20)$$

$$\breve{p}_j^{-} = \sum_{k=1}^{n} d\left(\tilde{v}_{jk}, \acute{v}_k^{-}\right) \; j = 1,2,3\ldots m; k = 1,2,3,\ldots,n \quad (21)$$

Step 6 Obtain the closeness coefficient. Opricovic and Tzeng (2004) were suggested MCDM technique for VIKOR and TOPSIS comparative analysis as an alternative solution. They suggested that TOPSIS cannot be used for prioritising the factors. Hence, we suggest the $\widetilde{CC}$ is distinct from calculating the fuzzy gap- degree based on fuzzy closeness coefficients for enablers. After $\breve{p}_j^{+}$ and $\breve{p}_j^{-}$ of all enabler have been determined, obtain the similarities to ideal solution. This phase overcomes the resemblances with an ideal solution by formula

$$\widetilde{CC} = \frac{\breve{p}_j^{-}}{\breve{p}_j^{+} + \breve{p}_j^{-}} = 1 - \frac{\breve{p}_j^{+}}{\breve{p}_j^{+} + p_j^{-}}, \; i = 1,2,3 \ldots m$$

3 Proposed methodology

As mentioned in the Introduction, we propose an integrated MCDM approach under fuzzy environment for modelling and prioritisation of the enablers of supply chain responsiveness. Our proposed integrated Fuzzy MCDM approach is displayed in Fig. 1. It comprises of two phases as. In the first Phase, Fuzzy DEMATEL is used to model the ReSCM enablers and in the second phase, applied Fuzzy AHP to calculate the criteria weights of ReSCM enablers and fuzzy TOPSIS to prioritise the enablers. A panel of experts based on their technical expertise in the automotive supply chain is constituted. Three experts from the case organisation and two experts from academia were identified. All the members of the team have more than a decade of experience in the relevant field. These experts were also consulted for collecting the pairwise comparison between the enablers for conducting Fuzzy DEMATEL analysis and the relative importance of enablers for conducting Fuzzy AHP–TOPSIS analysis.

3.1 Modelling ReSCM enablers of an Indian automotive manufacturer using Fuzzy DEMATEL

The Initial direct relation matrix is shown as the linguistic variables in Table 2 give a pairwise relation between the ReSCM enablers. The cause and effect behaviour were obtained by executing the mathematical steps, as mentioned in Sect. 2.3. A Cause and Effect diagram has been built with (D + R) values in the horizontal axis as "prominence" and (D-R) values as "relation" in the vertical axis. The enabler is placed into the effectiveness category if the value (D − R) is negative. This implies that enablers belong to this group are affected by other parameters. If (D − R) is positive, this has a big impact and needs to be changed (Seker and Zavadskas 2017).

3.2 Prioritising ReSCM enablers of an Indian automotive manufacturer using Fuzzy AHP-TOPSIS technique

The combination of Fuzzy AHP and Fuzzy TOPSIS techniques led to a priority assessment of ReSCM enablers. The hierarchical decision structure of ReSCM enablers is constructed, as shown in Fig. 2. Based on the literature survey, six criteria were identified, as shown in Table 3 to evaluate the enablers. The alternatives listed in Table 3 refer to the evaluation criteria. Industry and academia experts were asked to compare the criteria in a pairwise fashion with the linguistic variables shown in Table 4.

Further, Fuzzy AHP is used to calculate the relative weights of criteria, as explained in Sect. 2.4. Further in Fuzzy TOPSIS, these weights are used in a fuzzy framework to evaluate various ReSCM enabler using mathematical formulae as described in Sect. 2.5. The linguistic variables as given in Table 5 are used for conducting a Fuzzy TOPSIS technique. The fuzzy set theory used in the analysis to resolve the uncertainties of the assessment. Eventually, a case study of the Indian automotive supply chain is used to analyse the proposed model.

4 Case illustration

The practical application of this research is to identify, prioritise and analyse the enablers of responsiveness of Indian automotive supply chain. An empirical case study from an Indian automotive manufacturer is presented to illustrate the proposed Integrated Fuzzy DEMATEL-AHP-

