

CHAPTER 4

EVALUATING THE RESILIENCE LEVEL OF AN INDIAN MANUFACTURING SUPPLY CHAIN

Resilience in the SC context is the technological and behavioral capability that enables it to prepare for uncertain events and minimize the probability, impact, and time to recover from the disruptions (Rajesh, 2019a). The resilience capabilities and practices discussed in chapter 3 enable the SC to adapt and accommodate the positive and negative influences of the business, social, and ecological disruption impact. Moreover, the causal-dependence relationships among the practices and their impact on enabling the resilience characteristic to the SC will help SC experts to align the policies and the resources to develop a RSC. However, it has often been observed that the practitioner faces problems in planning, implementing, and controlling the resilient behavior of the SC solely based on the knowledge of the resilient practices and the causal dependence relationships among them. Thus identifying the attributes of the resilient practices will aid the realization of the resilient behavior of a SC through proper implementation of practices.

Further, the literature suggests that resilient practices and their attributes are less tangible and can be suitably quantified using expert linguistic scores. Thus, using a tool that absorbs the impreciseness and vagueness present in the linguistic scores is desirable. The resilience score quantification of the SC also leads to identifying the performing and non-performing sections of the SC (Rajesh, 2019b; Patel et al., 2017). In addition, matching the case organization SC resilience level with the linguistic or desired resilience levels will further enable the decision-makers to strategically assign, implement and promote the available capacity to improve the resilience capability of the

SC. Moreover, this quantified value of resilience level can be used to compare the SCs, thus providing information regarding the improvement required to become the best in class among the competitors (Rajesh and Ravi, 2015). Hence, in this chapter, considering the importance of the resilience level assessment, an attempt is made to identify the attributes of the practices enabling the resilient capability of the SCs and provide a novel approach to quantify the resilience ability of a SC corresponding to the Indian iron and steel manufacturing firm.

Considering our chapter scope, a fuzzy logic approach is used to quantify the resilience level of the case organization. According to Lin et al. (2006), a fuzzy logic approach is a handy tool for assessing a system comprising impreciseness and vagueness in behavior. Similarly, Rajesh (2019) considered it the best tool in a situation comprising group decision-making and cognitive uncertainties. Thus, this approach quantifies not only the resilience level of the SC but also it minimizes the vagueness and uncertainty present in the expert's response following the fuzzification and de-fuzzification approach. With the focus on developing a RSC, in this chapter, seventy-six attributes corresponding to the nineteen practices of the RSC are identified (Figure 4.2). Further, considering these practices and attributes, the fuzzy logic approach enables assessing the resilience level called the resilience fuzzy index (RFI). Moreover, a fuzzy performance index (PFI) is also evaluated, providing information regarding the SC's non-performing section.

4.1. Conceptual framework

The opportunities and the challenges faced by manufacturing organizations in the 21st-century business environment have made the management of the SC a great challenge for practitioners. From the literature review, it is perceived that the assessment of the resilience level of the SC can help the managers in this regard. It enables the managers

to understand the vulnerability and the competitive position of their SC during internal and external disruptions. The various steps involved in evaluating the resilience level of a SC are provided in Figure 4.1. The proposed framework is incorporated to evaluate the resilience level of the SC corresponding to an iron and steel manufacturing firm in India.

The chapter 3, comprises nineteen practices of the RSC whose successful implementation enables the resilient capabilities of the SC. In this chapter, the attributes of these nineteen practices that help practitioners strategize their capacities, resources, and policies for their implementation are identified. Thus it is conceptually categorized RSC into three layers, i.e., goal (RSC), resilient practices, and the attributes of the resilient practices (Table 4.1), as presented in Fig 4.2. In this chapter, nineteen resilient practices of the SC that are discussed in chapter 3 are used, and their corresponding attributes are identified in the following two steps. Firstly, a thorough literature review is carried out, and the academician's view is taken to identify all the possible attributes of the resilient practices corresponding to the case organization. Secondly, the insights of the case organization and other related industry experts are collected to finalize the list of attributes for this study. A total of seventy-six attributes have been finalized for this research, as presented in Table 4.1.

Further, it is observed that most of the attributes are qualitative and can be most suitably described in linguistic terms. Moreover, the linguistic terms are subjective to the decision-maker; therefore, subjective decision-making tool comprising grey theory, fuzzy set theory, etc., can be most suitably employed that quantify not only the linguistic terms but also absorbs the vagueness and impreciseness present in the data (Rajesh, 2019; Lin et al., 2006).

However, fuzzy logic was found to be the most appropriate approach in managerial decision-making and proposal of the fuzzy indices among the available theories (Radivojević and Gajović, 2014; Lin *et al.*, 2006).

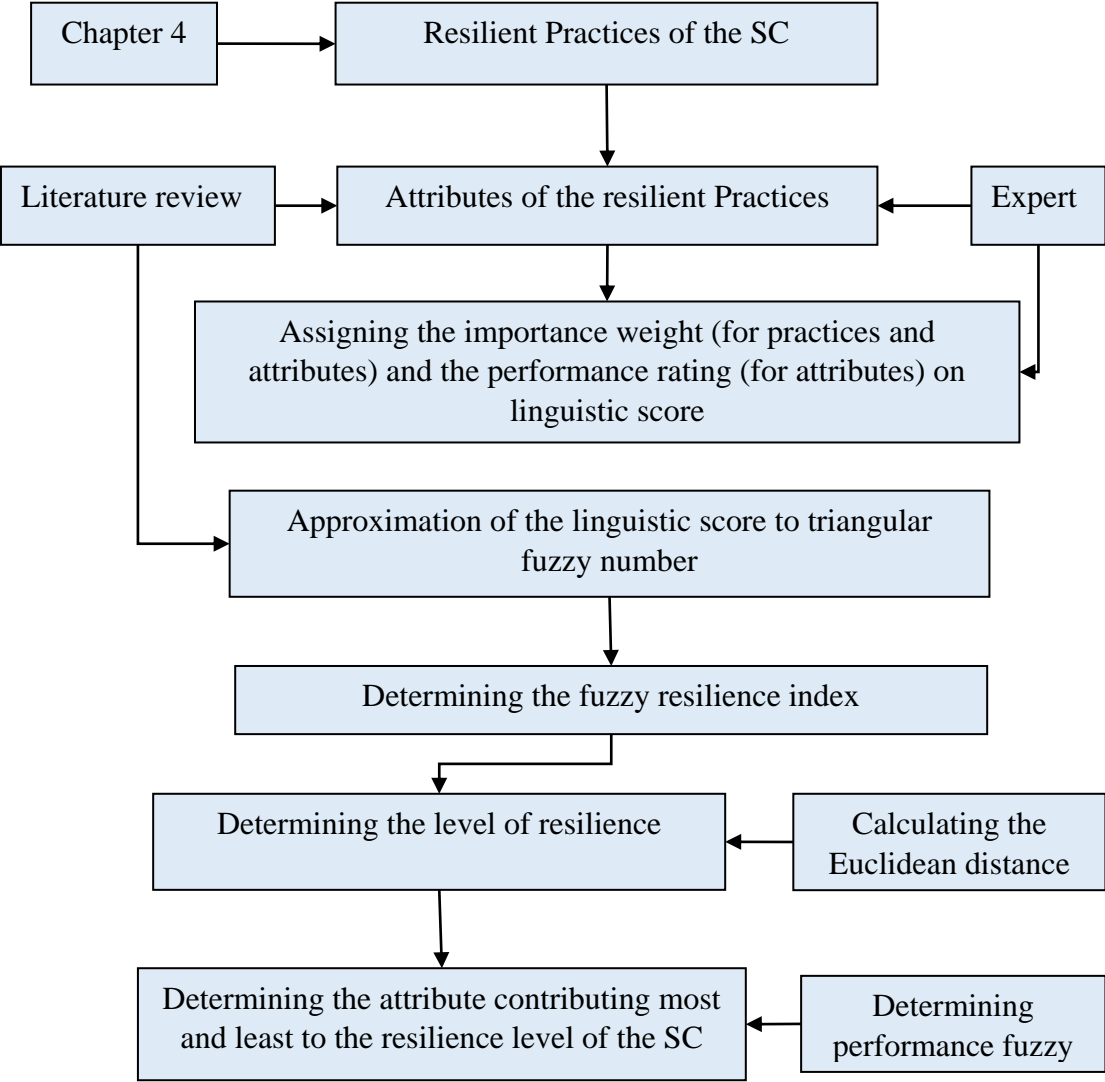


Figure 4.1. Framework for the assessment of the resilience level of the SC

Table 4.1: Attributes of the RSC

Resilient practice	Attributes	Reference	Remarks
Flexibility (P_1)	Re-configurability of the manufacturing system (A_{11}).	Rajesh (2019); Pavlov et al. (2018), Rajesh (2018), Datta et al (2017), Tukamuhabwa et al. (2015), Ambulkar et al. (2015), Levalle et al. (2015)	Enable the production system to accommodate the variability in product design and production volume
	Multi-skilled human resources and outsourcing of knowledge (A_{12}).	Neumeyer and Liu (2021), Tukamuhabwa et al. (2015), Christopher and Holweg (2011), Park (2011), Tang (2008)	Enables behavioral flexibility of human resource
	Multiple suppliers, contract flexibility, and high control over lead time (A_{13}).	Bhattacharya and Bagchi (2019), Das and Abdel-Malek (2003), Tukamuhabwa et al. (2015), Namdar et al. (2018)	Enables the availability of raw materials and other supplies
	Multi-mode and multi-carrier transportation system (A_{14}).	Tukamuhabwa et al. (2015), Sodhi et al., (2012), Filippi et al. (2011), Tang (2006)	Enables the accommodation of variability in
Postponement (P_2)	Outsourcing the material and semi-finished products (A_{21}).	Ruiz-Torres et al. (2019), Chatagnier (2019), Thiyagarajan et al. (2018), Carvalho, et al., (2012), Tukamuhabwa et al. (2015), Tang (2006)	Enables to compensate for the supply failure and improve the organizations' competitiveness.
	Delaying the product differentiation till actual orders are received (A_{22}).	Ye et al. (2020), Mikkola and Skjøtt-Larsen (2004), Bish and Chen (2015), Fang et al. (2012)	It improves the availability of raw material and semi-finished goods and thus enables mass customization.

