Modeling performance indicators of resilient pharmaceutical supply chain

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Abstract

Purpose – In the recent dynamic market, supply chain disruptions are rapidly increasing with varied customer demand, technological changes, uncertain pandemic events etc. To overcome the unexpected disruptions, supply chain of each business should be resilient and pharmaceutical supply chain (PSC) is no exception. Motivated by the challenges and unexpected pandemic disruptions, this paper aims to examine the performance indicators (PIs) of the resilient PSC and to predict the resilience level for a certain time period in the context of Bangladesh.

Design/methodology/approach – The aim of this paper presents a structured framework based on the Delphi method, fuzzy DEMATEL (Decision Making Trial and Evaluation Laboratory) and system dynamics (SD). The proposed methodology was validated using expert's inputs from the relevant field in Bangladesh. This study reveals the influential relationships of indicators and resilience level using fuzzy DEMATEL and SD to improve the resiliency.

Findings – Findings revealed that "Supply chain risk orientation", "Visibility", "Flexibility", "Agility in supply chain" and "Collaboration" are the top five influential performance indicators for resilient PSC. The cause and effect relationship found that "IT capability", "Flexibility", "Supply chain network design", "Resource availability", "Supply chain risk orientation" and "Velocity" were in cause category which play a vital role for establishing resilient supply chain. SD approach has developed a model for predicting the resilience level of the supply chain.

Originality/value – This work is one of the initial contributions in the literature that has targeted on the identification and analysis of the significant PIs and predicting the resilience level of the PSC.

Keywords Pharmaceutical industry, Supply chain resilience, Performance indicators, Fuzzy DEMATEL, System dynamics model

Paper type Research paper

1. Introduction

Over the past few decades, corporate world has become more turbulent and vulnerable in nature due to rapid globalization, varied customers' interest and demand, technological changes, unexpected pandemic outbreaks etc. Firms are facing enormous pressure to manage and control their supply chains effectively. To secure the market position, business organizations are searching for proper strategies that may enhance their strengths in some key areas of their supply chains and operations. Establishing resilient supply chain is one of the fruitful strategies to overcome the adverse situation tactfully as well as to improve the overall business performance (Rajesh, 2018). Over the past few years, a lot of academicians and industry practitioners have shown much interest for the establishment of resilient supply chain (Chowdhury *et al.*, 2019). Moreover, recently, a novel and wide-ranging disruptive pandemic called COVID-19 outbreak has put resiliency into the spotlight. This pandemic has

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hit the global supply chains adversely. Amid such turbulence, this outbreak has provided organizations a golden opportunity to revisit the strategy and accelerate their capabilities for the adaption of long-term resiliency in their network for managing future challenges (Ivanov, 2020).

A resilient supply chain can sidestep avoidable risks and has the potentiality to bounce back fast from uncertain occurrences. It is to be noted that more than 80% of global firms are now interested for the adoption of resilient supply chain (Bhatia *et al.*, 2013). However, after establishing resilient supply chain, it is required to monitor and measure the performance of supply chain resilience continuously. It is essential for the business organizations to establish relevant and significant performance indicators (PIs) to measure the resilience of the supply chain (Behzadi *et al.*, 2020). Researchers and industry practitioners have performed many studies to identify the most pertinent PIs for measuring supply chain resilience (Hohenstein *et al.*, 2015; Bai and Satir, 2020). Ali *et al.* (2017) identified some non-financial key performance indicators (KPIs) for measuring supply chain resilience. Stone and Rahimifard (2018) reviewed 137 papers on supply chain from various renowned databases. Their findings also showed that most of the previous literatures were focused only on identification of the PIs of resilient supply chain. However, the companies and supply chain managers require not only the identification but also the understanding of relationships among these PIs to establish better performance evaluation strategy for resilient supply chain. To the best of our knowledge, the resilient supply chain PIs have not been modeled yet to better understand the relationships among them.

As an emerging sector of Bangladesh, pharmaceutical industry has also focused for the proper adoption of resilient supply chain concept. Daily commodity products like rice, oil, electricity etc. have almost simple ad static supply chains. On the other hand, having complex and dynamic structure, PSC face various challenges to establish resilience in the chain. In the context of Bangladesh, this sector plays a vital role providing lifesaving medicines. However, it becomes very difficult to maintain the smooth flow of medicines because huge population of Bangladesh causes the constant fluctuations in customer demand. So, in order to maintain the smooth flow of medicines from producers to customers amid such difficulties, a resilient supply chain is inevitable. There are some significant PIs that, if improved upon, will help the decision makers in making a supply chain more resilient. So, motivated by the current situation, this study proposed a structured framework for modeling the PIs of resilient PSC. However, after reviewing the previous literature and analyzing the research gap, this study raises the following research questions (RQs):

RQ1. What are the key PIs of resilient supply chain in the context of pharmaceutical industry?

RQ2. What are the interactions among them?

RQ3. How can the policy makers predict the resilience level for a certain period?

Based on the above research questions, this study has formulated the following specific research objectives (ROs):

RO1. To identify the most significant PIs for measuring the performance of resilient PSC in the context of Bangladesh.

RO2. To understand the causality of relationships among them.

RO3. To develop a model for predicting the resilience level of the PSC.

To achieve the above objectives, this study has deployed the Delphi based fuzzy DEMATEL approach to identify and analyze the most significant PIs of PSC and developed a SD model for predicting the resilience of the supply chain. The Delphi based fuzzy DEMATEL approach has the advantages of extracting the research data from the experts based on their prior experiences and developing cause and effect diagram along with prominence rank under fuzzy environment (Abdullah and Zulkifli, 2019). After examining the cause and effect relationships among the indicators, SD model is developed. Therefore, integrating fuzzy DEMATEL with SD helps to construct more robust models.

2. Related studies

This section presents the review of previous literature for building a theoretical foundation of this study.

2.1 Supply chain resilience

Over the last few decades, the researchers and supply chain practitioners are working out to establish resilient supply chain to deal with uncertainty and disruptions (Pettit *et al.*, 2019). This concept of supply chain resilience has gained attention because it deals with designing the supply chain to enhance the capability of retuning to its original state from unexpected events or disruptions (Christopher and Peck, 2004; Ralston and Blackhurst, 2020). According to Fiksel *et al.* (2015), supply chain resilience is an essential proactive approach which helps the companies to reduce traditional risks. Resilient supply chain has the ability to identify the risks, ameliorate the impact and come back rapidly from man-made or natural occurrences (Singh *et al.*, 2019a, b; Lee and Rha, 2016). In today's dynamic market, establishing resilience in the supply chain has become one of the utmost challenges for supply chain specialists and managers.

2.2 Assessment of PSC resilience

PSC is considered to be more complex than the other industries (Zahiri *et al.*, 2017). Nowadays, supply chain resilience has become a widely used area of interest among researchers and supply chain practitioners of pharmaceutical companies. In the supply chain resilience literature, various quantitative approaches have been previously applied by researchers for resilience assessment (Hossain *et al.*, 2019; Yaroson *et al.*, 2019). Pettit *et al.* (2013) proposed a tool for supply chain resilience assessment and management which was called the SCRAM tool. Another assessment in the literature is the fundamentals of the grey systems theory to evaluate and analyze the supply chain resilience (Rajesh, 2020).

In the recent studies, Rajesh (2018) used VIKOR method for assessing supply chain resilience. Aigbogun *et al.* (2018) proposed another quantitative cross sectional design for resilience assessment. Another study was conducted with the integrated method of ANP and DEMATEL by Leksono (2019). Ahmed *et al.* (2020) developed a framework to model the barriers of closed loop supply chain. A logical framework for assessing supply chain resilience based on PIs was provided by Song *et al.* (2019). The proposed framework provided an insight about resilient supply chain by representing linkages between some indicators and a set of performance measures. Banihashemi *et al.* (2019) explored the relationship between reverse logistics and sustainability performance.