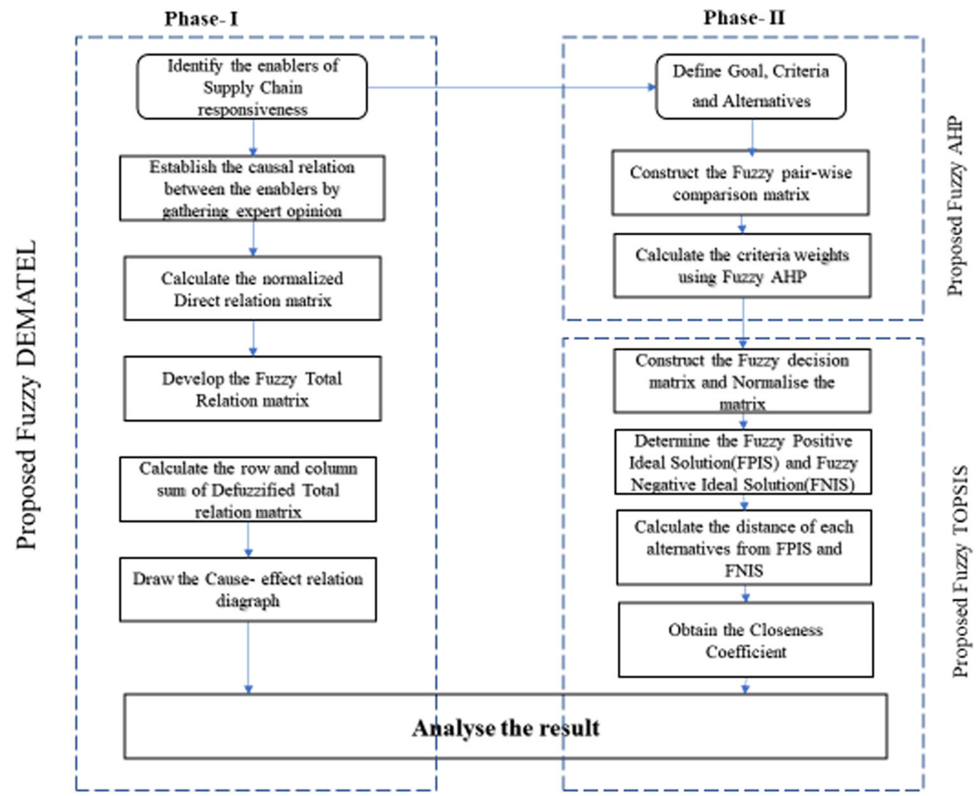

Fig. 1 Proposed integrated Fuzzy MCDM approach

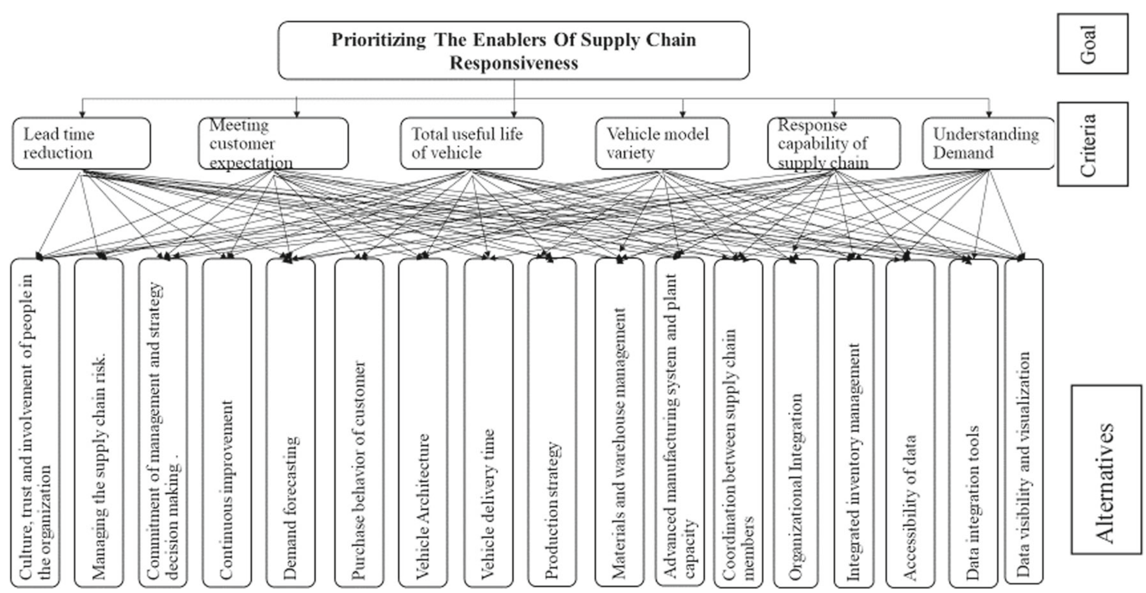

Fig. 2 Decision structure of supply chain responsiveness enablers

TOPSIS approach. XYZ Ltd (Name changed) is an Indian Multinational Automobile manufacturing company, headquarters in India. It is a part of an Indian conglomerate and product includes all varieties of automobiles including passenger cars and commercial vehicles. The company has more than 80,000 employees in different managerial levels. The customer's demand is fulfilled through several dealer's showroom and authorised service centre across the country in the downstream supply chain.

After identifying the enablers and developing the integrated Fuzzy MCDM methodology, we have presented it before the case organisation. On the basis of discussion with the general manager of the case organisation, an expert panel of three senior managers based on their

Table 5 Linguistic scales for the rating of enablers

Linguistic terms	Corresponding fuzzy number
Very poor (VP)	(0,1,3)
Poor (P)	(1,3,5)
Fair (F)	(3,5,7)
Good (G)	(5,7,9)
Very good (VG)	(7,9,10)

qualifications and experience in the field of supply chain management is constituted. All the members of the team have more than a decade of experience in the relevant field. We have included two academic experts in the field of supply chain management to the expert team. These members of the team were directly interviewed to gather the necessary data for the research. A total of 17 enablers were selected for final assessment as listed in Table 1. Members were given their expert opinion to prioritise the enablers and formulate the interrelationship among the enablers using Fuzzy linguistic scale. The discussion with the decision-making team would lead to the formation of the Fuzzy relationship matrices and the proposed Fuzzy DEMATEL-AHP-TOPSIS methodology was executed as described in the next section.

5 Data analysis and results

Necessary data for the study were collected through our conversation with the expert team. The data analysis was carried out in two phases. In the first phase, the causal relationship and degree of prominence were derived using the Fuzzy DEMATEL technique. The second phase consists of prioritising enablers using Fuzzy AHP–Fuzzy TOPSIS approach. A detailed description of data analysis and result is reported below:

5.1 Phase I—development of Fuzzy DEMATEL

The fuzzy DEMATEL applied for developing the interrelation between the identified enablers of ReSCM in Indian automotive manufacturer is explained below:

The critical enablers of responsiveness in the Indian automotive supply chain collected from the literature reviews and expert opinion from experts. The identified enablers were approved by a team of experts as stated in the previous section. A total of 17 enablers were selected for final assessment as listed in Table 1. The assessment matrix, as shown in Table 6, is obtained after organising a brainstorming session among the experts. Developed the Initial direct relation matrix, shown in Table 7, using Eq. (1) with Fuzzy linguistic scale given in Table 2. Combined all fuzzy direct relation matrices established by the experts using Eq. (2). Normalised the Fuzzy direct relation matrix using Eq. (3) and then developed the Fuzzy Total relation matrix using Eq. (4). The defuzzification was performed using Eqs. (5)-(10) and is reported as Defuzzified Total relation Matrix in Table 8. The inner dependency matrix is achieved through discarding the values below the threshold limit in total relation matrix and is shown in Table 9. The threshold value is obtained by averaging the values in the total relation matrix (Quezada et al. 2018). The row sum(d) and column sum (r) were calculated using Eqs. (11)- (12) and the cause–effect values were attained as given in Table 10. The degree of prominence (d + r) is arranged in the descending order, as shown in Figs. 3 and 4 show the net cause–effect (*d-r*) values. The overall DEMATEL cause–effect diagram constructed by plotting all coordinates of ($d + r$, *d-r*) as shown in Fig. 5 to envisage the interrelationship between the enablers and provide evidence to investigate which are the most critical enablers and how influence affected enables.