	Use of standardized raw material and production process (A_{23}).	Kamalahmadi and Parast (2016), Rajesh (2019), Lee (2011), Costinot et al. (2013), Van Hoek et al. (2001)	Improves raw material availability and promotes productivity.
	Having different strategies for different groups of products (A_{24}).	Prajogo et al. (2018), Vonderembse et al. (2006), Battezzati and Magnani (2000), Deep and Dani (2009)	Enables effective and efficient control over the production process and quick changeover during disruptions.
Visibility (P_3)	Anticipation and understanding of market trends (A_{31}).	Golan et al. (2020), Ivanov and Dolgui (2020), Ivanov and Dolgui (2019), Neubauer (2018), Srinivasan Radhakrishnan, (2018), Bei and Wijewardana (2012), Das and Lashkari (2015), Glickman and White (2006), Pettit et al. (2010)	Leads to competitive advantage and the opportunities.
	Anticipation and understanding of technology up-gradation (A_{32}).	Agarwal and Seth (2021), Singh and Singh (2019), Ivanov and Dolgui (2019), Ivanov and Dolgui (2020), Kamalahmadi and Parast (2016), Pettit et al. (2010), Simba et al. (2017), Ponomarov and Holcomb (2009), Pettit et al. (2008)	Enables the adaptation of the SC to the changing business environment.
	Tracing and tracking SC activities, e.g., inventory position, production process, purchase schedule, transshipments, etc. (A_{33}).	Simba et al. (2017), Tukamuhabwa et al. (2015), Rice and Spayd (2005)	Improves the control over SC activities.
	Understanding the	Yazdani et al. (2019),	Improves the

	performance of the other members of the SC (A_{34}).	Colicchia et al. (2019), Colicchia and Strozzi (2012), Samsuddin et al. (2018), Saenz and Revilla (2014), Matook et al. (2009), Behdani et al. (2012)	creation of contingent resources to combat any variability in the SC process.
Agility (P_4)	Short product development cycle and quick changeover (A_{41}).	Mao et al. (2020), Balaei et al. (2020), Sodhi and Tang (2012), Pero et al. (2010), Carvalho et al. (2011), Min and Zhou (2002)	It improves customer satisfaction, mitigates the disruption impacts, and enables competitive gain.
	Quickness in material procurement, information sharing, and capacity improvement (A_{42}).	Ivanov and Dolgui (2020), Mattila and Pommelin-andrejeff (2017), Kumar et al. (2017), Sodhi and Tang (2012), Columbi et al. (2012), Puga et al. (2009)	It improves customer satisfaction, mitigates the disruption impacts, and enables competitive gain.
	Quick decision-making and implementation (A_{43}).	Ivanov and Dolgui (2020), Abimbola and Khan (2019), Chowdhury and Quaddus (2016), Banyai (2016), Christopher and Peck (2004)	Mitigates the uncertainty associated with the SC and combats the disruption impact.
	Small set up time and lead time (A_{44}).	Rajesh (2018), Govindan et al. (2017), Cantor <i>et al.</i> (2014), Tang (2005)	Improves the control over supply and demand variabilities.
Collaboration (P_5)	Trust-based relationships with the members of the SC (A_{51}).	Tukamuhabwa et al. (2015), Johnson et al. (2013), Wieland and Wallenburg (2013), Ryciuk and Nazarko (2020)	Promotes cooperation and commitment among the SC members.
	Involvement of upstream and downstream members in strategic decision-making (A_{52}).	Rajesh (2019), Margolis et al. (2018), Rajesh (2018), Jain et al. (2017), Pettit et al. (2010), Vishnu et al.	Minimizes the sources of the risks and improves the decision efficacy.

		(2019)	
	Coordination and cooperation among SC members during disruptions or breakdowns (A_{53}).	Negri et al. (2021), Asian and Nie (2014), Choi et al. (2013), Xiao et al. (2012)	Minimizes the disruptions impact and recovery time.
	Authority, responsibility, and knowledge sharing among the SC members (A_{54}).	Rajesh (2019), Birks (2016), Miller (1992), Laanti (2013), Hoejmose et al. (2013)	Minimizes the risk and promotes innovation.
Information sharing (P_6)	Use of information and communication technology (A_{61}).	Zhang et al. (2021), Sabu et al. (2018), Patel et al. (2017), Rajesh (2017), Li et al. (2017), Tukamuhabwa et al. (2015)	Improves the efficiency and efficacy of data collection and its sharing.
	Creating and sharing reliable information (A_{62}).	Agarwal and Seth (2021), Negri et al. (2021), Rajesh (2019), Jain et al. (2017), Carvalho et al. (2011), Lee et al. (2000)	Minimizes the risk sources.
	Real-time information sharing (A_{63}).	Agarwal and Seth (2021), Rajesh (2020), Hohenstein et al. (2016), Ali et al. (2017), Jain et al. (2017), Soni et al. (2014), Carvalho et al. (2011)	Enables quick decision-making and its implementation.
	Skilled human resource for information management (A_{64}).	Agarwal and Seth (2021), Neumeyer and Liu (2021), Hosseini et al. (2019), Neubauer (2018), Shibin <i>et al.</i> (2016), Markman (2013)	Minimizes information management-related errors.
Strategic stocking (P_7)	Outsourcing and make to stock for critical supplies (A_{71}).	Tukamuhabwa et al. (2015), Iakovou et al. (2007), Tang (2006), Christopher and Peck (2004)	Enables the production continuity during market uncertainty.

	Having contingent supplier (A_{72}).	Garcia (2021), Duchek (2020), Ivanov and Dolgui (2019), Chowdhury et al. (2019), Brandon-Jones et al. (2014)	Minimizes the risk of supply failure.
	Positioning of inventory at a secured place (Which is also accessible to other SC members during disruptions) (A_{73}).	Lücker and Seifert (2017), Iakovou et al. (2007), Tang (2005), Ponomarov and Holcomb (2009), Croom (2001)	Absorbs the supply and demand variability.
Redundancy (P_8)	Multiple supply base (A_{81}).	Namdar et al. (2018), Jain et al. (2017), Wang et al. (2015), Saenz and Revilla (2014), Azevedo et al. (2011), Tang (2005)	Minimizes the supply risk.
	Practicing make and buy strategy (A_{82}).	Baharmand et al. (2019), Kumar et al. (2014), Liu et al. (2010), Tang (2006)	Enables quick fulfillment of customers order.
	Multi-skilled human resource (A_{83}).	Asghar et al. (2021), Hosseini et al. (2019), Neubauer (2018), Christopher and Holweg (2011), Thun et al. (2011)	Minimizes the production risk due to absenteeism.
	Multiple production lines (A_{84}).	Hosseini et al. (2019), Neubauer et al. (2018), Ali et al. (2017), Wu et al. (2013), Park (2013), Giaretta (2005)	Minimizes the risk of production system failure and improves product availability to the market.
	Multiple warehousing and transportation facilities (A_{85}).	Ellegaard (2008), Manuj and Mentzer (2008)	Improves the product availability to the market.
Risk management culture (P_9)	Risk assessment and mitigation planning at every stage of decision-making (A_{91}).	Pettit et al. (2013), Punniamorthy et al. (2013), Wieland and Wallenburg (2012), Christopher and Peck	Enables the development of preventive measures against the vulnerabilities.

		(2004)	
	Continuous strive for process improvement and innovation (A_{92}).	Ye et al. (2020), Sinha et al. (2004), Giaretta (2005), Carvalho et al. (2011), Cole ((2002)	Leads to cost minimization, productivity improvement, and combat changing customer needs
	Continuous strive to identify and reduce the source of risk and develop the culture of risk management training (A_{93}).	Tukamuhabwa et al. (2015), Miles et al. (2014), Ambulkar et al. (2015), Kamalahmadi and Parast (2016), Maskey et al. (2020), Musa (2012), Wadhwa et al. (2008)	Reduces the source and the impacts of the risk.
	Risk and reward sharing among SC partners (A_{94}).	Patel. et al. (2017), Pettit et al. (2013), Wakolninger and Cruz (2011), Jüttner and Maklan (2011), Manuj and Mentzer (2008)	Improves the intuitive participation of SC members in risk and disruption management
	Prepositioning the business continuity team (A_{95}).	Duchek (2020), Mackay et al. (2019), Hosseini et al. (2019), Ivanov and Dolgui (2019), Rajesh (2018), Ali et al. (2017), Tucker (2015)	Develops the contingent strategy to mitigate and recover from the disruption
Dynamic pricing (P_{10})	Pricing based on the product availability and demand rate (A_{101}).	Sharma et al. (2021), Liu et al. (2006), Yang and Zhang (2014), Jia and Hu (2011), Biller et al. (2005), Gallego and Ryzin (1994)	Controls the variability and demand.
	Pricing based on competitor performance (A_{102}).	Gibbs et al. (2018), Zhang (2016), Biller et al. (2005)	Improves the competitiveness and market cover.
	Pricing based on raw material cost and availability (A_{103}).	Jamali and Rasti-Barzoki (2018), Li et al. (2019), Yong et al. (2012), Tang and Tomlin (2008), Liu et al. (2006)	Controls the variability in supply.

	Pricing based on customer perception towards the product (uniqueness, quality, etc.) (A_{104}).	Dubey et al. (2019), Chung and Li (2013), Biller et al. (2005)	Improves the market cover and revenue.
Silent product rollover (P_{11})	Working over range and variety of products (New as well as substitutable products) (A_{111}).	Zhang et al. (2021), Ramanath and Sonia (2018), Taghavi and Chinnam (2014), Carvalho et al. (2011), Christopher and Towill (2000) Agarwal et al. (2006), Takada et al. (1995)	Improves the customer satisfaction and product replacement during supply and demand failure.
	Continuous strive to improve production and logistics capacity (A_{112}).	Sharma et al. (2021), Youn et al. (2017), Carvalho et al. (2011), Vonderembse et al. (2006)	Enables the quick changeover during and after the disruptions.
	Continuous strive to understand the changing customer demand (A_{113}).	Asghar et al. (2021), Youn et al. (2017), Carvalho et al. (2011), Cai et al. (2009)	Drive the quick replenishment of the market demand.
	Having a cross-functional team (A_{114}).	Boubaker et al. (2022), Asghar et al. (2021), Flothmann et al. (2018), Pujawan and Geraldin (2009)	Enables the development of formal processes to manage
Warehouse and inventory management (P_{12})	Following modern logistics practices (E.g., wave picking, cross-docking, etc.) (A_{121}).	Murray (2019), Lopienski (2021)	Minimizes the logistics cost and replenishment time.
	Classifying the material/products based on criticality, demand rate, cost, availability, size, type, etc. (A_{122})	Manjulata (2022), Barros et al. (2021), Gonçalves et al. (2020)	Improves the efficiency
	Practicing established safety standards and procedures for inventory management	Duchek (2020), Murray (2019), Vastveit et al. (2015)	Enable quick replenishment of supplies