2.3 Performance indicators (PIs) in the context of resilient PSC

Many researchers have already identified a number of PIs for resilient supply chain. To find out the PIs in the context of resilient PSC, relevant articles were reviewed from various databases (Google scholar, Scopus etc.)using key words such as "supply chain resilience", "supply chain resilience performance indicators", "pharmaceutical supply chain performance indicators" etc. After reviewing the literature, we found 19 most relevant supply chain resilience PIs for further analysis. Table 1 represents these 19 PIs with definition. Many researchers emphasized on supply chain collaboration to be an important PI for supply chain resilience although it is very difficult to implement (Christopher and Peck, 2004; Papadopoulos *et al.*, 2017). Some researchers have found that supply chain visibility plays a significant role in establishing resilient supply chain (Swift *et al.*, 2019). Hafezalkotob and Zaman (2019) identified sustainability as an important PI for resilient supply chain. Production capacity also determines the performance of a resilient supply chain (Chowdhury and Quaddus, 2016; Jain *et al.*, 2017; Kaur *et al.*, 2020).

2.4 Research gaps and research problem definition

For the past few decades, researchers have contributed a lot in the field of resilient supply chain performance measurement. All the research studies provide resilience supply chain PIs

Table 1.
Relevant PIs of resilient PSC

No	PIs	Definition	Sources
1	Collaboration	It is defined as two or tiers of supply chain working jointly in planning and operations	Papadopoulos *et al.* (2017)
2	Visibility	Ability of a firm to locate the inventory easily	Swift *et al.* (2019)
3	Information sharing	Information sharing among the members is important to improve the resilience of a supply chain	Moktadir *et al.* (2018)
4	Agility	Ability of a firm to manufacture and deliver items with short lead times	Kamalahmadi and Parast (2016), Ali *et al.* (2017), Christopher and Peck (2004)
5	Flexibility	Ability of a firm to restructure their operations and strategy to respond quickly to customer demands	Pettit *et al.* (2013)
6	Sustainability	Related to supply chain network in terms of environment and waste costs	Hafezalkotob and Zamani (2019), Yang *et al.* (2018)
7	Redundancy	A firm must create redundancy in terms of capacity throughout the supply chain to improve the resilience	Ali *et al.* (2017), Christopher and Peck (2004)
8	Creating robust supply chain	Ability to protect against disruptions and reduce their impact once they occur	Papadopoulos *et al.* (2017)
9	SC risk orientation	Orientation of supply chain risk factors across the firm	Christopher and Peck (2004)
10	Available resource	Availability of required resources to improve the supply chain resilience	Christopher and Peck (2004), Chowdhury and Quaddus (2016)
11	Velocity	Ability of the firm to complete the supply chain activities as quickly as possible	Christopher and Peck (2004)
12	Production capacity	The maximum volume of products that can be produced by a firm	Chowdhury and Quaddus (2016)
13	Revenue sharing	Revenue sharing among the different tiers of supply chain	Yu *et al.* (2020)
14	Partnership for risk sharing	Partnership among the different tiers of supply chain for risk sharing	Jain *et al.* (2017)
15	Adaptability	Ability to adjust the supply chain design when the market demand shifts	Chowdhury and Quaddus (2016), Jain *et al.* (2017)
16	SC network design	Efficient supply chain design affects the resilience of the supply chain	Moktadir *et al.* (2018); Tang, 2006
17	Security	Security and privacy of data, information and other activities across the supply chain	Jain *et al.* (2017)
18	Awareness/ sensitiveness	Real time monitoring of each activities within a supply chain	Jain *et al.* (2017)
19	Market position	Competitive position of a firm in the market	Fiksel *et al.* (2015)

for overall organization. However, identification of proper PIs and modeling those indicators to assess supply chain resilience for pharmaceutical industries are still required further investigations. Therefore, the goals of this study are to identify and analyze the appropriate PIs and to develop a model for predicting the resiliency level in the context of Bangladeshi pharmaceutical company. To address these research gaps, the contributions of this study and problem definition are stated as follows:

(1) Finding the major PIs in the field of pharmaceutical industry supply chains.

(2) Evaluating the ranking of these indicators according to their influence and identifying the cause and effect relationship.

(3) Building a SD model for predicting the resiliency level.

3. Methods

In this section, the details of the proposed methodology for analyzing the PIs and assessing the resilience of PSC have been explained. Figure 1 shows the flow diagram of the proposed research framework.

3.1 Performance indicators selection using Delphi method

In this study, the Delphi method has been applied to identify the significant PIs of resilient PSC in two phases after reviewing the previous literature. It is an iterative process of collecting and assessing data from a group of experts through a series of structured questionnaires (Jason and Glenwick, 2016; Lee and Seo, 2016). This tool is extensively used in supply chain, demand forecasting and complex decision making. (Belton *et al.*, 2019; Moktadir *et al.*, 2019).

In phase 1, most relevant indicators of resilient PSC were selected by the industrial experts using primary questionnaire (Appendix 1) and in phase 2, evaluation of comprehensive relationships among these indicators was done by evaluators using the secondary questionnaire (Appendix 2). Using the judgmental sampling technique, 10 pharmaceutical companies of Bangladesh were selected that were trying to identify and evaluate the PIs for improving their performance level. Due to confidentiality, symbolic names were used instead of the real names of these companies. For phase 1, 20 respondents were selected using purposive sampling method (Guarte and Barrios, 2006). The profile of the case pharmaceutical companies and the respondents are represented in Table 2.

Initially, a total of 19 PIs of resilient PSC were identified after reviewing previous literature resources (Table 1). The primary questionnaire (Appendix 1) was sent to the respondents through email to select the most relevant PIs from these 19 PIs. The purpose of the study was communicated with them and they were requested to provide their feedback to check the validity of those PIs for PSC. They were given the chance to add or remove any indicator of resilient PSC. Based on the experts' opinions, a total of 12 PIs were sorted out. Table 3 presents the identified PIs through Delphi method.

3.2 Relationship assessment of PIs using fuzzy DEMATEL

3.2.1 Fuzzy set theory. The fuzzy theory was proposed and introduced by Zadeh (1965). This tool mainly deals with the vagueness problems of linguistic variables in reality. It has the capability of assessing the subjective and imprecise judgments provided by individuals or expert panels. In this study, a widely used and well- established triangular fuzzy number (TFN) has been considered. Before using fuzzy based tools, fuzzy numbers