According to our findings of Fuzzy DEMATEL analysis, waiting period for vehicle's delivery (E8) has the highest prominence value, and hence it has the highest correlation with other enablers. This ensures that the supply chain must ensure timely delivery of vehicles. While observing Degree of prominence graph displayed in Fig. 3, it is clear that other enablers that belong to top five are "Commitment of management and Strategy decision making (E3)", "Managing the supply chain risk (E2)", "Demand Forecasting (E5)", and "Culture, trust and involvement of people in the organisation (E1)". Figure 4 shows the Cause–effect diagram. An enabler whose (d-r) > 0 is categorised as cause enabler and if (*d-r* < 0 then it grouped as effect enabler. According to this analysis, "Commitment of management and Strategy decision making (E3)", "Demand forecasting (E5)", "Continuous improvement (E4)", "Advanced Manufacturing System and plant capacity (E11)", "Vehicle architecture (E7)", "Accessibility of data (E15)", "Data Integration tools (E16)" are grouped as cause enablers. It is observed that "Commitment of management and Strategy decision making (E3)" has the largest positive value, which indicates that E3 is the primary causal factor.

The degree of dominant character (*d*+ *r* in Fuzzy DEMATEL signifies the firmness of effects both forwarded and received. If the value of (*d-r*) > 0, then the enabler factor forwarded the influence on another enabler more than it receives. If (d-r) < 0, the enablers receive the influence from another enabler more than it forwarded. The findings from Cause–effect diagram, Fig. 5 reveals that "Commitment of management and Strategy decision making(E3)", "Demand forecasting(E5)", "Continuous improvement (E4)", "Vehicle architecture(E7)", "Advanced Manufacturing System and plant capacity (E11)", "Accessibility of data (E15)" and "Data Integration tools (E16)" are the influence forwarding enablers. These enablers will influence "Culture, trust and involvement of people in the organisation (E1)", "Managing the supply chain risk (E2)", "Purchase behaviour of customer (E6)", "Waiting period for vehicle's delivery (E8)", "Production Strategy (E9)", "Material and warehouse management (E10)", "Coordination between supply chain members (E12)", "Organizational Integration (E13)", "Integrated inventory management (E14)", and "Data visibility and visualisation (E17)". Furthermore, among the effect enablers, Data visibility and visualisation (E17) is closest to the middle; this means that the recognised causal enablers have less impact. The inner dependency matrix is shown in Table 9 depicts that all the enablers except "Material and warehouse management (E10)" has a significant relation between other enablers. Figure 5 displays the overall prominence-cause relation diagram that has

Table 6 Assessment matrix by expert

	E1	E2	E3	E4	E5	E6	E7	E8	E9
E1	NO	H	L	L	VL	VL	L	H	L
E2	H	NO	L	VL	VL	VL	VL	L	H
E3	VH	VH	NO	H	L	L	L	H	H
E4	L	L	L	NO	VL	VL	H	H	H
E5	L	L	L	H	NO	H	H	VH	VH
E6	VL	VL	VL	VL	L	NO	H	L	VL
E7	L	L	VL	VL	L	VL	NO	H	H
E8	L	H	L	VL	L	VH	L	NO	L
E9	H	L	VL	L	VL	VL	VL	VH	NO
E10	VL	VL	VL	L	VL	H	VL	L	VL
E11	H	VH	L	L	VL	VL	L	H	VH
E12	L	H	L	VL	L	VL	VL	L	VL
E13	VL	L	VL	VL	L	VL	VL	L	VL
E14	L	VL	VL	L	VL	VL	VL	H	VL
E15	L	H	VL	L	H	VL	VL	VL	L
E16	L	L	L	VL	L	L	L	L	L
E17	L	H	L	VL	VL	L	VL	L	L

	E10	E11	E12	E13	E14	E15	E16	E17
E1	VL	L	L	L	L	L	VL	VL
E2	L	L	L	L	L	H	VL	VL
E3	H	VH	L	H	H	L	H	H
E4	L	VH	L	L	L	L	L	H
E5	H	NO	L	L	H	H	L	VH
E6	VL	VL	VL	VL	VL	VL	VL	VL
E7	L	H	L	L	L	L	L	L
E8	H	L	L	L	L	VL	VL	VL
E9	L	VL	VL	VL	VL	L	L	L
E10	NO	VL	VL	VL	VL	VL	VL	VL
E11	VH	NO	L	L	L	VL	VL	VL
E12	H	VL	NO	H	L	L	VL	VL
E13	L	VL	VH	NO	L	L	L	L
E14	H	VL	L	H	NO	VL	VL	VL
E15	L	VL	H	L	L	NO	VH	VH
E16	L	VL	VL	VL	L	VL	NO	H
E17	VL	VL	L	L	L	L	L	NO