	(A ₁₂₃)		
	Contingency plan against disruptions, e.g., buffer stock, supplier and logistics alternatives, etc. (A ₁₂₄)	Rajesh (2019), Chopra and Sodhi (2012), Danese (2011), Blackhurst et al. (2005), Eriksson and McConnell (2011)	To absorb the disruption impact.
	Using warehouse and inventory management tools (A ₁₂₅)	Lopienski (2021), Razavian et al. (2021), Alawneh and Zhang (2018), Patel et al. (2017), Ambulkar et al. (2015)	Close control over variability in supply and demand using warehouse and inventory management tools
Adaptability (P ₁₃)	Continuous approach for capability improvement through technology up-gradation, training of human resources, research and development, etc. (A ₁₃₁).	Neumeyer and Liu (2021), Boubaker et al. (2022), Patel. (2017), Kanten et al. (2017), Sahu et al. (2017), Cole ((2002)	Enables to adopt the changing market condition.
	Having a strategic team to scan opportunities, vulnerabilities, and disruptions impact. (A ₁₃₂).	Boubaker et al. (2022), Patel. et al. (2017), Kanten et al. (2017), Hohenstein et al. (2015), Williams et al. (2009)	Improves the responsiveness of the SC.
	Decentralized decision making and flexibility in policy implementation (A ₁₃₃).	Helmrich et al. (2021), Duchek (2020), Faguet et al. (2014)	Improves high control over short term and mid-range supply and demand variabilities.
	Quick rearrangement of resources and capability development (A ₁₃₄).	Balaei et al. (2020), Mao et al. (2020), Ivanov and Sokolov (2010), Tang (2005), Sodhi and Tang (2012)	Improves the product availability.
Economic supply incentives (P ₁₄)	Minimum order guarantee to the suppliers (A ₁₄₁).	Rothestein (2019), Chintapalli et al. (2017), Chow et al. (2012), Tang (2005),	It guarantees and improves the long-term relationships among upstream and downstream

			members.
	Helping financially to other members of the SC in adversities (A_{142}).	Pakdeechoho and Sukhotu (2018), Lokesh et al. (2017), Huang et al. (2015), Tukamuhabawa et al. (2015), Tang (2005)	Improves capability and quick recovery from disruptions.
	Sharing knowledge and technology with the SC members to upgrade or develop new capabilities (A_{143}).	Asghar et al. (2021), Pakdeechoho and Sukhotu (2018), Lokesh et al. (2017), Blome et al. (2014)	Improves the competency and the responsiveness of the SC.
	Sharing benefits with the other members of the SC (A_{144}).	Pakdeechoho and Sukhotu (2018), Sodhi and Tang (2012), Faisal (2010), Simatupang et al. (2000)	Improves the trust of togetherness and the capability of the members.
Improve financial strength (P_{15})	Developing emergency funds, diversifying the business financing, buying insurance, etc. (A_{151}).	Business insurance (2021), Juttner and Maklan (2011), Skipper and Hanna (2009)	Improves the financial robustness of the SC.
	Efficient and effective procurement strategy (A_{152}).	Lokesh et al. (2017), Juttner and Maklan (2011)	Minimizes the cost and procurement vulnerabilities.
	Replacing unwanted and ineffective assets with efficient and effective assets (A_{153}).	Business insurance (2021), Rothstein (2019), Lokesh et al. (2017)	Improves the cash availability and organization competence.
	Seeking financial aid from the government and financial institutions (A_{154})	Business insurance (2021), Blome and Schoenherr (2011), Yang et al. (2019), Bei and Wijewardana (2012), Gurtu and Johny (2021), Wicher and Lenort (2012), Filser et al. (2014)	Improves the organizational goodwill and the financial strength.
Assortment planning (P_{16})	Forecasting market demand based on past records and expert research, i.e., demand	Sharma et al. (2021), Agrawal and Smith (2015), Talebian et al. (2013), Vaidyanth	Minimizes the uncertainty associated with over and under

	learning (A_{161}).	(2011)	production.
	Knowledge of competitor performance (A_{162}).	Bahng et al. (2018), Agrawal and Smith (2015), Zou and Cavusgil (2002)	Enables the organizations in strategizing their production processes and the product offerings they make to the customers.
	Market clustering based on region, demand rate, product type/variability, customer demographic and psychographic status, etc. (A_{163}).	Umpfenbach et al. (2018), van Ryzin and Vulcano (2013), Kok et al. (2007)	Provide information regarding the product to be promoted.
	Product promotion based on its specialty and demand rate (A_{164}).	Bahng et al. (2018), Agrawal and Smith (2015), Li (2014), Sun et al. (2003)	Enable market gain.
SC restructuring (P_{17})	Understanding of core and reconfigurable parts of SC (A_{171}).	Chandra and Grabis ((2016),) Cândido et al. (2009), MA et al. (2007)	Provides the scope for reconfiguring the SC.
	Preparedness for restructuring (A_{172}).	Asghar et al. (2021), Flothmann et al. (2018), Rehman and Subash Babu (2013), Radosevic et al. (2013)	Promotes budget allocation, human resource training, cooperation and commitment among SC members, etc.
	Continuously strive to identify alternatives for the supplier, logistics facilities, production unit, distribution centers, etc., (A_{173}).	Kumar et al. (2014), Dev et al. (2014), Peleg-Gillai et al. (2006)	Enables quick rearrangement of the resource to develop newer capabilities.
Virtual Enterprising (P_{18})	Alliance with a new member (A_{181}).	Chandra and Grabis (2016), Iakovou et al. (2007)	It improves the SC performance through capability improvement.
	Short term strategic alliance (A_{182}).	Sáenz et al. (2018), Patel et al. (2017), Chandra and Grabis	Enables achievement of a specific SC goal,

		(2016), Iakovou et al. (2007)	such as disruption recovery, training, customer services, etc.
	Virtual integration among the SC (A_{183}).	Pankowska (2019), Carvalho et al. (2011), Ivanov and Sokolov (2009), Vonderembse et al. (2006)	Use technology for cooperation and coordination among the alliance partner or cyber-physical system.
Market Sensitivity (P_{19})	Regular as well as independent reviews of organization performance with changing business environment (A_{191}).	Lokesh et al. (2017), Kamalahmadi and Parast (2016), Tseng et al. (2015), Christopher and Peck (2004)	Identifies the loopholes and factors leading to SC vulnerability.
	Investment in resources and staff development to accommodate the market change (A_{192}).	Rajesh (2018), Carvalho et al. (2011), Richey and Autry (2009), Stemmler ((2002)	Enables the SC to adapt to the market trends.
	SC members accommodate one another's requests to fulfill customer demands (A_{193}).	Christopher and Lee (2004)	Enables to manage the supply and demand variability.
	Use of predictive technology to sense and forecast the market demand (A_{194}).	Zhang et al. (2021), Kilcoure (2018), Agrawal and Smith (2015)	Minimizes the uncertainty associated with forecasting.

A fuzzy logic approach (Section 4.2) has been used to quantify the resilience level of the case organization SC. The inputs required in this process are obtained from the experts allied with India's iron and steel manufacturing company, having a global SC network. First, the experts are requested to provide the importance rating corresponding to each practice and its attributes on a seven-point rating scale. Secondly, the experts are requested to provide the performance rating of their SC that corresponds to each of the attributes. All the responses of the experts are collected in terms of the linguistic scores,

which are further approximated by triangular fuzzy numbers (Table 4.2). Moreover, based on these inputs resilience score of the case organization is evaluated in terms of RFI, which is further approximated to identify the resilience level using the Euclidean distance approach. Additionally, the fuzzy performance index (FPI) is evaluated to determine the attributes corresponding to which organizations are not performing.

4.2. Methodology: Fuzzy Logic Approach

In this chapter, a fuzzy logic-based model is developed to assess the resilience level of the SC. Moreover, considering the resilient practices and attributes, the resilience level of the case organization is quantified using the developed model. Herein, a triangular fuzzy rating scale is used to collect and quantify the expert response. The resilience score obtained will help the practitioner identify the gap between the actual and desired level of resilience for their SC. In this chapter, a step-by-step procedure is carried out to evaluate the resilience score, thus the resilience level of an Indian iron and steel manufacturing SC. In this, two scores, i.e., RFI and PFI are calculated, where RFI indicates the resilience level of the case organization and the PFI indicates the contribution of individual attributes in enabling the resilience ability of the SC.

Here, seventy-six attributes corresponding to the nineteen practices of RSC are identified based on the expert's opinion and the literature review. A committee of seven experts (having experience of 10 years and above) from the case organization is interviewed to finalize the attributes of the RSC. Moreover, their individual response is also collected regarding the importance weight and performance rating of the practices and attributes. The linguistic scale given by Lin et al. (2006) is used in this research to collect the expert's response. The various steps involved in this evaluation approach are provided in the following sections.