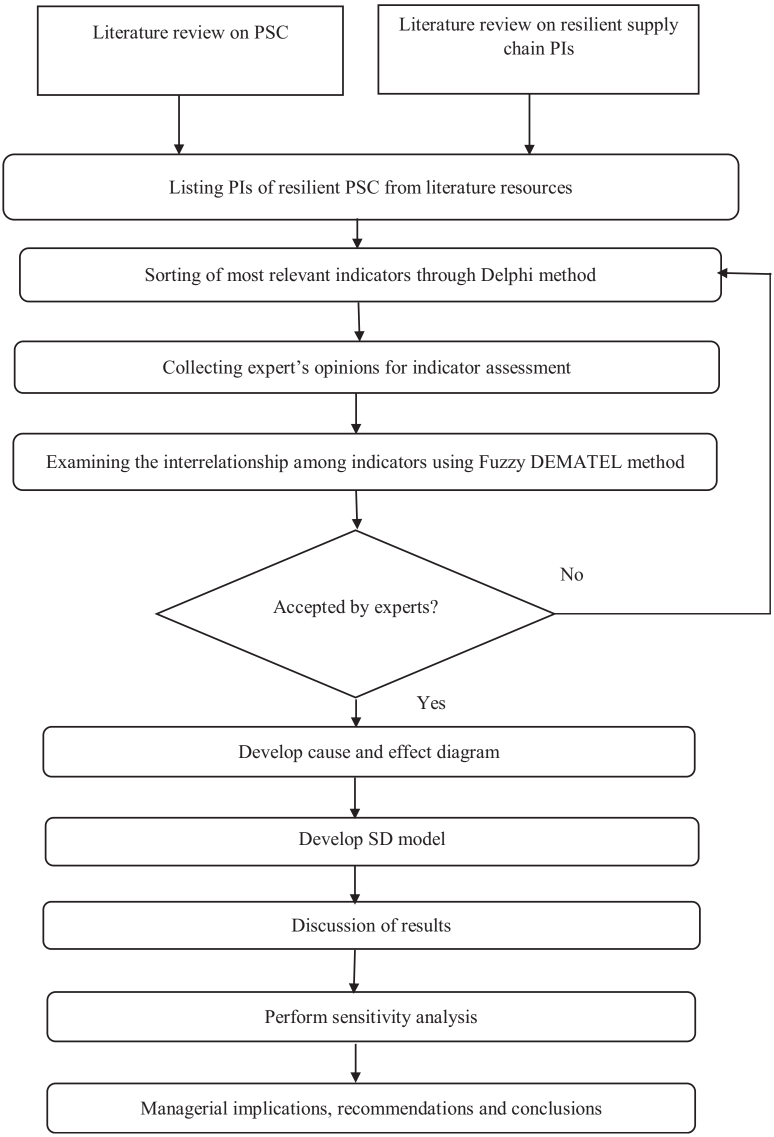

Figure 1.
Flow diagram of the current research

are required to convert into crisp values (defuzzification).Among various methods, Converting Fuzzy data into the Crisp Scores (CFCS) is extensive in terms of providing better crisp values than other similar methods (Wu and Lee, 2007). According to membership functions, the total score can be found as a weighted average. Let, $A_{ij} = (u_{ij}^n, v_{ij}^n, w_{ij}^n)$, mean the degree of criterion i that affects criterion j and fuzzy questionnaires n $(n = 1, 2, 3, \ldots\ldots\ldots, h)$. The crisp value of ith criteria can be obtained by four steps as follows (Opricovic and Tzeng, 2003):

Name of company	Respondents	Year of experience	Company size (employees, annual sales turn over)
"A" Pharmaceutical limited	Supply chain manager	15 years	Employee: 47,000
	Logistics manager	12 years	Turnover (2016): USD 544million
	Production manager	10 years	
"B" Pharmaceutical limited	Logistics manager	11 years	Employee: 32,000
	Assistant logistics manager	5 years	Turnover (2017): USD 238 million
	Supply chain executive	3 years	
"C" Pharmaceutical limited	Senior supply chain manager	15 years	Employee: 14,000 Turnover (2017): USD 102 million
	Supply chain manager	12 years	
	Logistics manager	7 years	
"D" Pharmaceutical limited	Production manager	11 years	Employee: 8,000
	Logistics manager	9 years	Turnover (2018): USD 89 million
	Supply chain manager	8 years	
"E" Pharmaceutical limited	Production manager	7 years	Employee: 8,000
	Supply chain manager	8 years	Turnover (2018): USD 89 million
"F" Pharmaceutical limited	Supply chain manager	10 years	Employee: 5,000
	Logistics manager	8 years	Turnover (2018): USD 70 million
"G" Pharmaceutical limited	Supply chain manager	8 years	Employee: around 5000\ Turnover (2018): USD 60 million
"H" Pharmaceutical limited	Supply chain executive	4 years	Employee: around 3000 Turnover (2018): around USD 50 million
"I" Pharmaceutical limited	Production executive	3 years	Employee: around 3000 Turnover (2018): USD 50 million
"J" Pharmaceutical limited	Assistant logistic manager	4 years	Employee: around 3000 Turnover (2018): USD 45 million

Table 2. Profile of case pharmaceutical companies and respondents

Performance indicators	Code
Collaboration	PI_1
SC risk orientation	PI_2
SC network design	PI_3
Creating robust supply chain	PI_4
Velocity	PI_5
Sustainability	PI_6
Flexibility	PI_7
Information sharing	PI_8
Visibility	PI_9
Adaptability	PI_{10}
Available resources	PI_{11}
Agility	PI_{12}

Table 3. The list of PIs identified through the Delphi method

Step 1. Perform normalization

$$xw_{ij}^{n} = \left(r_{ij}^{n} - \min u_{ij}^{n}\right) \Big/ \Delta_{\min}^{\max} \quad (1)$$

$$xv_{ij}^{n} = \left(v_{ij}^{n} - \min u_{ij}^{n}\right) \Big/ \Delta_{\min}^{\max} \quad (2)$$

$$xu_{ij}^n = \left(u_{ij}^n - \min u_{ij}^n\right) \Big/ \Delta_{\min}^{\max} \tag{3}$$

where $\Delta_{min}^{max} = \max w_{ij}^n - \min u_{ij}^n$;

Step 2: Calculate the right (ws) and left (us) normalized values

$$xws_{ij}^n = xw_{ij}^n \Big/ \left(1 + xw_{ij}^n - xv_{ij}^n\right) \tag{4}$$

$$xus_{ij}^n = xv_{ij}^n \Big/ \left(1 + xv_{ij}^n - xu_{ij}^n\right) \tag{5}$$

Step 3: Estimate total normalized crisp values

$$x_{ij}^n = \left[xus_{ij}^n\left(1 - xus_{ij}^n\right) + xws_{ij}^n \times xws_{ij}^n\right] \Big/ \left[1 - xus_{ij}^n + xws_{ij}^n\right] \tag{6}$$

Step 4: Compute crisp values

$$Z_{ij}^n = u_{ij}^n + x_{ij}^n \times \Delta_{\min}^{\max} \tag{7}$$

3.2.2 Fuzzy DEMATEL method. The Decision Making Trial and Evaluation Laboratory (DEMATEL) approach is a simple method for evaluating the relationship among various alternatives based on the pair-wise comparison. This method was first proposed by Fontela and Gabus (1974). It was widely used in analyzing complex structural models of causality between complex factors. Integrating fuzzy systems with DEMATEL enables the decision-makers to evaluate the complex factors easily (which are difficult to quantify and usually expressed with linguistic variables). Table 4 shows the triangular fuzzy linguistic scale for direct relation criteria. The steps of fuzzy-DEMATEL are presented as follows (Kazancoglu *et al.*, 2018):

Step 1: Development of the fuzzy initial direct relation matrix A by integrating the inputs from experts.

Step 2: Development of crisp direct relation matrix Z using Eqns (1)–(7).

Step 3: Construction of standardized matrix X using the following equation

$$X_{ij} = \frac{Z_{ij}}{S} \tag{8}$$

where $S = \max\{\max\sum_{j=1}^{n} Z_{ij},\ \ \max\sum_{i=1}^{n} Z_{ij}\}$

Table 4. The fuzzy linguistic scale

Linguistic variables	Triangular fuzzy number
No influence (N)	(0, 0, 0.25)
Very low influence (VL)	(0, 0.25, 0.50)
Low influence (L)	(0.25, 0.50, 0.75)
High influence (H)	(0.50, 0.75, 1.0)
Very high influence (VH)	(0.75, 1.0, 1.0)

Step 4: Total relation matrix T construction using the following equation

$$T = X(I - X)^{-1} \tag{9}$$

where I indicates the identity matrix.

Step 5: Then the degree of influential impact (D) and the degree of influenced impact (J) are calculated as follows:

$$D = \sum_{j=1}^{n} t_{ij} \tag{10}$$

$$J = \sum_{i=1}^{n} t_{ij} \tag{11}$$

Step 6: In this step, $(D+J)$ and $(D-J)$ are calculated. $(D+J)$ indicates the prominence vector and $(D-J)$ indicates the relation vector.

Step 7: Finally, the causal diagram is developed using the prominence vector and relation vector.

4. An illustrative example

For verifying the proposed methodology, a pharmaceutical company located in Tangail, Bangladesh was selected to analyze the PIs and predict the resilience level of the supply chain. Due to confidentiality, the name of the case company has been kept anonymous. For the assessment of the relationships among the performance indicators using fuzzy DEMATEL for the case company, 5 evaluators were selected. In fuzzy DEMATEL, 4–12 evaluators are suitable for data collection. In this study, five evaluators were selected to keep the calculation simple. They were selected based on their working experience and positions in the relevant department. The profile of these five evaluators has been shown in Table 5. The questionnaire (Table A4) was sent through email after explaining to them the objectives of the study.

4.1 Assessment of resilient PSC performance indicators

At this stage of the study, performance indicators of resilient PSC of the selected pharmaceutical company were assessed using the fuzzy DEMATEL method. The resilience performance indicators represented in Table 3 were selected for the case company. Then, through the secondary questionnaire (Appendix 2), the data were obtained from the five professional evaluators for fuzzy DEMATEL. The linguistic scale shown in Table 4 was used through the one-to-one interview for data collection. The fuzzy DEMATEL method was applied through the following steps.