Table 7 Initial direct relation matrix

	E1	E2	E3	E4	E5	E6	E7	E8	E9
E1	(0,0,0.25)	(0.5,0.75,1)	(0.25,0.5,0.75)	(0.25,0.5,0.75)	(0,0.25,0.5)	(0,0.25,0.5)	(0.25,0.5,0.75)	(0.5,0.75,1)	(0.25,0.5,0.75)
E2	(0.5,0.75,1)	(0,0,0.25)	(0.25,0.5,0.75)	(0,0.25,0.5)	(0,0.25,0.5)	(0,0.25,0.5)	(0,0.25,0.5)	(0.25,0.5,0.75)	(0.5,0.75,1)
E3	(0.75,1,1)	(0.75,1,1)	(0,0,0.25)	(0.5,0.75,1)	(0.25,0.5,0.75)	(0.25,0.5,0.75)	(0.25,0.5,0.75)	(0.5,0.75,1)	(0.5,0.75,1)
E4	(0.25,0.5,0.75)	(0.25,0.5,0.75)	(0.25,0.5,0.75)	(0,0,0.25)	(0,0.25,0.5)	(0,0.25,0.5)	(0.5,0.75,1)	(0.5,0.75,1)	(0.5,0.75,1)
E5	(0.25,0.5,0.75)	(0.25,0.5,0.75)	(0.25,0.5,0.75)	(0.5,0.75,1)	(0,0,0.25)	(0.5,0.75,1)	(0.5,0.75,1)	(0.75,1,1)	(0.75,1,1)
E6	(0,0.25,0.5)	(0,0.25,0.5)	(0,0.25,0.5)	(0,0.25,0.5)	(0.25,0.5,0.75)	(0,0,0.25)	(0.5,0.75,1)	(0.25,0.5,0.75)	(0,0.25,0.5)
E7	(0.25,0.5,0.75)	(0.25,0.5,0.75)	(0,0.25,0.5)	(0,0.25,0.5)	(0.25,0.5,0.75)	(0,0.25,0.5)	(0,0,0.25)	(0.5,0.75,1)	(0.5,0.75,1)
E8	(0.25,0.5,0.75)	(0.5,0.75,1)	(0.25,0.5,0.75)	(0,0.25,0.5)	(0.25,0.5,0.75)	(0.75,1,1)	(0.25,0.5,0.75)	(0,0,0.25)	(0.25,0.5,0.75)
E9	(0.5,0.75,1)	(0.25,0.5,0.75)	(0,0.25,0.5)	(0.25,0.5,0.75)	(0,0.25,0.5)	(0,0.25,0.5)	(0,0.25,0.5)	(0.75,1,1)	(0,0,0.25)
E10	(0,0.25,0.5)	(0,0.25,0.5)	(0,0.25,0.5)	(0.25,0.5,0.75)	(0,0.25,0.5)	(0.5,0.75,1)	(0,0.25,0.5)	(0.25,0.5,0.75)	(0,0.25,0.5)
E11	(0.5,0.75,1)	(0.75,1,1)	(0.25,0.5,0.75)	(0.25,0.5,0.75)	(0,0.25,0.5)	(0,0.25,0.5)	(0.25,0.5,0.75)	(0.5,0.75,1)	(0.75,1,1)
E12	(0.25,0.5,0.75)	(0.5,0.75,1)	(0.25,0.5,0.75)	(0,0.25,0.5)	(0.25,0.5,0.75)	(0,0.25,0.5)	(0,0.25,0.5)	(0.25,0.5,0.75)	(0,0.25,0.5)
E13	(0,0.25,0.5)	(0.25,0.5,0.75)	(0,0.25,0.5)	(0,0.25,0.5)	(0.25,0.5,0.75)	(0,0.25,0.5)	(0,0.25,0.5)	(0.25,0.5,0.75)	(0,0.25,0.5)
E14	(0.25,0.5,0.75)	(0,0.25,0.5)	(0,0.25,0.5)	(0.25,0.5,0.75)	(0,0.25,0.5)	(0,0.25,0.5)	(0,0.25,0.5)	(0.5,0.75,1)	(0,0.25,0.5)
E15	(0.25,0.5,0.75)	(0.5,0.75,1)	(0,0.25,0.5)	(0.25,0.5,0.75)	(0.5,0.75,1)	(0,0.25,0.5)	(0,0.25,0.5)	(0,0.25,0.5)	(0.25,0.5,0.75)
E16	(0.25,0.5,0.75)	(0.25,0.5,0.75)	(0.25,0.5,0.75)	(0,0.25,0.5)	(0.25,0.5,0.75)	(0.25,0.5,0.75)	(0.25,0.5,0.75)	(0.25,0.5,0.75)	(0.25,0.5,0.75)
E17	(0.25,0.5,0.75)	(0.5,0.75,1)	(0.25,0.5,0.75)	(0,0.25,0.5)	(0,0.25,0.5)	(0.25,0.5,0.75)	(0,0.25,0.5)	(0.25,0.5,0.75)	(0.25,0.5,0.75)

	E10	E11	E12	E13	E14	E15	E16	E17
E1	(0,0.25,0.5)	(0.25,0.5,0.75)	(0.25,0.5,0.75)	(0.25,0.5,0.75)	(0.25,0.5,0.75)	(0.25,0.5,0.75)	(0,0.25,0.5)	(0,0.25,0.5)
E2	(0.25,0.5,0.75)	(0.25,0.5,0.75)	(0.25,0.5,0.75)	(0.25,0.5,0.75)	(0.25,0.5,0.75)	(0.5,0.75,1)	(0,0.25,0.5)	(0,0.25,0.5)
E3	(0.5,0.75,1)	(0.75,1,1)	(0.25,0.5,0.75)	(0.5,0.75,1)	(0.5,0.75,1)	(0.25,0.5,0.75)	(0.5,0.75,1)	(0.5,0.75,1)
E4	(0.25,0.5,0.75)	(0.75,1,1)	(0.25,0.5,0.75)	(0.25,0.5,0.75)	(0.25,0.5,0.75)	(0.25,0.5,0.75)	(0.25,0.5,0.75)	(0.5,0.75,1)
E5	(0.5,0.75,1)	(0,0,0.25)	(0.25,0.5,0.75)	(0.25,0.5,0.75)	(0.5,0.75,1)	(0.5,0.75,1)	(0.25,0.5,0.75)	(0.75,1,1)
E6	(0,0.25,0.5)	(0,0.25,0.5)	(0,0.25,0.5)	(0,0.25,0.5)	(0,0.25,0.5)	(0,0.25,0.5)	(0,0.25,0.5)	(0,0.25,0.5)
E7	(0.25,0.5,0.75)	(0.5,0.75,1)	(0.25,0.5,0.75)	(0.25,0.5,0.75)	(0.25,0.5,0.75)	(0.25,0.5,0.75)	(0.25,0.5,0.75)	(0.25,0.5,0.75)
E8	(0.5,0.75,1)	(0.25,0.5,0.75)	(0.25,0.5,0.75)	(0.25,0.5,0.75)	(0.25,0.5,0.75)	(0,0.25,0.5)	(0,0.25,0.5)	(0,0.25,0.5)
E9	(0.25,0.5,0.75)	(0,0.25,0.5)	(0,0.25,0.5)	(0,0.25,0.5)	(0,0.25,0.5)	(0.25,0.5,0.75)	(0.25,0.5,0.75)	(0.25,0.5,0.75)
E10	(0,0,0.25)	(0,0.25,0.5)	(0,0.25,0.5)	(0,0.25,0.5)	(0,0.25,0.5)	(0,0.25,0.5)	(0,0.25,0.5)	(0,0.25,0.5)
E11	(0.75,1,1)	(0.25,0.5,0.75)	(0.25,0.5,0.75)	(0.25,0.5,0.75)	(0.25,0.5,0.75)	(0,0.25,0.5)	(0,0.25,0.5)	(0,0.25,0.5)
E12	(0.5,0.75,1)	(0,0.25,0.5)	(0,0,0.25)	(0.5,0.75,1)	(0.25,0.5,0.75)	(0.25,0.5,0.75)	(0,0.25,0.5)	(0,0.25,0.5)
E13	(0.25,0.5,0.75)	(0,0.25,0.5)	(0.75,1,1)	(0,0,0.25)	(0.25,0.5,0.75)	(0.25,0.5,0.75)	(0.25,0.5,0.75)	(0.25,0.5,0.75)
E14	(0.5,0.75,1)	(0,0.25,0.5)	(0.25,0.5,0.75)	(0.5,0.75,1)	(0,0,0.25)	(0,0.25,0.5)	(0,0.25,0.5)	(0,0.25,0.5)
E15	(0.25,0.5,0.75)	(0,0.25,0.5)	(0.5,0.75,1)	(0.25,0.5,0.75)	(0.25,0.5,0.75)	(0,0,0.25)	(0.75,1,1)	(0.75,1,1)
E16	(0.25,0.5,0.75)	(0,0.25,0.5)	(0,0.25,0.5)	(0,0.25,0.5)	(0.25,0.5,0.75)	(0,0.25,0.5)	(0,0,0.25)	(0.5,0.75,1)
E17	(0,0.25,0.5)	(0,0.25,0.5)	(0.25,0.5,0.75)	(0.25,0.5,0.75)	(0.25,0.5,0.75)	(0.25,0.5,0.75)	(0.25,0.5,0.75)	(0,0,0.25)