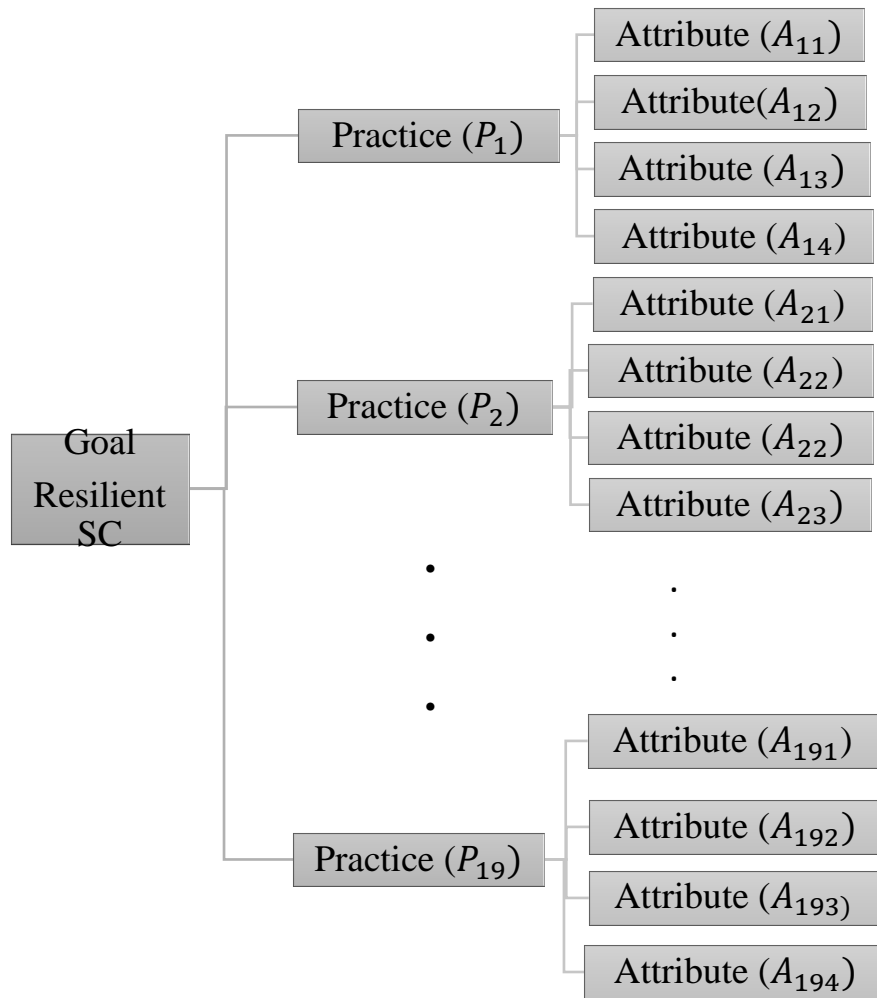


Figure 4.2. Framework for the RSC

4.2.1. Linguistic scale for the assessment of the importance weight and the performance rating

The resilience score evaluation requires the expert's assessment regarding each of the practices and attributes in terms of the rating scales and weighting. And also, it is believed that these parameters of the RSC are qualitative, and it is almost impossible to accurately determine their exact scores (Lin et al., 2006; Patel et al., 2017). Therefore, in this research, linguistic terms are used. The linguistic scales ranging from worst to excellent are used for rating the attributes, and the linguistic scale ranging from very low to very high is used for weights of practices and the attributes. Moreover, these linguistic terms are quantified by assigning the corresponding fuzzy score. The

linguistic terms and their corresponding membership functions used in this study are obtained from literature such as Chen and Hwang, 1992; Lin et al., 2006; Patel et al., 2017; and Rajesh, 2019. In this study, triangular fuzzy membership functions are obtained for the linguistic scores given by the experts. Seven-point scale is used for the performance rating (Excellent (E), Very Good (VG), Good (G), Fair (F), Poor (P), Very Poor (VP), and Worst (W)) as well as weighting (Very High (VH), High (H), Fairly High (FH), Medium (M), Fairly Low (FL), Low (L), and Very Low (VL)) as provided in Table 4.2.

4.2.2. Collecting and aggregating the expert response

The assessment score regarding weight and performance rating is collected from the seven experts of the case organization through a Google form-based multiple choice question type questionnaire. These experts are thorough with the challenges and opportunities of the present competitive business environment, the concept of risk management and RSC, and the factors affecting the company's performance. The questionnaire used in this study comprises the statements regarding the practices and the attributes and the seven-point scale describing their weights and performance ratings. The responses collected from the experts are presented in Table 4.3, which is further converted to fuzzy numbers using the information provided in Table 4.2.

Many methods are available for the aggregation of the expert's score, such as the arithmetic mean approach, median approach, and mode approach; however, the arithmetic means the approach is most widely accepted in the aggregation of the expert's opinion (Lin et al., 2006). Let, E_t represent the experts chosen for the study, such that $t = 1, 2, \dots, a$, where a represents the number of experts. Let, P_i represent the i^{th} practices of the RSC and A_{ij} represents the j^{th} attribute of the i^{th} practices.

Moreover, let the performance rating is represented by R , and the weight is represented by W . Such that R_{ijt} represent the performance rating given by t^{th} expert for j^{th} attribute of i^{th} practices, W_{ijt} represent the weight allotted by t^{th} expert for j^{th} attribute of i^{th} practices, and W_{it} represent the weight allotted by t^{th} expert for i^{th} practices. Thus, using equations 4.1, 4.2, and 4.3, the expert's response can be aggregated for the importance weight of the practices (W_i), importance weight of the attributes (W_{ij}), and the performance rating corresponds to the attributes (R_{ij}) respectively. The aggregated value corresponds to the priority weight of the practices are provided in Table 4.3, aggregated value corresponds to the attributes regarding their priority weights and the performance rating is provided in Table 4.4 and Table 4.5.

Table 4.2: Linguistic scale and associated Triangular fuzzy number

Performance rating		Importance weight	
Linguistic score	Associated fuzzy values	Linguistic score	Associated fuzzy values
Worst (W)	(0, 0.05, 0.15)	Very Low (VL)	(0, 0.05, 0.15)
Very Poor (VP)	(0.1, 0.2, 0.3)	Low (L)	(0.1, 0.2, 0.3)
Poor (P)	(0.2, 0.35, 0.5)	Fairly Low (FL)	(0.2, 0.35, 0.5)
Fair (F)	(0.3, 0.5, 0.7)	Medium (M)	(0.3, 0.5, 0.7)
Good (G)	(0.5, 0.65, 0.8)	Fairly high (FH)	(0.5, 0.65, 0.8)
Very Good (VG)	(0.7, 0.8, 0.9)	High (H)	(0.7, 0.8, 0.9)
Excellent (E)	(0.85, 0.95, 1.0)	Very High (VH)	(0.85, 0.95, 1.0)

$$W_i = \frac{W_{i1}(+)W_{i2}(+)...(+)W_{ia}}{a} \quad (4.1)$$

$$W_{ij} = \frac{W_{ij1}(+)W_{ij2}(+)...(+)W_{ija}}{a} \quad (4.2)$$

$$R_{ij} = \frac{R_{ij1}(+)R_{ij2}(+)...(+R_{ija}}{a} \quad (4.3)$$

As a sample of computation, the aggregated value corresponds to the *Flexibility in SC* practice, and its attributes are provided below:

- a) Aggregated weight of the RSC practice - Flexibility in SC

$$W_1 = \frac{W_{11}(+)W_{12}(+) \dots (+)W_{17}}{7}$$

$$W_1 = \frac{M(+)\text{FH}(+)H(+)\text{M}(+)\text{M}(+)\text{FH}(+)\text{FH}}{7}$$

W_1

$$= \frac{(0.3,0.5,0.7)(+)(0.5,0.65,0.8)(+)(0.7,0.8,0.9)(+)(0.3,0.5,0.7)(+)(0.30,0.50,0.7)(+)(0.5,0.65,0.80)(+)(0.5,0.65,0.80)}{7}$$

$$= (0.44,0.61,0.77)$$

- b) Aggregated weight of the attribute of flexibility in SC - Re-configurability of the manufacturing system to accommodate different product designs, product mix, and production volume (A_{11})

$$W_{11} = \frac{W_{111}(+)W_{112}(+) \dots (+)W_{117}}{7}$$

$$= \frac{\text{FH}(+)\text{M}(+)\text{H}(+)\text{FH}(+)\text{FH}(+)\text{M}(+\text{H})}{7}$$

$$= \frac{(0.50,0.65,0.80)(+)(0.30,0.50,0.70)(+)(0.70,0.80,0.90)(+)(0.50,0.65,0.80)(+)(0.50,0.65,0.80)(+)(0.30,0.50,0.70)(+)(0.70,0.80,0.90)}{7}$$

$$= (0.50,0.65,0.80)$$

- c) Aggregated performance rating for an attribute of flexibility in SC - Re-configurability of the manufacturing system to accommodate different product designs, product mix, and production volume (A_{11})

$$R_{11} = \frac{G(+)\text{VG}(+)\text{VG}(+)\text{VG}(+)\text{F}(+)\text{E}(+)\text{E}}{7}$$

Table 4.3: Importance weight of the RSC practices

RSC practices (P_i)	Importance weight (w_{ij})							Average fuzzy weight (W_{ij})
	E_1	E_2	E_3	E_4	E_5	E_6	E_7	
Flexibility (P_1)	M	FH	H	M	M	FH	FH	0.44,0.61,0.77
Postponement (P_2)	VH	FL	FL	M	M	FH	FL	0.36,0.52,0.67
Visibility (P_3)	VH	H	H	FH	VH	VH	H	0.74,0.84,0.93
Agility (P_4)	VH	FH	H	H	FH	H	FH	0.64,0.76,0.87
Collaboration (P_5)	VH	VH	VH	FH	H	VH	H	0.76,0.86,0.94
Information Sharing (P_6)	VH	FH	FH	M	H	H	H	0.61,0.74,0.86
Strategic stocking (P_7)	VH	FL	H	M	FH	H	FH	0.54,0.67,0.80
Redundancy (P_8)	M	M	FH	H	FL	M	M	0.37,0.54,0.71
Risk management culture (P_9)	FH	FH	H	FH	FH	H	FH	0.56,0.69,0.83
Dynamic pricing (P_{10})	FL	M	M	FL	FL	M	FH	0.29, 0.46,0.63
Silent product rollover (P_{11})	FH	VH	VH	H	VH	VH	H	0.76,0.86,0.94
Warehouse and inventory management (P_{12})	M	FH	FH	M	H	FH	FH	0.47,0.63,0.79
Adaptability (P_{13})	VH	FH	VH	VH	H	VH	FH	0.73,0.84,0.93
Economic supply incentive (P_{14})	H	H	VH	FH	FH	FH	FH	0.61,0.74,0.86
Improve financial strength (P_{15})	H	H	H	FH	H	VH	H	0.69,0.80,0.90
Assortment planning (P_{16})	L	M	M	FL	FL	FH	M	0.27,0.44,0.60
SC restructuring (P_{17})	M	FH	FL	FL	M	FH	FH	0.36,0.52,0.69
Virtual Enterprising (P_{18})	H	FH	M	FL	FL	H	FH	0.44,0.59,0.73
Market Sensitivity (P_{19})	VH	M	H	FH	FH	H	FH	0.58,0.71,0.84

$$= \frac{(0.5,0.65,0.8)(+)(0.7,0.8,0.9)(+)(0.7,0.8,0.9)(+)(0.7,0.8,0.9)(+)(0.3,0.5,0.7)(+)(0.85,0.95,1)(+)(0.85,0.95,1)}{7}$$