Evaluator	Experience (Years)	Job title
Evaluator 1	>15	Supply chain manager
Evaluator 2	>10	Supply chain manager
Evaluator 3	>9	Production manager
Evaluator 4	>7	Supply chain manager
Evaluator 5	>8	Assistant manager (logistics)

Table 5. Profile of the five evaluators

4.1.1 Step 1: development of the fuzzy initial direct relation matrix. At first, the pair wise comparisons among the resilience PSC indicators were constructed by using the fuzzy linguistic variables. The linguistic assessment by the five evaluators is shown in Table A5 in Appendix 3. These linguistic variables were then converted into triangular fuzzy numbers and fuzzy initial direct relation matrix was developed by taking the average of these fuzzy numbers. The fuzzy initial direct relation matrix is shown in Table A6 in Appendix 3.

4.1.2 Step 2: constructing the crisp direct relation and total relation matrix. The crisp direct relation matrix from the average fuzzy initial direct relation matrix was computed using Eqn (1)–(7). The total relation matrix was derived from the crisp relation matrix using Eqns (8) and (9). The total relation matrix is shown in Table A7 in Appendix 3.

4.1.3 Step 3: deriving the prominence vector and the cause-effect diagram. The degree of influential impact (D) and the degree of influenced impact (R) were calculated from the total relation matrix using Eqns (10) and (11). Finally, the prominence vector and relation vector were obtained. Prominence vector and relation vector along with the ranking were represented in Tables 6 and 7 respectively. To develop the cause and effect diagram, the relation vector was used. All the indicators having positive relation values ($D - R$) were grouped into cause group and indicators with negative relation values were grouped into an effect group.

5. Results and discussion

5.1 Cause and effect relationships among the performance indicators

In this section, the findings from the implementation of fuzzy DEMATEL have been discussed. The ($D + R$) scores indicate the relative importance of the resilient PSC performance indicators. Therefore, a higher score of the indicators represents higher priority

Rank	Indicators	$(D+R)$
1	PI_1	14.474
2	PI_2	14.452
3	PI_9	13.269
4	PI_7	13.196
5	PI_{12}	12.976
6	PI_6	12.960
7	PI_8	12.780
8	PI_{11}	12.613
9	PI_{10}	12.598
10	PI_3	12.578
11	PI_5	11.996
12	PI_4	11.294

Table 6.
Prominence vector of PIs

Rank	Cause group	$(D-R)$	Rank	Effect group	$(D-R)$
1	PI_8	1.333463	1	PI_6	−1.87736
2	PI_7	0.933013	2	PI_{12}	−1.44572
3	PI_3	0.718546	3	PI_1	−0.36317
4	PI_{11}	0.680435	4	PI_4	−0.19854
5	PI_2	0.291422	5	PI_9	−0.09903
6	PI_5	0.0528242	6	PI_{10}	−0.03131

Table 7.
Relation vector of PIs

in the indicator's ranking system. Table 6 represents the prominence vector of the resilience PIs obtained from the fuzzy DEMATEL. According to the prominence vector, the top five performance indicators are "Collaboration (PI_1)", "SC risk orientation (PI_2)", "Visibility (PI_9)", "Flexibility (PI_7)" and "Agility (PI_{12})" which were ranked based on $(D+R)$ scores. "Available resource (PI_{11})", "Adaptability (PI_{10})", "SC network design (PI_3)", "Velocity (PI_5)" and "Robustness (PI_4)" are the last five PIs in the prominence ranking although they have significant impact on the resilience of PSC.

The cause and effect relationships of these PIs of resilience PSC can be understood from the relation vector (Table 7). The $(D-R)$ score represents the relation characteristics of the indicators. The positive $(D-R)$ score indicates the cause group and negative $(D-R)$ score indicates the effect group. According to the relation vector, "IT capability (PI_8)", "Flexibility (PI_7)", "SC network design (PI_3)", "Available resource (PI_{11})", "SC risk orientation (PI_2)" and "Velocity (PI_5)" were grouped into cause category since they have positive $(D-R)$ scores. On the other hand, "Sustainability (PI_6)", "Agility (PI_{12})", "Collaboration (PI_1)", "Creating robust supply chain (PI_4)", "Visibility (PI_9)" and "Adaptability (PI_{10})" were grouped into effect category. All these six indicators are influenced by other performance indicators. Figure 2 shows the cause and effect relation of the resilient supply chain performance indicators.

"Information sharing (PI_8)" has got the first position in the cause category. This indicator has significant impact on establishing resilient PSC. Lack of proper information sharing causes inefficiency of coordinating action and disruptions in overall supply chain (Yu *et al.*, 2020). It is very important to exchange the right information, for increasing resilience within the supply chain (Faisal *et al.*, 2006). Colicchia *et al.* (2019) also found information sharing as one of the significant performance indicators of supply chain. To maximize resilience in the PSC, it is important to make a community of active partners within the current, complex, indeterminate supply chain environment and proper information should flow between all partners of this particular group (Setak *et al.*, 2018; Tohidi *et al.*, 2017). The top management should take action to concern about their information sharing to build resilient PSC. The second indicator in the causal group is "Flexibility (PI_7)". Lack of flexibility causes fluctuation in lead times and delays in product quality and information (Giannoccaro *et al.*, 2003). The numerous styles of flexibility may boost the resilience of PSC, together with versatile travel, versatile work game plans (Pettit *et al.*, 2013). "SC network design (PI_3)" is another important causal indicator for resilient PSC. Poor network design is responsible for production of short deliveries,

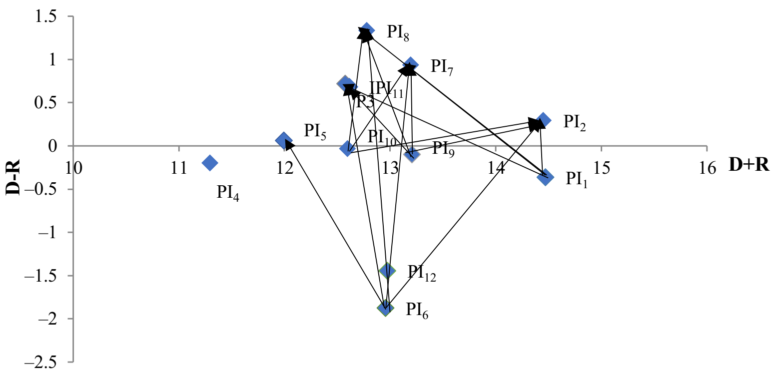

Figure 2.
Cause and effect diagram of resilient PSC performance indicators

poor quality issues and delays. It is important for a proper understanding of the architecture of the supply chain network to make supply chain resilient (Giannoccaro *et al.*, 2018). Rajesh (2019) performed a study on resilient supply chain and showed that network design has a significant influence on the performance of the resilient supply chain. "Available resources (PI_{11})" is the key to manage the resilience in the supply chain. When resources are available, it makes it easier to mitigate any disruption. "SC risk orientation (PI_{11})" is another causal indicator in case of PSC. However, risk orientation in the pharmaceutical supply chain is very difficult. An organization should take necessary action to identify and understand supply chain risks and take proper mitigation actions.

The effect category includes six indicators that can be highly affected by the factors in the cause group. "Sustainability (PI_6)", and "Agility (PI_{12})" hold the first and second position of the effect group respectively and they are highly interrelated. Lack of information sharing, limited resources, product complexity and environmental uncertainty affect these two factors. Different policies and management strategies should be taken by supply and operations managers to increase SC risk orientation and increase flexibility. Another crucial indicator is supply chain "Visibility (PI_9)". It can be affected by supply chain network design, flexibility, supply chain adaptability and collaboration in supply chain. "Adaptability (PI_5)" is the last indicator in the effect group. The stability of the supply chain depends on the flexibility of the system to respond to transitory problems and market fluctuations (Chowdhury and Quaddus, 2016). Supply chain and operations managers should formulate strategy to improve the supply chain resilience by setting target for these performance indicators and following proper action plan.