Table 8 Defuzzied total relation matrix

	E1	E2	E3	E4	E5	E6	E7	E8	E9
E1	0.04	0.09	0.06	0.06	0.05	0.05	0.06	0.09	0.07
E2	0.08	0.05	0.06	0.05	0.05	0.05	0.05	0.08	0.08
E3	0.11	0.12	0.05	0.09	0.07	0.07	0.08	0.11	0.1
E4	0.08	0.08	0.07	0.04	0.05	0.05	0.08	0.1	0.09
E5	0.08	0.08	0.07	0.09	0.04	0.09	0.09	0.11	0.11
E6	0.05	0.05	0.04	0.04	0.05	0.03	0.07	0.06	0.05
E7	0.07	0.08	0.05	0.05	0.06	0.05	0.04	0.09	0.09
E8	0.07	0.09	0.06	0.05	0.06	0.09	0.07	0.05	0.07
E9	0.08	0.07	0.05	0.06	0.04	0.05	0.05	0.1	0.04
E10	0.04	0.05	0.04	0.05	0.04	0.07	0.04	0.06	0.04
E11	0.09	0.1	0.06	0.06	0.04	0.05	0.06	0.09	0.1
E12	0.07	0.09	0.06	0.05	0.06	0.05	0.05	0.07	0.05
E13	0.05	0.07	0.05	0.05	0.06	0.05	0.05	0.07	0.05
E14	0.06	0.05	0.04	0.06	0.04	0.04	0.04	0.08	0.05
E15	0.07	0.09	0.05	0.07	0.08	0.05	0.05	0.07	0.07
E16	0.07	0.07	0.06	0.05	0.06	0.06	0.06	0.07	0.07
E17	0.07	0.09	0.06	0.05	0.05	0.06	0.05	0.07	0.07

	E10	E11	E12	E13	E14	E15	E16	E17
E1	0.06	0.06	0.07	0.07	0.07	0.06	0.05	0.05
E2	0.07	0.06	0.07	0.07	0.07	0.08	0.05	0.05
E3	0.1	0.1	0.08	0.1	0.1	0.08	0.09	0.09
E4	0.08	0.09	0.07	0.07	0.07	0.07	0.07	0.09
E5	0.1	0.05	0.08	0.08	0.09	0.09	0.07	0.1
E6	0.05	0.04	0.04	0.04	0.04	0.04	0.04	0.04
E7	0.08	0.08	0.07	0.07	0.07	0.07	0.06	0.07
E8	0.09	0.06	0.07	0.07	0.07	0.05	0.05	0.05
E9	0.07	0.05	0.05	0.05	0.05	0.06	0.06	0.06
E10	0.03	0.04	0.04	0.04	0.04	0.04	0.04	0.04
E11	0.1	0.04	0.07	0.07	0.07	0.05	0.05	0.05
E12	0.08	0.05	0.04	0.08	0.07	0.06	0.05	0.05
E13	0.07	0.04	0.09	0.04	0.06	0.06	0.06	0.06
E14	0.08	0.04	0.06	0.08	0.04	0.05	0.04	0.05
E15	0.07	0.05	0.08	0.07	0.07	0.04	0.09	0.1
E16	0.07	0.05	0.05	0.05	0.07	0.05	0.04	0.08
E17	0.06	0.05	0.07	0.07	0.07	0.06	0.06	0.04

been built to represent general trends and connections between all enablers simultaneously.