$$= (0.66,0.78,0.89)$$

Table 4.4: Importance weight for the attributes of the RSC practices

(P_i)	Attributes (A_{ij})	Importance weight of attribute (w_{ij})							Average fuzzy weight (W_{ij})
		E_1	E_2	E_3	E_4	E_5	E_6	E_7	
P_1	A_{11}	FH	M	H	FH	FH	M	H	0.50,0.65,0.80
	A_{12}	H	FH	FH	M	M	FL	VH	0.48,0.63,0.77
	A_{13}	H	FH	H	FH	M	M	H	0.53,0.67,0.81
	A_{14}	H	FH	M	FL	M	FL	H	0.41,0.56,0.71
P_2	A_{21}	FH	FL	FH	M	FL	VH	VH	0.49,0.63,0.76
	A_{22}	H	M	L	M	M	H	VH	0.46,0.61,0.74
	A_{23}	H	H	H	FH	M	FH	H	0.59,0.71,0.84
	A_{24}	VH	H	H	FH	M	H	H	0.64,0.76,87
P_3	A_{31}	H	H	VH	FH	M	VH	H	0.66,0.78,0.89
	A_{32}	H	H	VH	M	FH	H	VH	0.66,0.78,0.89
	A_{33}	VH	H	H	M	FH	H	H	0.64,0.76,0.87
	A_{34}	VH	H	VH	M	M	H	VH	0.65,0.78,0.89
P_4	A_{41}	VH	H	VH	H	M	VH	FH	0.68,0.80,0.90
	A_{42}	H	VH	VH	H	M	FH	H	0.66,0.78,0.89
	A_{43}	H	H	VH	H	FH	VH	VH	0.74,0.84,0.93
	A_{44}	H	H	FH	H	M	FH	H	0.59,0.71,0.84
P_5	A_{51}	H	H	FL	FH	M	M	VH	0.51,0.65,0.79
	A_{52}	FH	H	M	FH	M	L	H	0.44,0.59,0.73
	A_{53}	VH	VH	VH	H	M	M	VH	0.67,0.80,0.90
	A_{54}	H	VH	VH	H	M	L	H	0.60,0.71,0.80
P_6	A_{61}	H	H	VH	H	FH	VH	H	0.71,0.82,0.91

	A_{62}	H	VH	VH	H	FH	FH	VH	0.69,0.80,0.90
	A_{63}	H	VH	FH	H	M	VH	VH	0.71,0.82,0.91
	A_{64}	VH	VH	VH	H	FH	FH	VH	0.73,0.84,0.93
P_7	A_{71}	FL	M	VH	FH	FH	M	VH	0.50,0.65,0.79
	A_{72}	M	H	VH	FH	FH	L	VH	0.54,0.67,0.79
	A_{73}	M	H	FH	H	M	M	H	0.50,0.65,0.80
P_8	A_{81}	H	H	FH	H	M	VH	H	0.64,0.76,0.87
	A_{82}	FH	M	H	FH	M	H	H	0.53,0.67,0.81
	A_{83}	VH	FH	FH	FH	M	FH	H	0.55,0.69,0.83
	A_{84}	H	H	M	FH	M	H	VH	0.58,0.71,0.84
	A_{85}	FH	H	FL	H	M	VH	H	0.56,0.69,0.81
P_9	A_{91}	H	H	VH	FH	FH	VH	VH	0.71,0.82,0.91
	A_{92}	H	H	VH	H	H	H	VH	0.74,0.84,0.93
	A_{93}	H	VH	H	H	H	FH	H	0.69,0.80,0.90
	A_{94}	H	FH	FH	H	FH	H	VH	0.64,0.76,0.87
	A_{95}	VH	VH	H	H	FH	VH	H	0.74,0.84,0.93
P_{10}	A_{101}	H	H	FH	H	M	VH	H	0.64,0.76,0.87
	A_{102}	FH	H	VH	H	M	H	H	0.64,0.76,0.87
	A_{103}	H	H	FH	FH	M	FH	VH	0.87,0.71,0.84
	A_{104}	H	H	H	FH	M	H	VH	0.64,0.76,0.87
P_{11}	A_{111}	FH	H	FH	H	M	VH	VH	0.63,0.76,0.87
	A_{112}	H	H	VH	FH	M	H	H	0.64,0.76,0.87
	A_{113}	H	H	VH	H	M	FH	VH	0.66,0.78,0.89
	A_{114}	H	H	VH	FH	M	H	VH	0.66,0.78,0.89
P_{12}	A_{121}	H	H	FH	VH	M	VH	H	0.64,0.76,0.87
	A_{122}	H	H	VH	H	M	H	H	0.66,0.78,0.89

	A_{123}	H	H	VH	H	M	FH	H	0.64,0.76,0.87
	A_{124}	H	VH	H	H	M	H	H	0.66,0.78,0.89
	A_{125}	H	FH	VH	VH	M	VH	H	0.68,0.80,0.90
P_{13}	A_{131}	H	FH	VH	H	M	VH	H	0.66,0.78,0.89
	A_{132}	H	H	FL	H	M	H	VH	0.59,0.71,0.83
	A_{133}	H	H	VH	H	M	FH	H	0.64,0.76,0.87
	A_{134}	H	H	H	H	M	VH	VH	0.69,0.80,0.90
P_{14}	A_{141}	FH	M	FL	H	M	VH	H	0.51,0.65,0.79
	A_{142}	FH	FH	FL	FH	M	H	H	0.49,0.63,0.77
	A_{143}	H	FH	VH	VH	M	FH	VH	0.65,0.78,0.89
	A_{144}	H	FH	VH	VH	M	VH	VH	0.66,0.78,0.89
P_{15}	A_{151}	H	H	FH	H	M	VH	VH	0.66,0.78,0.89
	A_{152}	H	H	VH	H	M	H	VH	0.69,0.80,0.90
	A_{153}	FH	H	VH	H	M	FH	VH	0.36,0.76,0.87
	A_{154}	VH	H	FH	H	M	VH	VH	0.68,0.80,0.90
P_{16}	A_{161}	H	H	VH	H	M	VH	H	0.69,0.80,0.90
	A_{162}	FH	H	VH	H	M	FH	VH	0.63,0.76,0.87
	A_{163}	H	H	H	FH	M	VH	FH	0.61,0.74,0.87
	A_{164}	H	VH	FH	H	M	H	VH	0.66,0.78,0.89
P_{17}	A_{171}	H	FH	H	FH	M	VH	VH	0.63,0.76,0.87
	A_{172}	H	H	H	H	M	H	VH	0.72,0.82,0.91
	A_{173}	H	FH	VH	FH	M	VH	VH	0.65,0.78,0.89
P_{18}	A_{181}	H	H	FH	VH	M	VH	VH	0.68,0.80,0.90
	A_{182}	H	H	FH	H	M	H	H	0.61,0.74,0.86
	A_{183}	VH	VH	VH	VH	M	H	VH	0.71,0.82,0.91
P_{19}	A_{191}	H	FH	VH	H	M	M	H	0.58,0.71,0.84

A_{192}	H	H	VH	VH	M	FL	H	0.61,0.74,0.84
A_{193}	H	FH	VH	H	M	FL	H	0.56,0.69,0.81
A_{194}	VH	H	VH	H	M	M	VH	0.65,0.78,0.89

Table 4.5: Performance ratings for the attributes

RSC practices (P_i)	Attributes (A_{ij})	Performance rating with respect to attribute							Average performance rating (R_{ij})
		E_1	E_2	E_3	E_4	E_5	E_6	E_7	
P_1	A_{11}	G	V G	V G	V G	F	E	E	0.66,0.78,0.89
	A_{12}	E	E	F	V G	F	E	V G	0.65,78,0.89
	A_{13}	V G	V G	G	V G	F	E	G	0.61,0.74,0.86
	A_{14}	V G	V G	F	G	F	E	E	0.60,0.74,0.86
P_2	A_{21}	F	G	V G	G	F	E	V G	0.55,0.69,0.83
	A_{22}	E	F	G	G	F	E	V G	0.57,0.71,0.84
	A_{23}	E	E	V G	G	F	E	V G	0.68,0.80,0.90
	A_{24}	E	V G	F	V G	F	E	E	0.65,0.78,0.89
P_3	A_{31}	V G	E	E	V G	F	E	V G	0.71,0.82,0.91
	A_{32}	E	V G	E	G	F	E	E	0.70,0.82,0.91
	A_{33}	V G	E	E	V G	F	E	E	0.73,0.84,0.94
	A_{34}	V G	V G	G	G	F	E	E	0.63,0.76,0.87

P_4	A_{41}	V G	E	G	V G	F	E	E	0.68,0.80,0.90
	A_{42}	V G	E	G	G	F	E	E	0.65,0.78,0.89
	A_{43}	E	E	F	V G	F	E	V G	0.65,0.78,0.89
	A_{44}	E	V G	F	V G	F	E	G	0.60,0.74,0.86
P_5	A_{51}	V G	V G	F	V G	F	E	V G	0.61,0.74,0.86
	A_{52}	V G	V G	F	G	F	E	V G	0.58,0.71,0.84
	A_{53}	E	V G	G	V G	F	E	V G	0.66,0.78,0.89
	A_{54}	E	V G	V G	G	F	E	E	0.68,0.80,0.90
P_6	A_{61}	V G	E	V G	V G	F	E	E	0.71,0.82,0.91
	A_{62}	V G	E	G	G	F	E	E	0.65,0.78,0.89
	A_{63}	V G	E	V G	V G	F	E	E	0.71,0.82,0.91
	A_{64}	E	E	V G	G	F	E	G	0.65,0.78,0.89
P_7	A_{71}	G	G	V G	G	F	E	G	0.58,0.71,0.84
	A_{72}	V G	V G	V G	G	F	E	E	0.66,0.78,0.89
	A_{73}	G	G	G	V G	F	E	V G	0.58,0.71,0.84
P_8	A_{81}	V G	V G	G	V G	F	E	V G	0.64,0.76,0.87
	A_{82}	F	F	V G	G	F	E	E	0.54,0.69,0.83