5.2 System dynamics model for measuring resilience of PSC

System dynamics (SD) model has been developed for predicting the PSC resilience after identifying the cause group and effect group from the fuzzy DEMATEL. The system dynamics (SD) model was constructed in two phases. In the first phase, cause group and effect group were translated into partial causal loop diagram (CLD) and stock and flow diagram was developed from the causal loop diagram in the second phase. These phases are described as follows:

5.2.1 Phase 1: causal loop diagram (CLD) development. A causal loop diagram (CLD) of PSC resilience PIs was developed based on the cause and effect group derived from the fuzzy DEMATEL and some other auxiliary variables. These auxiliary variables were selected with the help of experts in Delphi phase. These variable were selected based on their prior experiences. Auxiliary variables are related to the main variables and the values of auxiliary variables are required to predict the values of stocks and flows. The values of auxiliary variables were collected from the case company. The eight most influential resilience PIs from the prominence vector (Table 7) were selected for developing the causal loop diagram. Table 8 presents the list of these resilience PIs and auxiliary variables.

For developing the CLD, Vensim PLE version 32 software has been used. The causal loop diagram is shown in Figure 3.

5.2.2 Phase 2: stock and flow diagram development. At the next step, stock and flow diagram was developed with the information from the CLD. Figure 4 shows the stock and flow diagram for predicting the resilience level of PSC. Here, the "SC Resilience" is the main stock. The other stocks in the model are "SC Agility", "Sustainability", "Lack of collaboration" and "Lack of visibility". Flows and the auxiliary variables have been created according to the information from the CLD.

Table 8. Description of PIs and auxiliary variables for CLD

CLD variables	Description
Product complexity	Complexity in the product technology or manufacturing
Product quality	Ability of the product to fulfill and meet customer requirements
SC agility	Description is given in Table 5
Environmental uncertainty	Changes in the business environment on which the company has little influence
Operational disruption	Disruptions in the production and distribution system
Vague terminology	Usage of imprecise and unclear terms and jargons
Absence of trust	Lack of trust among partners, employers and workers
Motivation	Initiatives taken by the management to increase enthusiasm among the workers
Coordination	The act of making people involved in strategic and operational plan and managing their activities
Management support	Support from the top management by providing adequate resources and empowering the managers
Supply chain network complexity	Degree of complexity in supply chain structure that consist of the supply members-upstream suppliers and downstream customers
Effectiveness of SC network design	Effect of SC network design in increasing the collaboration
SC flexibility	Description is given in Table 3
SC velocity	Description is given in Table 3
Sustainability	Description is given in Table 3
SC risk orientation	Description is given in Table 3
Available resource	Description is given in Table 3
Regulation	Laws or legal issues imposed by the government
Lack of collaboration	Opposite in collaboration which is given in Table 3
Lack of visibility	Opposite in visibility which is given in Table 3

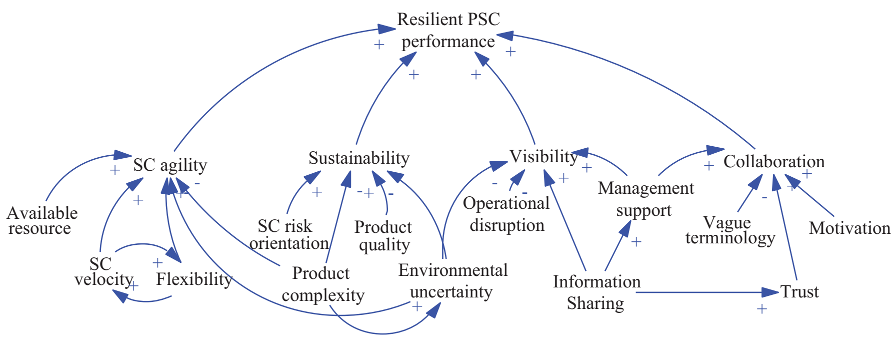

Figure 3. Causal loop diagram for resilient PSC performance

The equation was set for each flow in the model by consulting with the experts. Then, this model was implemented to the case pharmaceutical company for predicting the resilience level of the supply chain. At first, the initial values of each stock were given after consulting with the case pharmaceutical company's top management. Then, the target values of each auxiliary variables were given in the model. This data was given by the supply chain department of the case company and they set the values of each variable ranges between 0 and 1 considering the current condition of each variable. Then, the simulation was run for 100 months for observing the resilience level for the case pharmaceutical company. The equations and initial values used for different variables in the model are given below:

SC velocity = 0.1
SC flexibility (Rate) = 0.1
Available resource = 0.2
SC Agility *Available resource * SC velocity * SC flexibility (rate)
SC Agility = Initial SC Agility + increase in SC agility – decrease in SC agility
Initial SC Agility = 0.1
Decrease in SC Agility = SC Agility * product Complexity * Environment Uncertainly * Regulation
Regulation = 0.1
Product complexity = 0.02
Product quality = 0.1
SC risk orientation = 0.1
Increase in sustainability = Sustainability * Product quality * SC risk orientation
Sustainability = Initial Sustainability + increase in Sustainability – decrease in sustainability
Initial Sustainability = 0.2
Decrease in sustainability = Product complexity * Environmental uncertainly * Operational disruption * Sustainability
Operational Disruption = 0.03
Environmental uncertainly = 0.02
SC network complexity = 0.01
Increase in lack of visibility = Lack of visibility * SC network complexity * Environmental uncertainly * Operational disruption
Information Sharing = 0.02
Management Support = 0.2
Lack of visibility = Initial Lack of visibility + (increase in lack of visibility – decrease in lack of visibility)
Initial Lack of visibility = 0.3
Decrease in lack visibility = Lack of visibility * Management support * Information sharing
Effective team work = 0.03
Effectiveness of SC network design = 0.05
Absence of trust = 0.03
Use of vague terminology = 0.02
Lack of collaboration = Initial Lack of collaboration + Increase in Lack of collaboration – Decrease in Lack of collaboration
Initial Lack of collaboration = 0.01
Increase in Lack of collaboration = Lack of collaboration * Absence of trust * Use of vague terminology
Decrease in Lack of collaboration = Lack of collaboration * Effectiveness of SC network design * Effective team work
Increase = SC Resilience * (SC Agility * Sustainability)
Decrease = SC Resilience * (Lack of collaboration * Lack of visibility)
SC Resilience = Initial SC Resilience + (increase – decrease)
Initial SC Resilience = 20

Figure 5 shows the predicted conditions of supply chain agility, sustainability, collaboration and supply chain visibility. It is noted that if the case pharmaceutical company takes action according to their target, then their supply chain sustainability will improve rapidly. However, supply chain agility will improve very slowly. Besides this, lack of collaboration and lack of visibility will be minimized within the next 100 months.

Figure 6 shows the predicted resilience level of the case pharmaceutical company for the next 100 months. At present, the resilience level of the supply chain of the company is 20 which means very low. The curve indicates that the level of supply chain resilience will be improved very quickly after a certain time if the company can maintain their strategy and action plans.

6. Sensitivity analysis

Sensitivity analysis is usually performed to examine the reliability of the decisions made by the evaluators (Tanino, 1999). Sensitivity analysis is conducted by keeping equal weights