5.2 Phase II—development of Fuzzy AHP–TOPSIS

The second phase of this work is to prioritise the enablers of ReSCM in Indian automotive manufacturer by the proposed Fuzzy AHP-TOPSIS technique. The enablers of ReSCM are prioritised with respect to the weightage of the evaluation criteria shown in Table 3. The fuzzy pairwise comparison matrix is developed after consultation with the experts and is shown in Table 11. The fuzzy relative weight matrix for all criteria is obtained by using Eq. (13) and is shown in Table 12. The consistency index (CI), consistency rate (CR), and random index were obtained from Saaty Table (Donegan and Dodd 1991). As the value of CR obtained is less than 0.1, this can be said that the matrix of reference is of strong consistency (Beikkhakhian et al. 2015). The fuzzy weights of Criteria C1, C2, C3, C4,

Table 9 Inner dependency matrix

	E1	E2	E3	E4	E5	E6	E7	E8	E9
E1		0.09						0.09	0.07
E2	0.08							0.08	0.08
E3	0.11	0.12		0.09	0.07	0.07	0.08	0.11	0.1
E4	0.08	0.08	0.07				0.08	0.1	0.09
E5	0.08	0.08	0.07	0.09		0.09	0.09	0.11	0.11
E6							0.07	0.06	
E7	0.07	0.08						0.09	0.09
E8	0.07	0.09				0.09	0.07		0.07
E9	0.08	0.07						0.1	
E10						0.07			
E11	0.09	0.1	0.06	0.06			0.06	0.09	0.1
E12	0.07	0.09						0.07	
E13		0.07						0.07	
E14	0.06							0.08	
E15	0.07	0.09		0.07	0.08			0.07	0.07
E16	0.07	0.07						0.07	0.07
E17	0.07	0.09						0.07	0.07

	E10	E11	E12	E13	E14	E15	E16	E17
E1			0.07	0.07	0.07	0.06		
E2	0.07		0.07	0.07	0.07	0.08		
E3	0.1	0.1	0.08	0.1	0.1	0.08	0.09	0.09
E4	0.08	0.09	0.07	0.07	0.07	0.07	0.07	0.09
E5	0.1		0.08	0.08	0.09	0.09	0.07	0.1
E6								
E7	0.08	0.08	0.07	0.07	0.07	0.07	0.06	0.07
E8	0.09		0.07	0.07	0.07			
E9	0.07							
E10								
E11	0.1		0.07	0.07	0.07			
E12	0.08			0.08	0.07	0.06		
E13	0.07		0.09		0.06			
E14	0.08			0.08				
E15	0.07		0.08	0.07	0.07		0.09	0.1
E16	0.07				0.07			0.08
E17			0.07	0.07	0.07			

Threshold value, $\alpha = 0.06$

C5and C6 obtained are (0.04,0.07,0.12), (0.11,0.2,0.36), (0.04,0.08,0.15), (0.06,0.1,0.19), (0.04,0.07,0.12), and (0.19,0.32,0.52), respectively. From the results, it is observed that “Understanding the nature and variability of demand [C6]” is the most significant criteria followed by “Lead time reduction [C1]”, “Meeting the customer expectation [C2]”, “Vehicle Model variety [C4]”, “Total useful life of vehicle [C3]” and “Response capability of supply chain [C5]”.

After computing the weights of the criteria, the next step is to rank the enablers of supply chain responsiveness using Fuzzy TOPSIS. For this, the Fuzzy Decision matrix was constructed for the enablers using Eq. (14), as depicted in Table 13. The linguistic scale used for rating the enablers is given in Table 4. The fuzzy-decision matrix is normalised by using Eqs. (15) and (16). The weighted assessment matrix was calculated by multiplying criteria weights with the Fuzzy decision matrix using Eq. (17). The distance of the enablers from positive ideal solution and negative ideal

Table 10 Importance and cause–effect values

Code	Enablers	$d+r$	$d-r$
E1	Culture, trust and involvement of people in the organisation	2.26	−0.13
E2	Managing the supply chain risk	2.36	−0.25
E3	Commitment of management and strategy decision making	2.46	0.60
E4	Continuous improvement	2.21	0.30
E5	Demand forecasting	2.31	0.51
E6	Purchase behaviour of customer	1.74	−0.17
E7	Vehicle architecture	2.12	0.16
E8	Waiting period for vehicle's delivery	2.51	−0.27
E9	Production Strategy	2.18	−0.22
E10	Material and warehouse management	2.02	−0.49
E11	Advanced manufacturing system and plant capacity	2.10	0.22
E12	Coordination between supply chain members	2.12	−0.08
E13	Organisational integration	2.09	−0.14
E14	Integrated inventory management	2.03	−0.19
E15	Accessibility of data	2.20	0.16
E16	Data integration tools	1.99	0.05
E17	Data visibility and visualisation	2.09	−0.05

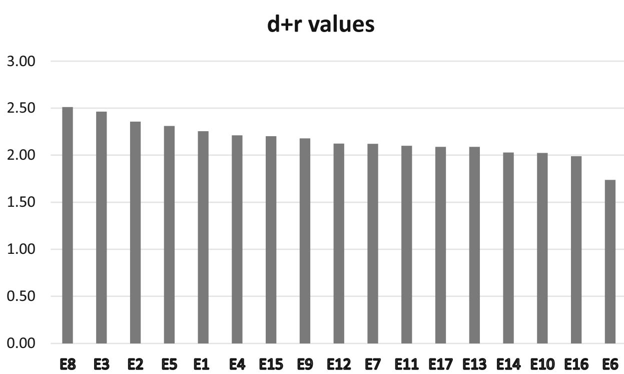

Fig. 3 Degree of prominence graph

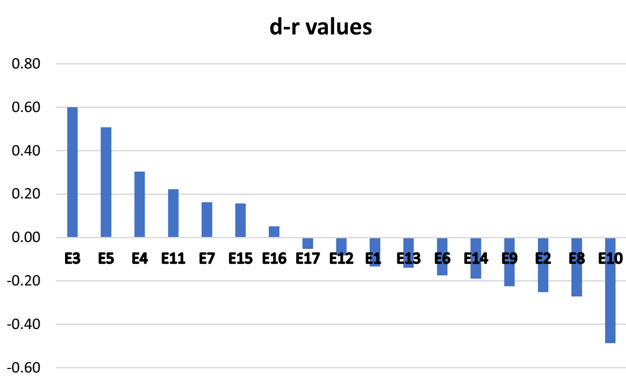

Fig. 4 Cause–effect graph

solution were calculated Using Eqs. (18) – (21). Now, closeness coefficient based on closeness to ideal solution is calculated using Eq. (22). The distances of Enablers to ideal solutions, the related closeness coefficients $(\widetilde{CC})$ and the ranking of the enablers is given in Table 14. The ranking of the enablers was carried out based on the $\widetilde{CC}$ value.