	A_{83}	E	E	P	G	F	E	E	0.63,0.76,0.86
	A_{84}	E	G	P	G	F	E	E	0.58,0.71,0.83
	A_{85}	G	G	F	V G	F	E	V G	0.55,0.69,0.83
P_9	A_{91}	E	E	G	V G	F	E	E	0.70,0.82,0.91
	A_{92}	E	E	G	G	F	E	G	0.62,0.76,0.87
	A_{93}	E	E	V G	G	F	E	V G	0.68,0.80,0.90
	A_{94}	E	V G	F	V G	F	E	E	0.64,0.78,0.88
	A_{95}	E	V G	P	G	F	E	V G	0.59,0.71,0.83
P_{10}	A_{101}	V G	G	G	G	F	E	V G	0.58,0.71,0.84
	A_{102}	V G	G	V G	V G	F	E	V G	0.64,0.76,0.87
	A_{103}	V G	V G	V G	V G	F	E	E	0.69,0.80,0.90
	A_{104}	G	V G	G	G	F	E	G	0.55,0.69,0.83
P_{11}	A_{111}	E	E	E	G	F	E	E	0.72,0.84,0.93
	A_{112}	E	E	E	G	F	E	E	0.72,0.84,0.93
	A_{113}	E	E	E	G	F	E	E	0.72,0.84,0.93
	A_{114}	E	E	V G	V G	F	E	E	0.73,0.84,0.93
P_{12}	A_{121}	F	P	G	G	F	E	V G	0.48,0.63,0.77
	A_{122}	F	G	V G	G	F	E	V G	0.55,0.69,0.83
	A_{123}	E	E	E	G	F	E	G	0.67,0.80,0.90
	A_{124}	E	E	E	V G	F	E	E	0.72,0.84,0.93

	A_{125}	E	E	V G	G	F	E	E	0.70,0.82,0.91
P_{13}	A_{131}	G	V G	F	V G	F	E	E	0.57,0.71,0.84
	A_{132}	V G	E	F	V G	F	E	V G	0.63,0.76,0.87
	A_{133}	G	F	P	V G	F	E	V G	0.51,0.65,0.79
	A_{134}	G	V G	VP	V G	F	E	E	0.57,0.69,0.80
P_{14}	A_{141}	F	V G	G	G	F	E	V G	0.58,0.71,0.84
	A_{142}	G	V G	F	V G	F	E	V G	0.58,0.71,0.84
	A_{143}	V G	V G	G	G	F	E	G	0.58,0.71,0.84
	A_{144}	G	V G	V G	G	F	E	G	0.58,0.71,0.84
P_{15}	A_{151}	V G	V G	F	V G	F	E	E	0.63,0.73,0.87
	A_{152}	E	E	P	V G	F	E	V G	0.64,0.76,0.86
	A_{153}	E	G	G	G	F	E	E	0.62,0.76,0.87
	A_{154}	E	E	G	V G	F	E	V G	0.68,0.80,0.90
P_{16}	A_{161}	E	E	V G	V G	F	F	V G	0.63,0.76,0.87
	A_{162}	E	V G	V G	G	F	F	E	0.60,0.74,0.76
	A_{163}	E	E	G	V G	F	F	G	0.53,0.67,0.81
	A_{164}	E	E	P	V G	F	F	V G	0.56,0.69,0.81
P_{17}	A_{171}	V	F	V	G	F	E	V	0.58,0.71,0.84

		G		G				G	
	A_{172}	G	E	V	V	F	E	E	0.68,0.80,0.90
				G	G				
	A_{173}	V	E	G	V	F	E	E	0.68,0.80,0.90
		G			G				
P_{18}	A_{181}	G	V	V	G	F	E	E	0.63,0.76,0.87
			G	G					
	A_{182}	G	V	V	G	F	E	E	0.63,0.76,0.87
			G	G					
	A_{183}	G	V	F	G	F	E	E	0.57,0.71,0.84
			G						
P_{19}	A_{191}	V	V	V	V	F	F	V	0.59,0.71,0.84
		G	G	G	G			G	
	A_{192}	E	E	V	V	F	F	V	0.63,0.76,0.87
				G	G			G	
	A_{193}	V	V	V	V	F	F	V	0.59,0.71,0.80
		G	G	G	G			G	
	A_{194}	V	E	P	G	F	F	V	0.51,0.65,0.79
		G						G	

4.2.3. Evaluating the resilience fuzzy index (RFI) and performance fuzzy index (PFI)

RFI represents the resilience level of a SC corresponding to an organization and is represented in terms of the cumulative effects of all the parameters that enable the resilience characteristics of a SC. For our study, this research identified nineteen resilient practices and their seventy-six corresponding attributes that lead to the development of a RSC. The RFI is obtained by aggregating the resilience score of the individual resilient practice of the SC. Moreover, PFI is evaluated to identify the contribution of each attribute in enabling the SC's current resilience position (Rajesh, 2019; Lin et al., 2006). This study research follows the approach discussed by Patel et

al. (2017) and Vinodh and Vimal (2012) regarding the evaluation process. The steps involved in evaluating the RFI and PFI are discussed in sections 4.2.3.1 to 4.2.3.4.

4.2.3.1. Evaluating resilience score at resilient practice level (RP_i)

The resilience at an individual resilient practice level is the aggregated resilience score of the corresponding attributes. It is evaluated by using equation 4.4.

$$RP_i = \frac{\sum_{j=1}^n R_{ij}(\cdot)W_{ij}}{\sum_{j=1}^n W_{ij}} \quad 4.4$$

Where,

W_{ij} = Average importance weight of the j^{th} attributes of a i^{th} practices (Table 4.4)

R_{ij} = Average performance rating of the j^{th} attributes of a i^{th} practices (Table 4.5)

RP_i = Resilience score of i^{th} practice

$j=1, 2 \dots n$. n =number of attributes corresponds to resilient practice i

Here, the calculation of the resilience score for *Flexibility* is provided as a sample:

$$RP_1 = \frac{(0.50,0.65,0.80)(\cdot)(0.66,0.78,0.89)(\cdot)(0.48,0.63,0.77)(\cdot)(0.65,78,0.89)(+)(0.53,0.67,0.81)(\cdot)(0.61,0.74,0.86)(+)(0.41,0.56,0.71)(\cdot)(0.60,0.74,0.86)}{(0.66,0.78,0.89)(+)(0.65,78,0.89)(+)(0.61,0.74,0.86)(+)(0.60,0.74,0.86)}$$

$$= (0.63, 0.76, 0.87)$$

Similarly, the score pertaining to each of the practices is calculated and is provided in Table 4.6.

4.2.3.2. Evaluating the resilience fuzzy index (RFI)

RFI of the SC is calculated by aggregating the resilient scores of practices obtained through their attributes using equation 4.5.

$$RFI = \frac{\sum_i^{19} W_i(\cdot)RP_i}{W_i} \quad (4.5)$$

$$RFI = (0.63,0.76,0.87)$$

$$= \left[\begin{array}{l} (0.44,0.61,0.77)(\cdot)(0.63,0.76,0.87)(+) \\ (0.36,0.52,0.67)(\cdot)(0.63,0.76,0.87)(+) \\ (0.74,0.84,0.93)(\cdot)(0.69,0.81,0.91)(+) \\ (0.64,0.76,0.87)(\cdot)(0.65,0.77,0.88)(+) \\ (0.76,0.86,0.94)(\cdot)(0.64,0.76,0.87)(+) \\ (0.61,0.74,0.86)(\cdot)(0.68,0.80,0.90)(+) \\ (0.54,0.67,0.80)(\cdot)(0.61,0.74,0.86)(+) \\ (0.37,0.54,0.71)(\cdot)(0.59,0.72,0.84)(+) \\ (0.56,0.69,0.83)(\cdot)(0.64,0.77,0.88)(+) \\ (0.29,0.46,0.63)(\cdot)(0.61,0.74,0.86)(+) \\ (0.76,0.86,0.94)(\cdot)(0.72,0.84,0.93)(+) \\ (0.47,0.63,0.79)(\cdot)(0.63,0.76,0.87)(+) \\ (0.73,0.84,0.93)(\cdot)(0.57,0.70,0.82)(+) \\ (0.61,0.74,0.86)(\cdot)(0.58,0.71,0.84)(+) \\ (0.69,0.80,0.90)(\cdot)(0.64,0.77,0.88)(+) \\ (0.27,0.44,0.60)(\cdot)(0.58,0.72,0.84)(+) \\ (0.36,0.52,0.69)(\cdot)(0.65,0.77,0.88)(+) \\ (0.44,0.59,0.73)(\cdot)(0.61,0.74,0.86)(+) \\ (0.58,0.71,0.84)(\cdot)(0.58,0.71,0.84) \end{array} \right] \left[\begin{array}{l} (0.44,0.61,0.77)(+)(0.36,0.52,0.67)(+) \\ (0.74,0.84,0.93)(+)(0.64,0.76,0.87)(+) \\ (0.76,0.86,0.94)(+)(0.61,0.74,0.86)(+) \\ (0.54,0.67,0.80)(+)(0.37,0.54,0.71)(+) \\ (0.56,0.69,0.83)(+)(0.29,0.46,0.63)(+) \\ (0.76,0.86,0.94)(+)(0.47,0.63,0.79)(+) \\ (0.73,0.84,0.93)(+)(0.61,0.74,0.86)(+) \\ (0.69,0.80,0.90)(+)(0.27,0.44,0.60)(+) \\ (0.36,0.52,0.69)(+)(0.44,0.59,0.73)(+) \\ (0.58,0.71,0.84) \end{array} \right]$$

The membership function of RFI can be represented by equation 4.6 and Figure 4.3.

$$U_{RFI}(x) = \begin{cases} 0 & \text{if } x \leq a \\ \frac{x-a}{b-a} & \text{if } a < x \leq b \\ \frac{c-x}{c-b} & \text{if } b \leq x < c \\ 0 & \text{if } x \geq c \end{cases} \quad (4.6)$$

Where,

a = Lower number of triangular fuzzy numbers corresponds to RFI

b = middle number of triangular fuzzy numbers corresponds to RFI

c = upper number of triangular fuzzy numbers corresponds to RFI

Table 4.6. Resilience score at resilient practice level

P_i	W_i	RP_i
P_1	(0.44,0.61,0.77)	(0.63,0.76,0.87)
P_2	(0.36,0.52,0.67)	(0.63,0.76,0.87)
P_3	(0.74,0.84,0.93)	(0.69,0.81,0.91)
P_4	(0.64,0.76,0.87)	(0.65,0.77,0.88)
P_5	(0.76,0.86,0.94)	(0.64,0.76,0.87)
P_6	(0.61,0.74,0.86)	(0.68,0.80,0.90)
P_7	(0.54,0.67,0.80)	(0.61,0.74,0.86)
P_8	(0.37,0.54,0.71)	(0.59,0.72,0.84)
P_9	(0.56,0.69,0.83)	(0.64,0.77,0.88)
P_{10}	(0.29, 0.46,0.63)	(0.61,0.74,0.86)
P_{11}	(0.76,0.86,0.94)	(0.72,0.84,0.93)
P_{12}	(0.47,0.63,0.79)	(0.63,0.76,0.87)
P_{13}	(0.73,0.84,0.93)	(0.57,0.70,0.82)
P_{14}	(0.61,0.74,0.86)	(0.58,0.71,0.84)
P_{15}	(0.69,0.80,0.90)	(0.64,0.77,0.88)
P_{16}	(0.27,0.44,0.60)	(0.58,0.72,0.84)
P_{17}	(0.36,0.52,0.69)	(0.65,0.77,0.88)
P_{18}	(0.44,0.59,0.73)	(0.61,0.74,0.86)
P_{19}	(0.58,0.71,0.84)	(0.58,0.71,0.84)