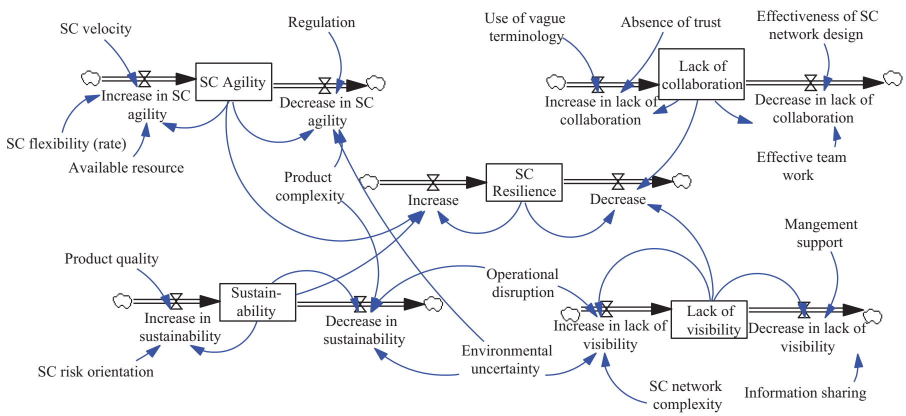

Figure 4.
Stock and flow diagram for measuring resilience of PSC

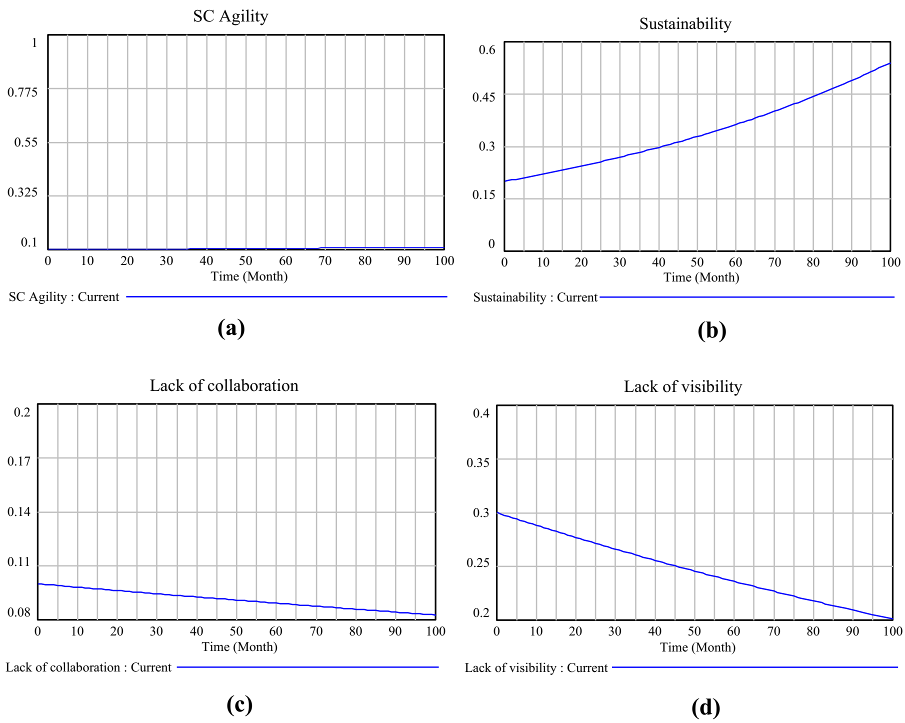

Figure 5.
Prediction of levels of performance indicators

and adjusts more weights to any evaluator to realize the effects of using various combinations of decision criteria weight (Goodridge, 2016). In this study, the results obtained from fuzzy DEMATEL have been verified by performing sensitivity analysis. Five scenarios were assumed to conduct this sensitivity analysis. Different weights of evaluators were given based on their working experience in different scenarios which is shown in Table 9.

Initially, each evaluator was given equal weight (Scenario-1). After that, the weights of the evaluators were changed based on their working experiences to analyze how much the prominence rank, and the cause and effect relations vary. Since Evaluator 1 and Evaluator 2 were more experienced than all other evaluators, their weights were assigned higher than other evaluators in the next three scenarios. Then the cumulative average initial matrix was derived shown in appendix D4. Then, the fuzzy DEMATEL was applied on the same data in each scenario to observe the reliability of the results. Figure 7 shows the results obtained in different scenarios. Prominence rank of the resilient PSC performance indicators was stable in different scenarios although the weights of the evaluators were varied. Accordingly, the cause and effect relations among the resilient PSC performance indicators were varied a little with insignificant impact in each scenario. Cause group and effect group hold the same members in each scenario. Therefore, it is clear that the obtained results are not much sensitive to the variation of weights among the evaluators which indicates the high reliability of the results of the current research. As a result, the understanding of evaluators about the resilient pharmaceutical supply chain is adequate for this study.

7. Managerial implications

The major contribution of this work is the identification and prioritization of PIs of resilient PSC, which are significant to increase resilience as well as to improve overall performance. Another contribution of this work is a proposed SD model that can be used to measure resilience of PSC by simulating performance level for a certain time. After the recognition of fundamental knowledge and the strengthening of resilient supply chain PIs and the result of simulation, the business manager will be able to enhance resilient supply chain performance

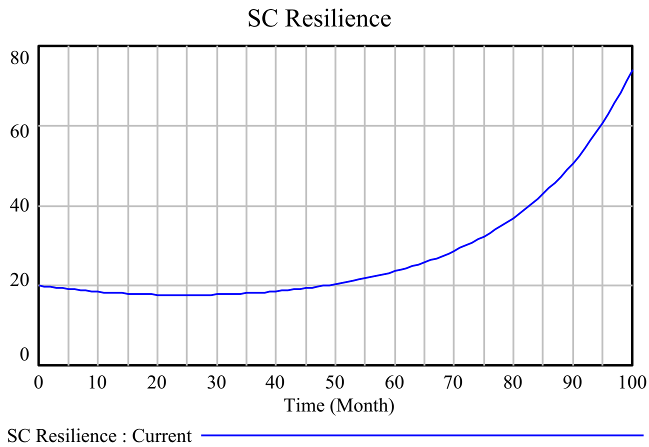

Figure 6. Prediction of resilience of PSC

Table 9. Different importance weights of evaluators in sensitivity analysis

Evaluators	Scenario-1	Scenario-2	Scenario-3	Scenario-4	Scenario-5
Evaluator-1	0.2	0.4	0.4	0.3	0.35
Evaluator-2	0.2	0.2	0.3	0.3	0.2
Evaluator-3	0.2	0.2	0.15	0.2	0.2
Evaluator-4	0.2	0.1	0.1	0.1	0.1
Evaluator-5	0.2	0.1	0.05	0.1	0.15

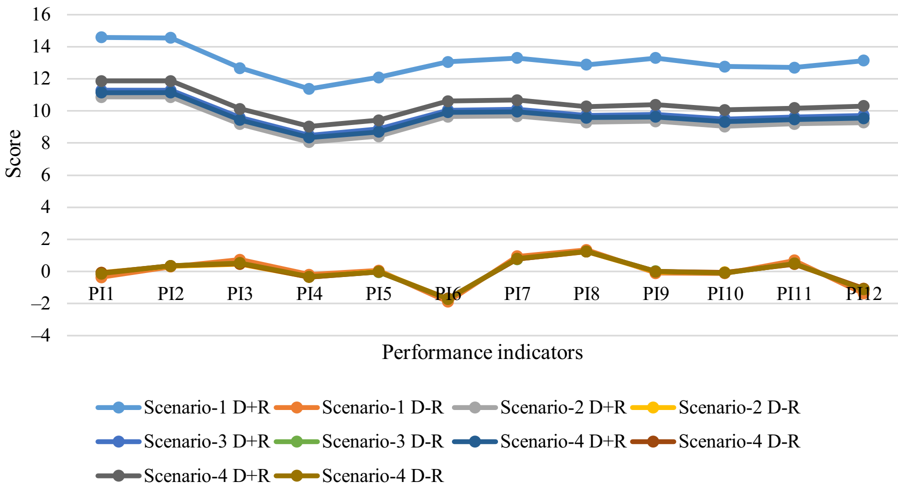

Figure 7.
Prominence rank and cause–effect relations from sensitivity analysis

by introducing constructive supply chain policies. This research will help policymakers to identify the most relevant metrics of success and recommend ways to improve the outcomes in PSC. Some of the policies are also recommended for helping managers to improve PSC resilience, given as below:

(1) Improving the resilience of a PSC requires understanding and selecting the appropriate PIs of the resilient supply chain to optimize the efforts. This research will be helpful for the supply chain professionals and researchers to select the appropriate indicators and understand the relationships among them to improve the resilience of a supply chain.

(2) The pharmaceutical sector must formulate an effective strategy to improve the resilience of the supply chain. However, the effectiveness of the strategy must be assessed and the resilience level of the supply chain must be predicted on a regular basis. The fuzzy-DEMAEL part of this study will help the supply chain managers to formulate an effective strategy and the proposed SD model will help to predict the resilience level of the PSC.

8. Conclusions and future research directions

Establishing resilience in the supply chain has become one of the major challenges for the pharmaceutical industries. However, a structured framework is required to identify the PIs for developing resilient PSC successfully. Motivated by the drawbacks of previous research as well as the current pandemic situation, this study presents an integrated approach (Delphi based fuzzy DEMATEL and SD model) for assessing the contextual relationships among the indicators and predicting the resilience level for a certain time period.