The proposed Fuzzy AHP-Fuzzy TOPSIS analysis reveals that the first five crucial enablers for the supply chain responsiveness for an Indian automobile manufacturer are Commitment of management and Strategy decision making (E3), Waiting period for vehicle's delivery(E8), Demand forecasting (E5), Culture, trust and involvement of people in the organisation (E1) and Distinguished Vehicle features (E7), respectively. Delivery of the vehicle within a short time has been one among the utmost significant enabler of supply chain responsiveness of the case organisation XYZ. The evidence from the Fuzzy AHP technique of ranking the criteria shows that new understanding of the nature and variability of vehicle demand will help the supply chain to attain responsiveness.

6 Managerial implications

The supply chain professionals are concerned about the increasing need for responsiveness and its impact on supply chain performance. Managing responsiveness without compromising efficiency is a challenging task. There is no comprehensive analytical framework in the literature, considering the critical aspects of the automotive supply chain's responsiveness. Such a framework will offer a deep look into the different experiences and legacy of supply chain responsiveness enablers. This study tries to bridge this difference by using an integrated Fuzzy MCDM approach. The Fuzzy DEMATEL-AHP-TOPSIS model

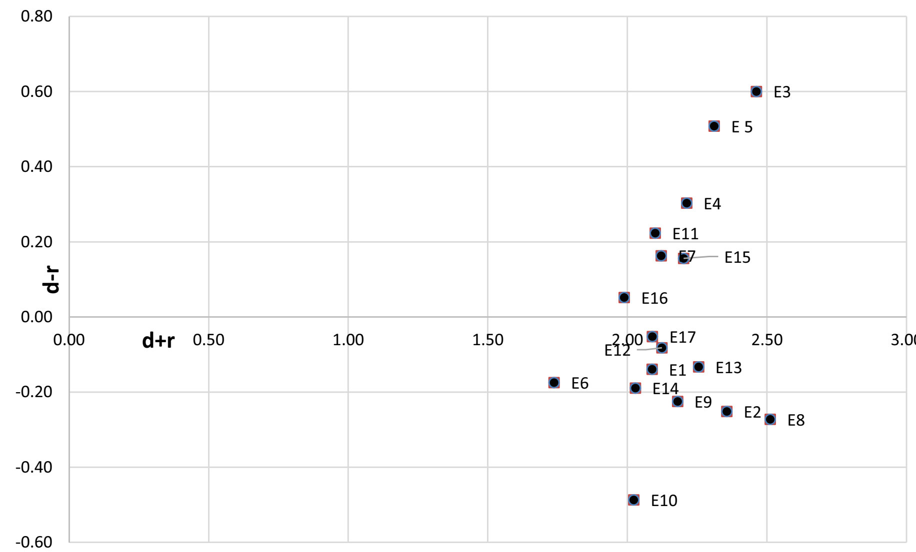

Fig. 5 Overall DEMATEL cause–effect diagram

Table 11 Fuzzy Pairwise comparison for AHP calculation

Criteria		C1	C2	C3	C4	C5	C6
C1	Lead time reduction	(1,1,1)	1/4,1/3,1/2	1/3,1/2,1	1,1,1	1/4,1/3,1/2	1/7,1/6,1/5
C2	Meeting the customer expectation	2,3,4	1,1,1	2,3,4	1,2,3	1/3,1/2,1	1,1,1
C3	Total useful life of vehicle	1,2,3	1/4,1/3,1/2	1,1,1	1/4,1/3,1/2	1/3,1/2,1	1/5,1/4,1/3
C4	Vehicle model variety	1,1,1	1/3,1/2,1	2,3,4	1,1,1	1/4,1/3,1/2	1/4,1/3,1/2
C5	Response capability of supply chain	2,3,4	1,2,3	1,2,3	2,3,4	1,1,1	1/3,1/2,1
C6	Understanding the nature and variability of demand	5,6,7	1,1,1	3,4,5	2,3,4	1,2,3	1,1,1

Table 12 Weights of Criteria

Criteria		Fuzzy weight	BNP	Rank
C1	Lead time reduction	(0.11,0.23,0.44)	0.259	2
C2	Meeting the customer expectation	(0.11,0.2,0.36)	0.227	3
C3	Total useful life of vehicle	(0.04,0.08,0.15)	0.091	5
C4	Vehicle Model variety	(0.06,0.1,0.19)	0.12	4
C5	Response capability of supply chain	(0.04,0.07,0.12)	0.074	6
C6	Understanding the nature and variability of demand	(0.19,0.32,0.52)	0.345	1

proposed in this work will help the supply chain managers of Indian automotive manufacturing companies understand different enablers to implement responsiveness in the supply chain. The relative significance and causal relationship of the various enablers and strategies used to implement responsiveness adoption from an industrial point of view will be necessary. This research will enable them to implement responsive supply chain practices more efficiently and effectively in the Indian automotive sector.

This paper's clear implication lies in identifying and analysing the enablers of supply chain responsiveness in Indian automotive manufacturer. Our study's findings are aligned with the results of Roh et al. 2014; Singh 2015; Moyano-Fuentes et al. 2016; Story et al. 2021 which emphasise that the automotive industry is more sensitive to supply chain responsiveness. The outcomes achieved through this research would help managers and practitioners enhance the successful application of the supply chain's responsiveness practices. The result of this study has the following managerial implications:

1. The study reveals that Commitment of management and Strategy decision making (E3), Demand forecasting (E5) and Waiting period for vehicle's delivery (E8)