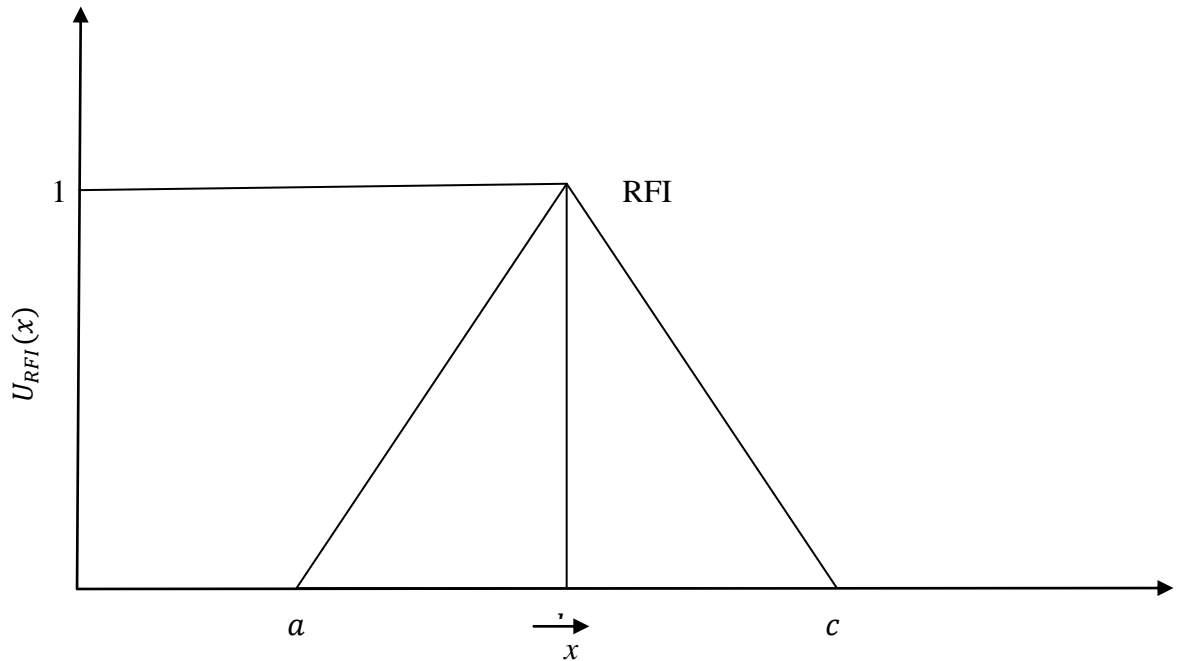


Figure 4.3. Membership function corresponds to RFI

4.2.3.3. Approximating the resilience level

After calculating the RFI, it is required to identify the resilience level of the case organization by comparing or matching it with the linguistic label of resilience. These linguistic resilient labels (RL_i) are *Definitely Resilient* (0.8,0.9,1), *Intensively resilient* (0.7,0.8,0.9), *Very Resilient* (0.6,0.7,0.8), *Highly Resilient* (0.5,0.6,0.7), *Resilient* (0.4,0.5,0.6), *Fairly resilient* (0.3,0.4,0.5), *Slightly Resilient* (0.2,0.3,0.4), *Low resilient* (0.1,0.2,0.3), and *Slowly Resilient* (0,0.1,0.2). Moreover, several approaches have been proposed so far, like the piecewise decomposition method, successive approximation method, and Euclidean distance method for matching the membership function with the linguistic terms. Among these tools, the Euclidean distance method has been the most suitable where the human response is considered (Guesgen and Albrecht, 2000; Lin et al., 2006).

The Euclidean distance method measures the Euclidean distance from a considered fuzzy number to each of the fuzzy numbers corresponding to the linguistic resilient

labels. Let, U_{RFI} and U_{RL_i} is the membership function corresponds to RFI and the linguistic resilient label i , respectively. Then, the distance between U_{RFI} and U_{RL_i} is obtained using equation 4.7.

$$D(RFI, RL_i) = \left\{ \sum_{x \in p} (U_{RFI}(x) - U_{RL_i}(x))^2 \right\}^{1/2} \quad (4.7)$$

Where,

$$p = \{x_0, x_1, \dots, x_m\} \subset [0,1], \text{ such that } 0 = x_0 < x_1 < \dots < x_m = 1$$

Let, $p = \{0, 0.05, 0.1, 0.15, 0.2, 0.25, 0.3, 0.35, 0.4, 0.45, 0.5, 0.55, 0.6, 0.7, 0.75, 0.8, 0.85, 0.9, 0.95, 1\}$. Now, the distance from RFI to the linguistic resilience score is calculated. The least distance value suggests the RFI's closeness to the corresponding linguistic resilience score. Hence, it indicates the resilience level of the case organization's SC.

The distance between RFI and the DR is calculated as,

$$\begin{aligned} D(RFI, DR) &= \left\{ (0.63 - 0.80)^2 + (0.76 - 0.90)^2 + (0.87 - 1.00)^2 \right\}^{1/2} \\ &= 0.26 \end{aligned}$$

Similarly, other distance is calculated and is provided in Table 4.7

And also, from Table 4.7, the shortest Euclidean distance between the RFI and RL_i is obtained to be 0.09, which corresponds to the Intensively resilient level. Hence, the case organization's SC is identified as intensively resilient. The matching of the RFI with the RL_i is pictorially represented in Figure 4.4

Table 4.7: Euclidean distance of RFI from linguistic resilience level

RFI	Linguistic resilience level (RL_i)	Euclidean distance
	Definitely resilient DF (0.8,0.9,1)	0.26
	Intensively resilient ER (0.7,0.8,0.9)	0.09
	Very resilient VR (0.6,0.7,0.8)	0.10
	Highly resilient HR (0.5,0.6,0.7)	0.27
(0.30,0.76,0.87)	Resilient R (0.4,0.5,0.6)	0.44
	Fairly resilient FR (0.3,0.4,0.5)	0.61
	Slightly resilient SR (0.2,0.3,0.4)	0.79
	Low resilient LR (0.1,0.2,0.3)	0.96
	Slowly resilient S (0,0.1,0.2)	1.13

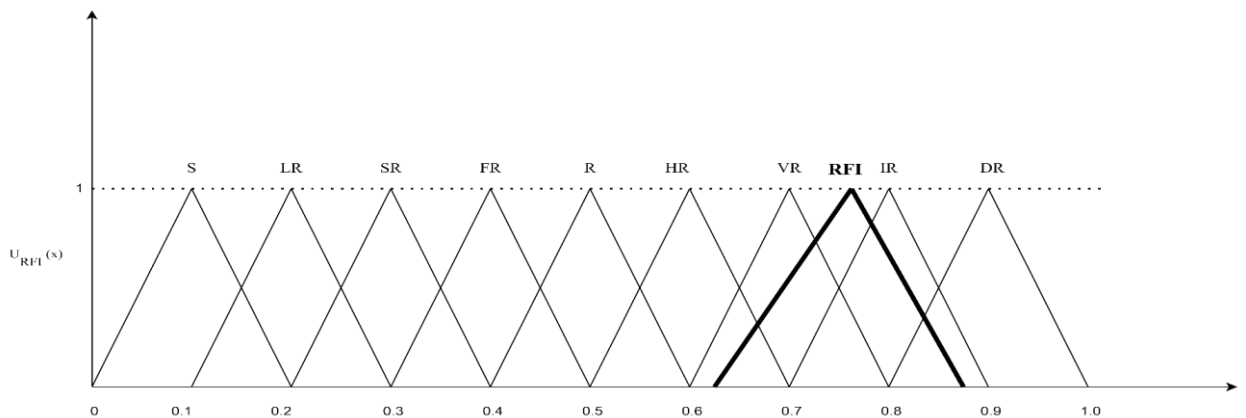


Figure 4.4. Matching RFI with RL_i

4.2.3.4. Evaluating the performance fuzzy index

From the above discussion, the resilience level of the case organization SC is found to be *Intensively resilient*. However, it can be made ‘definitely resilient’ by employing some extra effort. For this, first of all, it is required to identify the hindrances inhibiting attaining the desired level of resilience and then make the implications for the NCRS mitigating it. Thus, to identify attributes against which the SC is not performing, a Fuzzy Performance Index (PFI) is developed for all attributes. Such that, the value of

FPI suggests the contribution of each attribute in defining the resilience level. In this evaluation process, the performance rating, as well as the importance weight, is used as an input. However, using the importance weight (W_{ij}) directly will neutralize the performance rating. Therefore, the transformed W_{ij} , i.e., $[(1, 1, 1) (-) (W_{ij})]$ is used along with performance rating to obtain FPI. Thus FPI can be obtained using equation 4.8.

$$FPI_{ij} = W'_{ij}(\cdot)(R_{ij}) \quad (4.8)$$

Where, $W'_{ij} = [(1,1,1)(-)(W_{ij})]$

Here, the FPI corresponding to the attribute A_{11} is provided as a sample

$$\begin{aligned} FPI_{11} &= [(1,1,1,)(-)(0.50,0.65,0.80)](\cdot)(0.66,0.78,0.89) \\ &= (0.33,0.27,0.18) \end{aligned}$$

Further, most of the time, the mathematical operations on fuzzy numbers do not provide comparable sets; therefore, for comparing or ranking the FPI values of the attributes, it is first required to de-fuzzify (Rajesh, 2019; Patel et al., 2017; Chen et al., 2003). Let us name this FPI value as a crisp resilience score (CRS) which is calculated by following the approach discussed by Vinodh and Vimal (2012) and Patel et al. (2017), i.e., the Centroid area method.

$$CRS = \frac{(a+4b+c)}{6} \quad (4.9)$$

$$\begin{aligned} \text{CRS corresponding to } A_{11} &= \frac{0.33+4*0.27+0.18}{6} \\ &= 0.2659 \end{aligned}$$

Similarly, CRS is computed for all the attributes and is provided in Appendix B. Moreover, the CRS is normalized (NCRS) to obtain the individual contribution of the attribute PFI to the overall resilience index of the case organization SC. The CRS and NCRS of the attribute for which the organization is not performing are provided in Table 4.8. Further, according to Rajesh (2019), Bharat et al. (2017), and Lin et al. (2006), the attributes whose CRS is small are the obstacles in attainment of the RSC and are identified based on the threshold value decided by the experts of the case organization (Rajesh, 2019; Bharat et al., 2017; Lin et al., 2006). For our study, experts have chosen the threshold value of $NCRS=0.01$ because attributes with an NCRS value of 0.01 and above contribute to more than 85% of the resilience score of the case organization SC. The attributes with NCRS values less than 0.01 are provided in Table 4.8.