There are three major findings in this study. First, from the Delphi method, 12 most relevant PIs for resilient PSC were identified. Second, this study applied Fuzzy DEMATEL to determine the causal relationships among the identified PIs. This study contributes to the existing supply chain literature by exploring the relationships among the PIs of resilient PSC and developing an SD model to predict the resilience level. Here, the values of the elements of the developed SD model were set according to the assumptions of the top management of the case company. The model can be more robust if the real value for each element of the model is set.

Although this research indicates new insights into resilient PSC indicators, the research inevitably has limitations regarding data collection and validation. As in this research work, only 12 PIs are considered. More indicators can be analyzed to develop the model using fuzzy DEMATEL and system dynamics in further analysis. As the model is developed and verified on the basis of expert's opinions, biases can occur. The results of this study can be compared with other methods such as fuzzy TISM, grey based TISM etc. While the focus of this research is mainly on the PSC of Bangladesh, the proposed model can be applied to other industries, such as beverage, construction, manufacturing, service and so on, for identifying resilient supply chain performance indicators.

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Appendix 1

Primary questionnaires:

(1) Background information of the respondent:

(a) Name:

(b) Name of the companies:

(c) Designation:

(d) Years of experience:

(e) Major job responsibilities:

The most relevant indicators of resilient PSC were identified with the help of literature resources are following

			5: Highly important and 1: Very weakly important				
No	Performance indicators types	Yes/no	1	2	3	4	5
1	Agility						
2	Flexibility						
3	Creating robust supply chain						
4	Redundancy						
5	Visibility						
6	IT capability/information sharing						
7	Collaboration						
8	Sustainability						
9	Supply chain risk orientation						
10	Velocity						
11	Adaptability						
12	SC network design						
13	Market position						
14	Security						
15	Risk control						
16	Public-private partnership						
17	Awareness						
18	Production capacity						
19	Available resources						

Table A1. Most relevant performance indicators of resilient PSC

The most relevant indicators of resilient PSC were identified with the help of industrial experts using primary questionnaire are following

Table A2.
Identified the most relevant performance indicators

List of identified performance indicators	Code
Collaboration	PI_1
SC risk orientation	PI_2
SC network design	PI_3
Robustness	PI_4
Velocity	PI_5
Sustainability	PI_6
Flexibility	PI_7
Information Sharing	PI_8
Visibility	PI_9
Adaptability	PI_{10}
Available resources	PI_{11}
Agility	PI_{12}

Appendix 2

Secondary questionnaire

Q.3 Do you realize the assessment scale that we provided to assess the selected performance indicators? Please fill the pair wise relation:

Table A3.
The fuzzy linguistic scale for expert's evaluation

Linguistic variables	Triangular fuzzy number
No influence (N)	(0, 0, 0.25)
Very Low influence (VL)	(0, 0.25, 0.50)
Low influence (L)	(0.25, 0.50, 0.75)
High influence (H)	(0.50, 0.75, 1.0)
Very high influence (VH)	(0.75, 1.0, 1.0)

Please provide your opinion based on the following scale: No influence (N), Very low influence (VL), Low influence (L), High influence (H) and Very high influence (VH).

Expert name:

Linguistic assessment of comprehensive relationship of these indicators using the secondary questionnaire

Table A4.
Linguistic assessment of performance indicators

	PI_1	PI_2	PI_3	PI_4	PI_5	PI_6	PI_7	PI_8	PI_9	PI_{10}	PI_{11}	PI_{12}
PI_1	N											
PI_2		N										
PI_3			N									
PI_4				N								
PI_5					N							
PI_6						N						
PI_7							N					
PI_8								N				
PI_9									N			
PI_{10}										N		
PI_{11}											N	
PI_{12}												N

Appendix 3

	PI_1	PI_2	PI_3	PI_4	PI_5	PI_6
PI_1	(N,N,N,N,N)	(VH,H,H,VH,H)	(H,VH,H,H,H)	(VH,H,H,H,L)	(VH,H,L,L,L)	(VH,H,L,L,L)
PI_2	(VH,VH,H,H,H)	(N,N,N,N,N)	(VH,H,H,H.L)	(VH,VH,H,L,L)	(L,L,L,L,L)	(VH,H,H,H,H)
PI_3	(H,H,H,VH,H)	(L,L,L,L,L)	(N,N,N,N,N)	(VH,H,H,H,H)	(VL,VL,L,H,L)	(VL,L,L,L,L)
PI_4	(VH,VH,H,H,VH)	(H,L,L,H,H)	(L,L,L,L,L)	(N,N,N,N,N)	(N,N,VL,VL,VL)	(L,H,H,H,L)
PI_5	(L,L,L,H,H)	(L,H,H,H,L)	(VL,L,L,L,L)	(VL,VL,VL,VL,L)	(N,N,N,N,N)	(VH,VH,H,H,H)
PI_6	(VL,VL,L,L,L)	(L,L,L,H,H)	(VL,VL,N,VL,VL)	(VL,N,VL,VL,L)	(L,L,L,L,L)	(N,N,N,N,N)
PI_7	(VH,H,H,H,H)	(VH,VH,H,H,H)	(VL,L,L,L,L)	(VL,VL,VL,L,H)	(VH,VH,VH,VH,VH)	(VH,H,H,H,H)
PI_8	(VH,H,VH,VH,VH)	(VH,VH,H,L,L)	(VL,VL,VL,VL,L)	(VL,L,L,L,L)	(N,VL,L,L,H)	(VH,VH,H,H,H)
PI_9	(L,L,L,H,H)	(L,H,H,H,H)	(H,L,H,L,H)	(L,L,L,L,L)	(L,H,H,H,H)	(H,H,H,H,H)
PI_{10}	(VH,VH,VH,VH,VH)	(H,H,H,H,H)	(L,L,L,L,L)	(VL,VL,VL,L,L)	(L,L,L,L,L)	(VH,VH,H,H,H,H)
PI_{11}	(L,L,H,H,H)	(H,H,H,L,L)	(L,H,H,H,H)	(H,H,L,L,H)	(H,L,L,H,H)	(H,H,H,H,H)
PI_{12}	(H,H,L,L,L)	(L,L,L,H,H)	(L,H,H,H,H)	(L,L,H,H,H)	(L,L,L,L,H)	(L,H,H,L,L)

	PI_7	PI_8	PI_9	PI_{10}	PI_{11}	PI_{12}
PI_1	(L,H,H,H,H)	(VH,H,H,H,H)	(VH,H,L,L,L)	(H,L,L,L,L)	(L,H,L,L,L)	(L,L,H,H,L)
PI_2	(L,H,L,L,L)	(L,H,H,H,L)	(H,H,H,VH,VH)	(VH,H,VH,VH,VH)	(H,L,L,L,L)	(VH,VH,H,H,H)
PI_3	(N,N,VL,VL,VL)	(H,VH,VH,H,H)	(H,H,H,H,H)	(L,L,L,L,H)	(VH,VH,H,H,H)	(H,H,VH,VH,VH)
PI_4	(VL,VL,VL,L,L)	(VL,L,H,H,H)	(VL,VL,VL,VL,L)	(VL,L,L,L,L)	(VL,VL,L,H,H)	(VL,VL,L,L,H,)
PI_5	(H,H,LH,H,H)	(N,N,VL,L,L)	(L,L,L,L,H)	(L,L,H,H,H)	(N,VL,L,L,L)	(L,L,H,VH,VH)
PI_6	(L,L,L,L,L)	(VL,VL,VL,VL,L)	(L,H,H,H,H)	(L,L,L,H,H)	(H,H,L,L,H)	(VH,VH,VH,H,H)
PI_7	(N,N,N,N,N)	(VL,L,L,L,H)	(H,VL,L,H,H)	(H,VH,VH,H,H)	(H,L,H,L,H)	(VH,VH,H,H,H)
PI_8	(VH,H.H,H,H)	(N,N,N,N,N)	(H,VH,VH,VH,VH)	(L,L,L,L,L)	(H,H,H,L,L)	(VL,VH,VH,VH,H)
PI_9	(H,H,H,H,L)	(VL,VL,VL,VL,L)	(N,N,N,N,N)	(VL,L,H,H,H)	(H,H,H,H,H)	(VL,L,L,H,VH)
PI_{10}	(L,L,L,L,H)	(L,L,L,H,H)	(VL,L,H,H,H)	(N,N,N,N,N)	(N,VL,VL,L,L)	(VL,VL,L,L,L)
PI_{11}	(H,H,H,H,H)	(L,L,L,L,L)	(VL,L,H,H,H)	(L,L,L,L,L)	(N,N,N,N,N)	(L,L,L,H,H)
PI_{12}	(L,L,L,L,L)	(VL,VL,L,L,L)	(VL,L,L,H,H)	(VL,VL,L,L,VL)	(VL,VL,VL,L,L)	(N,N,N,N,N)