Table 13 Fuzzy decision matrix

CODE	Alternatives	Criteria					
		Lead time reduction C1	Meeting the customer expectation C2	Total useful life of vehicle C3	Vehicle Model variety C4	Response capability of supply chain C5	Understanding the nature and variability of demand C6
E1	Culture, trust and involvement of people in the organisation	G	G	F	F	VG	G
E2	Managing the supply chain risk	G	G	P	F	G	G
E3	Commitment of management and strategy decision making	VG	VG	F	VG	G	G
E4	Continuous improvement of vehicle design	G	G	VP	F	G	VG
E5	Demand forecasting	VG	G	G	F	G	G
E6	Purchase behaviour of customer	G	G	VP	G	P	P
E7	Vehicle architecture	G	G	F	F	G	G
E8	Waiting period for vehicle's delivery	G	G	F	VG	VG	VG
E9	Production planning and control	VG	G	P	VP	VG	G
E10	Material and warehouse management	G	F	VP	P	G	VG
E11	Advanced manufacturing system and plant capacity	VG	G	P	VG	VG	P
E12	Coordination between SC members	VG	G	P	P	G	G
E13	Long-term relationship between supply chain members	G	G	P	P	G	G
E14	Integrated inventory management	G	P	VP	VP	VG	VG
E15	Accessibility of sales data	P	P	P	P	G	VG
E16	Data integration tools	F	VG	G	F	P	P
E17	Visibility and visualisation of data	G	G	P	F	G	G

are the most critical enabler of supply chain responsiveness. These three enablers are in the top list of prominence values and cause enabler in the Fuzzy DEMATEL analysis and the priority list of Fuzzy TOPSIS. Therefore, policymakers should put more focus on these significant enablers while screening other enablers.

2. Waiting period for vehicle's delivery (E8) has the highest prominence value obtained from Fuzzy DEAMTEL analysis, and hence it has the highest correlation with other enablers. This ensures that the supply chain must ensure timely delivery of vehicles.
3. In this study, some enablers are more critical for the effective execution of a responsive supply chain. For instance, Commitment of management and Strategy decision making (E3) must be designed for the entire supply chain phase, but it remains a matter if this enabler for any supply chain operation is required. It naturally ensures that all the supply chain operations that flow out of this process will be supported if the enabler is executed.
4. By managing the significant enabler, the organisation may minimise supply chain responsiveness's adverse effects, such as repeated changes in planning activities

Table 14 The distances of Enablers to ideal solutions, the related closeness coefficients and the ranking

Enablers	$d+$	$d-$	$\widetilde{CC}$	Rank
E3	0.08	0.62	0.89	1
E8	0.08	0.62	0.88	2
E5	0.13	0.58	0.82	3
E1	0.17	0.55	0.76	4
E7	0.18	0.54	0.75	5
E4	0.18	0.53	0.75	6
E12	0.2	0.51	0.72	7
E2	0.2	0.52	0.72	8
E17	0.2	0.52	0.72	9
E9	0.22	0.49	0.69	10
E13	0.23	0.49	0.68	11
E10	0.25	0.45	0.64	12
E11	0.27	0.42	0.61	13
E14	0.32	0.37	0.53	14
E16	0.36	0.32	0.47	15
E6	0.38	0.33	0.46	16
E15	0.4	0.28	0.41	17

and an increase in the lead time, which are contributing to lowering the supply chain efficiency.

5. Demand forecasting (E5), identified as one of the crucial enablers, was suggested as an integral tool for estimating market patterns to respond proactively to market demand. Specific processes and practices to prevent crises and avoid risks must be formulated, especially for long lead times and unexpected changes in market size, customer, and industry needs (Syntetos et al. 2009). Our research proposes supply chain managers to develop more accurate demand forecasting techniques by integrating Big data analytics and machine learning.
6. Insight of this research will also encourage other manufacturing companies to identify, prioritise and analyse the enablers' interrelationship to improve their supply chain responsiveness.

7 Conclusions and future scope

The automotive supply chain has entered a new era. Responsive supply in the form of the fast delivery supply chain is getting ever more critical. This paper has identified and analysed the enablers of responsiveness in the Indian automotive supply chain. The fuzzy DEMATEL analysis reveals the listed enablers' interrelationship and further grouped them as cause and effect enablers. The findings of the study indicated that automotive manufacturers should pay great attention to five important cause enablers, namely "Commitment of management and Strategy decision making (E3)", "Demand forecasting (E5)", "Continuous improvement (E4)", "Advanced Manufacturing System and plant capacity (E11)", "Vehicle architecture (E7)", "Accessibility of data (E15)", "Data Integration tools (E16)". The findings of the Fuzzy DEMATEL study added that the automotive manufacturers are required to focus on the high, prominent enablers of supply chain responsiveness are "Waiting period for vehicle's delivery (E8)", "Commitment of management and Strategy decision making (E3)", "Managing the supply chain risk (E2)", "Demand Forecasting (E5)", and "Culture, trust and involvement of people in the organization (E1)".

The Fuzzy AHP-Fuzzy TOPSIS technique was carried to prioritise the enablers. From the Fuzzy AHP analysis, it is identified that Understanding the nature and variability of demand (C6), Lead time reduction (C1) and Meeting the customer expectation (C2) are the significant criteria to evaluate the enablers. Using Fuzzy TOPSIS, the enablers were prioritised by considering the criteria weights obtained from Fuzzy AHP. The Fuzzy TOPSIS analysis reveals that Commitment of management and Strategy decision making (E3), Waiting period for vehicle's delivery (E8), Demand forecasting (E5), Culture, trust and involvement of people in the organisation (E1) and Distinguished Vehicle features (E7) as the top five most influenced enablers of the responsive supply chain in Indian automotive manufacturer. Therefore, the supply chain practitioners should emphasise those dominating enablers, who have substantial control of dependency and control the other drivers with high driving power. This decision-making approach suggested allows the organisation to develop appropriate mitigation plans based on the significant responsiveness factors.

This study is not without conceptual and analytical limitations. In this study, a limited number of enablers are investigated for supply chain responsiveness. Further research may investigate other enablers' role in the broad area of responsiveness in the automotive supply chain or other industry sectors. Future researches can reveal the interrelation and the relative importance of enablers using other advanced decision-making techniques.

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Data availability Enquiries about data availability should be directed to the authors.

Declarations

Conflict of interest The authors whose names are listed immediately below certify that they have NO affiliations with or involvement in any organisation or entity with any financial interest (such as honoraria; educational grants; participation in speakers' bureaus; membership, employment, consultancies, stock ownership, or other equity interest; and expert testimony or patent-licensing arrangements), or non-financial interest (such as personal or professional relationships, affiliations, knowledge or beliefs) in the subject matter or materials discussed in this manuscript, Rinu Sathyan, Dr. P. Parthiban, Dr. R. Dhanalakshmi, Sachin M. S.

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