4.3. Result and discussion

This study focuses on developing an assessment tool comprising the resilient practices and their corresponding attributes to quantify a SC's resilience level. As it has been observed that the resilient characteristics of the SC are the result of the successful implementation of the various resilient practices, which are derived from their attributes. This chapter has considered nineteen resilient practices and their corresponding seventy-six attributes applicable to the manufacturing sector. These practices and attributes are provided in Table (4.1).

The practices and attributes discussed in this chapter can apply to most manufacturing firms with slight variation in their implementation significance and impact. These practices and attributes have become an integral part of the SC, making it resilient. Like, flexibility enables the SC network to compensate the variability in demand and supply

Table 4.8. Attributes with a low NCRS value

Attributes (A_{ij})	Crisp resilience score (CRS)	Normalized crisp resilience score (NCRS)
Quick decision-making and implementation (A_{43})	0.121	0.0081
Use of information and communication technology (A_{61})	0.145	0.0097
Real-time information sharing (A_{63})	0.145	0.0097
Skilled human resource for information management (A_{64})	0.122	0.0082
Risk assessment and mitigation planning at every stage of decision-making (A_{91})	0.145	0.0097
Continuous strive for process improvement and innovation (A_{92})	0.116	0.0078
Prepositioning the business continuity team (A_{95})	0.110	0.0074
Practice wave picking, cross-docking, etc., (A_{121})	0.147	0.0098
Classifying the material/products based on criticality, demand rate, cost, availability, size, type, etc. (A_{122})	0.149	0.0100
Quick rearrangement of resources to develop new capabilities (A_{134})	0.136	0.0091
Efficient and effective procurement strategy (A_{152})	0.149	0.0100
Forecasting markets demand based on past records and expert research (A_{161})	0.148	0.0099
Preparedness for restructuring (A_{181})	0.140	0.0094
Alliance to improve capability (A_{182})	0.149	0.0100
Virtual integration among the SC (A_{183})	0.125	0.0084
Use of predictive technology to sense and forecast the market demand (A_{194})	0.141	0.0094

-by controlling the production process, lead time, quantity procured, etc. Similarly, the postponement strategy enables the organizations to minimize the risk of obsolescence, and in the presence of other strategies like outsourcing and collaboration, it leads to a huge competitive gain during uncertainties. Likewise, visibility promotes understanding of the business environment and competitor performance, leading to planning and strategy making. At the same time, agility enables quickness at every level of the SC and is responsible for the successful implementation of many of the RSC strategies. Collaboration can be considered the SC's soul that binds the members together and leads to achieving the desired organizational goal. Information sharing can be assumed to be the connecting link between the SC members, while strategic stocking and redundancy lead to the absorption of the disruptions.

The culture of risk management promotes proactive capability development along with preparedness against uncertainty, whereas strategies like dynamic pricing, assortment planning, and silent product rollover enable the organizations to gain a competitive advantage and respond quickly to supply disruptions. Effective management of the warehouses and the inventories control the cost and the availability of the product, thus providing a buffer against the short-term market variability. Though the adaptability of the SC govern by many other strategies, considering it as a separate entity of RSC and employing extra effort to achieve it will enable the organizations to match with the changing business conditions in terms of technological improvement and competitor performances. Sharing economic incentives with the SC members promotes the level of collaboration along with the overall SC capability improvement to match the changing business condition. Financial strength defines the organizational ability to cope with the sudden changes in the market and disruptions to its SC, and also it enables the capability to grab the opportunities. It can also be considered as the promoter of

competitive gain. Restructuring of the SC is a two-way phenomenon; in the first, it is considered as the development of the newer capabilities by rearranging and creating the capabilities, while in the second, it is considered as the recovery option post disruptions. In both ways, it promotes the resilient ability of the SC.

Moreover, it has been observed that these practices and their attributes are intangible and inherited with uncertainty and complexity. Therefore, a fuzzy logic approach comprising the linguistic approximation and fuzzy arithmetic is used to develop the resilient status of a SC called resilient fuzzy index (RFI). The data required in this approach is obtained from the self-assessment committee comprising seven experts from the case organization. A seven-point rating scale (Table 4.2.) based self-assessment questionnaire was used to collect the expert response using an online platform. These responses are quantified through triangular fuzzy numbers to minimize the ambiguity and impreciseness associated with the resilience phenomenon and the assessor's response.

From the calculation, it is observed that the Euclidean distance between the resilience index and the approximated linguistic resilience score is minimum for the 'intensively resilient' level thus, the resilience level of the case organization is approximated as 'intensively resilient' (Table 4.7). Further, the extremely resilience level signifies the ability of the case organization SC to combat most of the internal, ecological, socio-economic, geo-political, etc., uncertainties associated with it and enables business continuity. Our findings are also in accordance with the quarterly reports published by the case organizations and also reports produced by independent agencies like Moody's investor service after the COVID-19. According to the reports, the case organization SC was able to maintain its supply of raw material with minimal deviation from the actual

capacity. And also, it was able to compensate for the sudden decline in local demand by exports and was able to run the organization at 50% human resource capacity in the worst phase of COVID-19 with lesser financial losses as compared to other sectors SCs. Though the case organization is found to be “Intensively resilient,” however, it is far from “definitely resilient.” Thus, it indicates the presence of some non-performing sections of the SC, which, if not sorted out timely, may lead to a drastic impact on the business continuity.

In this study, the PFI and the corresponding NCRS value are calculated as the indicator of the contribution of each of the attributes toward the resilience characteristics of the SC. It enables identifying the most contributing and non-contributing attributes to the overall resilience level of the SC. The case organization SC is performing extremely well for the attributes like the multi-mode and multi-carrier transportation system, collaborative decision making, multi-skilled human resources, postponement of product differentiation, the flexibility of the production system, and providing financial aid to weak link of the SC. However, this study focuses more on identifying the attributes that contribute less to the case organization’s resilience score. For this, the expert has set a threshold value of $NCRS = 0.010$, such that attributes having an NCRS value less than 0.010 suggest that against which attributes the organization and its SC members are not performing well. Thus from Table 4.8, it is evident that the case organization SC needs to work on improving its ability in quick decision-making and its follow-up to achieve the target.

Moreover, the case organization’s assessors feel that the organization may perform better by upgrading the information sharing and communication tools. It may also improve the decision-maker effectiveness by availing the right information at the right

time and, further, employing the skilled human resources that perform the day-to-day information sharing deeds and scoops out the information that helps in strategic decision-making. In addition, case organizations need to enlarge their effort and approach toward risk assessment, mitigation planning, process improvement, and improving the business continuity capability. Further, improving the logistic services while including the strategies like wave picking, cross-docking, classifying the shipments based on their usage value, etc., will help the case organization in improving the overall resilience of its SC. In addition, the case organization SC also lag the quickness in new capability development, cost-effective procurement of supplies, inaccurate and inefficient forecasting and forecasting tool, etc.

Moreover, the resilience of the case organization can be improved by enabling quick restructuring of the SC along with the strategical alliances, including virtual and goal-oriented integration. Hence, if the case organization is able to improve its performances against the attributes having an NCRS value of less than 0.010, then the Euclidean distance of the case organization's SC resilience level from the definitely resilient level will be reduced. Thus move closer to the definitely resilient level. However, to become definitely resilient, the case organization SC needs to improve its performance not only for the attributes having an NCRS value less than 0.010 but also for the attributes with a high value of NCRS because the performance of the case organization SC for the high-value NCRS value attribute is also not excellent.

4.4. Conclusion

This chapter identifies the attributes of the resilient practices discussed in chapter 3. In addition, these attributes represent the contributing elements of the RSC; thus, the SCs can also be evaluated against these attributes. Hence, in this chapter, the focus is on

identifying the attributes contributing resilience ability of the SC, developing a resilience evaluating model, evaluating the resilience level of the case organization, and also suggest the various changes that need to be carried out to make the SC true resilient (definitely resilient). Corresponding to the nineteen practices of the RSC, this study identifies seventy-six attributes, such that they jointly lead to the development of a 'definitely resilient' SC. Along with it, a fuzzy logic-based self-assessment SC resilience evaluating model is developed, whose input is the perception of the case organization experts regarding each attribute. The resilience score obtained will provide information regarding major areas of improvement, thus helping the decision-maker in their strategic decision-making and minimizing the associated uncertainty. It will also enable the practitioners to refine their strategies and plan to develop a true RSC.

Further, the resilience level of the case organization is found to be intensively resilient, thus suggesting a better state in the present uncertain business environment coupled with many man-made and ecological disruptions. And the attributes for which case organization is performing well are multi-mode and multi-carrier transportation system, collaborative decision making, multi-skilled human resources, postponement of product differentiation, the flexibility of the production system, and providing financial aid to weak link of the SC. However, the evaluated resilience level is far from the definitely resilient (desired) level, thus suggesting the presence of the attributes against which SC is not performing. These attributes can be considered the obstacle to the SC's resilience and require special attention by the decision-maker. The performance of the case organization SC needs to be improved against these attributes. The attributes against which the case organization SC is poorly performing are, Quick decision making and implementation, Use of upgraded information and communication tools, real-time information sharing, skilled human resources for information management, risk

assessment, and mitigation planning at every stage of decision-making, continuous strive for process improvement and innovation, and prepositioning the business continuity team.

Limitations and future scope

Though this chapter holistically covers the RSC's various paradigms and provides a novel approach to quantify the level of resilience, it has some limitations. In this study, the attributes against which the case organization SC is not performing is also evaluated; however, the obstacles responsible for this non-performance need to be identified. And also, the findings of this study are subjective to the knowledge and understanding of the assessors regarding RSC and firm operations. Therefore, this work can be further extended by employing more experts from different departments as well as different SC positions.