Table A5.
Linguistic assessment by the five evaluators

Table A6.
The fuzzy initial direct relation matrix (average)

	PI_1	PI_2	PI_3	PI_4	PI_5	PI_6
PI_1	(0, 0, 0.25)	(0.6, 0.85, 1)	(0.55, 0.8, 1)	(0.5, 0.75, 0.95)	(0.4, 0.65, 0.85)	(0.4, 0.65, 0.85)
PI_2	(0.6, 0.85, 1)	(0, 0, 0.25)	(0.5, 0.75, 0.95)	(0.5, 0.75, 0.9)	(0.25, 0.5, 0.75)	(0.55, 0.8, 1)
PI_3	(0.55, 0.8, 1)	(0.25, 0.5, 0.75)	(0, 0, 0.25)	(0.55, 0.8, 1)	(0.2, 0.45, 0.7)	(0.2, 0.45, 0.7)
PI_4	(0.65, 0.9, 1)	(0.4, 0.65, 0.9)	(0.25, 0.5, 0.75)	(0, 0, 0.25)	(0, 0.15, 0.4)	(0.4, 0.65, 0.9)
PI_5	(0.35, 0.6, 0.85)	(0.4, 0.65, 0.9)	(0.2, 0.45, 0.7)	(0.05, 0.3, 0.55)	(0, 0, 0.25)	(0.6, 0.85, 1)
PI_6	(0.15, 0.4, 0.65)	(0.35, 0.6, 0.85)	(0, 0.2, 0.45)	(0.05, 0.2, 0.45)	(0.25, 0.5, 0.75)	(0, 0, 0.25)
PI_7	(0.55, 0.8, 1)	(0.6, 0.85, 1)	(0.2, 0.45, 0.7)	(0.15, 0.4, 0.65)	(0.75, 1, 1)	(0.55, 0.8, 1)
PI_8	(0.7, 0.95, 1)	(0.5, 0.75, 0.9)	(0.05, 0.3, 0.55)	(0.2, 0.45, 0.7)	(0.2, 0.4, 0.65)	(0.65, 0.9, 1)
PI_9	(0.35, 0.6, 0.85)	(0.45, 0.7, 0.95)	(0.4, 0.65, 0.9)	(0.25, 0.5, 0.75)	(0.45, 0.7, 0.95)	(0.55, 0.8, 1)
PI_{10}	(0.75, 1, 1)	(0.55, 0.8, 1)	(0.25, 0.5, 0.75)	(0.1, 0.35, 0.6)	(0.25, 0.5, 0.75)	(0.6, 0.85, 1)
PI_{11}	(0.4, 0.65, 0.9)	(0.4, 0.65, 0.9)	(0.45, 0.7, 0.95)	(0.4, 0.65, 0.9)	(0.4, 0.655, 0.9)	(0.5, 0.75, 1)
PI_{12}	(0.35, 0.6, 0.85)	(0.35, 0.6, 0.85)	(0.45, 0.7, 0.95)	(0.4, 0.65, 0.95)	(0.3, 0.55, 0.85)	(0.35, 0.6, 0.85)

	PI_7	PI_8	PI_9	PI_{10}	PI_{11}	PI_{12}
PI_1	(0.45, 0.7, 0.95)	(0.55, 0.8, 1)	(0.4, 0.65, 0.85)	(0.3, 0.55, 0.8)	(0.3, 0.55, 0.8)	(0.35, 0.6, 0.85)
PI_2	(0.3, 0.55, 0.8)	(0.4, 0.65, 0.9)	(0.6, 0.85, 1)	(0.7, 0.95, 1)	(0.3, 0.55, 0.8)	(0.6, 0.85, 1)
PI_3	(0, 0.15, 0.4)	(0.6, 0.85, 1)	(0.5, 0.75, 1)	(0.3, 0.55, 0.8)	(0.6, 0.85, 1)	(0.65, 0.9, 1)
PI_4	(0.1, 0.35, 0.6)	(0.35, 0.6, 0.85)	(0.05, 0.3, 0.55)	(0.2, 0.45, 0.7)	(0.25, 0.5, 0.75)	(0.2, 0.45, 0.7)
PI_5	(0.5, 0.75, 1)	(0.1, 0.3, 0.55)	(0.3, 0.55, 0.8)	(0, 4, 0.65, 0.9)	(0.15, 0.35, 0.6)	(0.5, 0.75, 0.9)
PI_6	(0.25, 0.5, 0.75)	(0.05, 0.3, 0.55)	(0.45, 0.7, 0.95)	(0.35, 0.6, 0.85)	(0.4, 0.65, 0.9)	(0.65, 0.9, 1)
PI_7	(0, 0, 0.25)	(0.25, 0.5, 0.75)	(0.25, 0.5, 0.75)	(0.6, 0.85, 1)	(0.35, 0.6, 0.85)	(0.6, 0.85, 1)
PI_8	(0.55, 0.8, 1)	(0, 0, 0.25)	(0.7, 0.95, 1)	(0.25, 0.5, 0.75)	(0.4, 0.65, 0.9)	(0.65, 0.9, 0.1)
PI_9	(0.45, 0.7, 0.95)	(0.05, 0.3, 0.55)	(0, 0, 0.25)	(0.35, 0.6, 0.85)	(0.5, 0.75, 1)	(0.35, 0.6, 0.8)
PI_{10}	(0.3, 0.55, 0.8)	(0.35, 0.6, 0.85)	(0.35, 0.6, 0.85)	(0, 0, 0.25)	(0.1, 0.3, 0.55)	(0.15, 0.4, 0.65)
PI_{11}	(0.5, 0.75, 1)	(0.25, 0.6, 0.85)	(0.35, 0.25, 0.5)	(0.25, 0.5, 0.75)	(0, 0, 0.25)	(0.35, 0.6, 0.85)
PI_{12}	(0.25, 0.5, 0.75)	(0.3, 0.55, 0.8)	(0.15, 0.4, 0.65)	(0.1, 0.35, 0.6)	(0.1, 0.35, 0.6)	(0, 0, 0.25)

	PI_1	PI_2	PI_3	PI_4	PI_5	PI_6	PI_7	PI_8	PI_9	PI_{10}	PI_{11}	PI_{12}
PI_1	0.601	0.657	0.561	0.542	0.549	0.665	0.568	0.546	0.605	0.569	0.542	0.646
PI_2	0.710	0.599	0.578	0.562	0.557	0.705	0.575	0.552	0.647	0.627	0.562	0.692
PI_3	0.646	0.592	0.456	0.523	0.502	0.612	0.489	0.524	0.584	0.537	0.541	0.637
PI_4	0.563	0.519	0.433	0.371	0.401	0.539	0.430	0.431	0.460	0.451	0.435	0.508
PI_5	0.574	0.557	0.459	0.431	0.418	0.598	0.502	0.431	0.518	0.506	0.453	0.575
PI_6	0.514	0.513	0.405	0.392	0.436	0.474	0.446	0.397	0.496	0.466	0.447	0.548
PI_7	0.679	0.658	0.529	0.508	0.585	0.681	0.500	0.516	0.592	0.598	0.544	0.668
PI_8	0.691	0.648	0.515	0.514	0.530	0.689	0.579	0.464	0.633	0.564	0.551	0.672
PI_9	0.618	0.603	0.514	0.486	0.523	0.637	0.533	0.465	0.502	0.539	0.526	0.603
PI_{10}	0.634	0.592	0.482	0.454	0.485	0.620	0.501	0.477	0.544	0.459	0.466	0.564
PI_{11}	0.631	0.606	0.525	0.506	0.524	0.641	0.544	0.490	0.569	0.535	0.458	0.612
PI_{12}	0.553	0.531	0.466	0.450	0.453	0.552	0.459	0.424	0.498	0.458	0.436	0.479

Table A7.
Total relation matrix

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