Review on supply chain resilience: phenomena, modelling techniques and framework of resilience building strategies with future research directions

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Abstract: Supply chain resilience (SCR) is presently a rising concern caused by globalisation, which is subject to diverse types of disturbances. These disturbances need to be controlled in the right way, captivating the use of tools that can support resilient supply chain decisions. This research aims to provide a platform for academicians and practitioners trying to identify the current state of the work, gaps in existing research, and future directions on the topic. It offers a systematic literature review taking several papers to the extent of more than 100 papers published under the year frame from 2010–2020 into account. The research objectives are proposed and answered in this article, identifying of resilience strategies in supply chain, and various methodologies used by the academicians. Further, we develop a framework with inclusion of various strategies employed to increase resilience that can be used as a basis for understanding SCR. Various future directions for the researchers are presented, aiming to guide future research work in the area.

Keywords: supply chain; management supply chain resilience; literature review; uncertainty; disruptions; mitigation strategies.

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1 Introduction

Supply chain management plays a crucial role in supply chain (SC) decision making which is an indispensable planning approach within the SCs across function, time and space, with the desire of bettering the performance of the companies or industries in the SC as well as its broad integrated network (Shapiro and Philpott, 2007; Khan et al., 2021). SCs are becoming multi-facet, multi-dimensional due to resurgence of globalisation as many companies are expanding their network throughout the globe, leading to increase in SC design parameters which includes gigantic volume of data, hence are exposed to various risks resulting in poor estimations due to uncertainties, forecasting errors and wrong analysis of modelling processes (Li et al., 2020). Uncertainty is generally lack of certainty, a polysemic term (‘*poly*’ stands for ‘*many*’ and ‘*sema*’ stands for ‘sign’) which is defined by Möller and Beer (2004) as ‘*a steady assessment of the truth content of a proposition, e.g., in context to the happening of the event*’. These are the major treats for SC which lead to origin of risks, disturbances and further wreak havoc in SC resulting in disruptions. They create a random environment for the decision makers creating difficulties in implementing plans and managing the decision related to the planning of future events. Degree of complexity is very high when uncertainty is modelled into SCN.

In the present world, these uncertainties are the major threats for a SC because of refined trends such as globalisation, outsourcing, just-in-time (JIT) working standard, vendor managed inventory (VMI), and lean practices (Pramudyo and Luong, 2019; Jabbarzadeh et al., 2018a). Uncertainties related to strategic sources are major, while operational uncertainties are usually minute and continuous. These are classified in the literature into two categories: high chance causing low impact (HCLI) and Low chance causing high impact (LCHI) (Nezamoddini et al., 2020). HCLI happens due to an unexpected events such as fluctuation of demands and can be nurtured via proper planning related to different locations of facilities, its number or production capacities and channelised distribution of goods (Schütz et al., 2009). However, LCHI has very less frequency of occurring but the damage due to this can be of very high potential as the overall structure of SC is affected (Jabbarzadeh et al., 2018b). Akbari and Karimi (2015) have reported that disruption is an unpredicted event that damages life and infrastructure. They contribute to uncertainties in the various activities of production, supply and distribution capacities. SC disruptions are considered as rare events which is reasonably true, but the impact associated with these risks is several times greater than operational risks (Jabbarzadeh et al., 2016). COVID-19 pandemic caused a huge impact on the SC s throughout the world, a suspension in operations were firstly faced by China and further this pandemic created a gigantic disruptive event throughout the globe. It has been found by BCI (2020) that 73% of organisations encountered ‘significant’ detrimental effects due to this pandemic on their supply side. Almost all global nations like the US, Europe, India, Vietnam, Thailand, Korea, etc., suffered shortages in their product supplies, and moreover, lockdowns or shutoffs created a huge reduction in the demands of tourism-based industries (Li et al., 2020).

World is transforming faster and faster due to acceleration of activities, operations and new technologies. SCs are getting more and more complex, highly fragile and vulnerable to disruptions. Despite all the tools and techniques presently known, all the analytical power and smartness with which humans are enriched, systems are failing. Strategies, network designs, mitigation policies and contingency plans are not solving the present challenges. Traditional uncertainty and risk management methods cannot deal with present unpredictable events, hence, a lot of studies in the past tried to fill this gap by introducing concept of resilience and incorporating it into SCs in order to adapt, survive and plan in these unpredictable events. SCR has been a hot topic of research for more than three decades and requires various decisions for the proper configuration of the network and the movement of information, materials, and funds. Resilience is capacity to recuperate quickly from a difficult situation, so, in SC s resilience is the ability to retrieve back to a basic working state or relocate to a new more preferable state after being interrupted due to unfavourable events (Jabbarzadeh et al., 2018; Mikhail et al., 2019). Resilience can be integrated into a SCN, which can further enhance the resistance towards uncertainties and disruptions, additionally allowing quick recoveries back to basic working state. If resilience is built into SCN, it improves the long-term performance (Mikhail et al., 2019).

The aim of this paper is to deliver a systematic literature review and stipulate an in-depth analysis of emerging SCR concepts in peer-reviewed academic journals. The objective is to understand how resilience has been addressed in the literature and to understand the growth of various modelling techniques implemented by the academicians. After careful analysis the literature, a suitable framework is to be developed to add major contribution to this study. Moreover, the purpose of this study is to identify research gaps or future research directions to help the academician to improve the SC and make the network more impervious to risks and disruptions.

The first step in a profound literature review is to establish a clear focus. Hence, we thoroughly address clearly defined research objectives, which must be well specified, informative, and clearly addressed to avoid ambiguity. Hence, our structured review aims to target the following objectives:

1 Define resilience and its role in SC.

2 Identify and review the various strategies used in the past by the academicians and practitioners to understand the impact of resilience in SC, how is it addressed, quantified and incorporated in SC s.

3 Identify various modelling techniques used to integrate resilience in SC.

4 Discuss future research directions to help academicians to explore new research pathways.

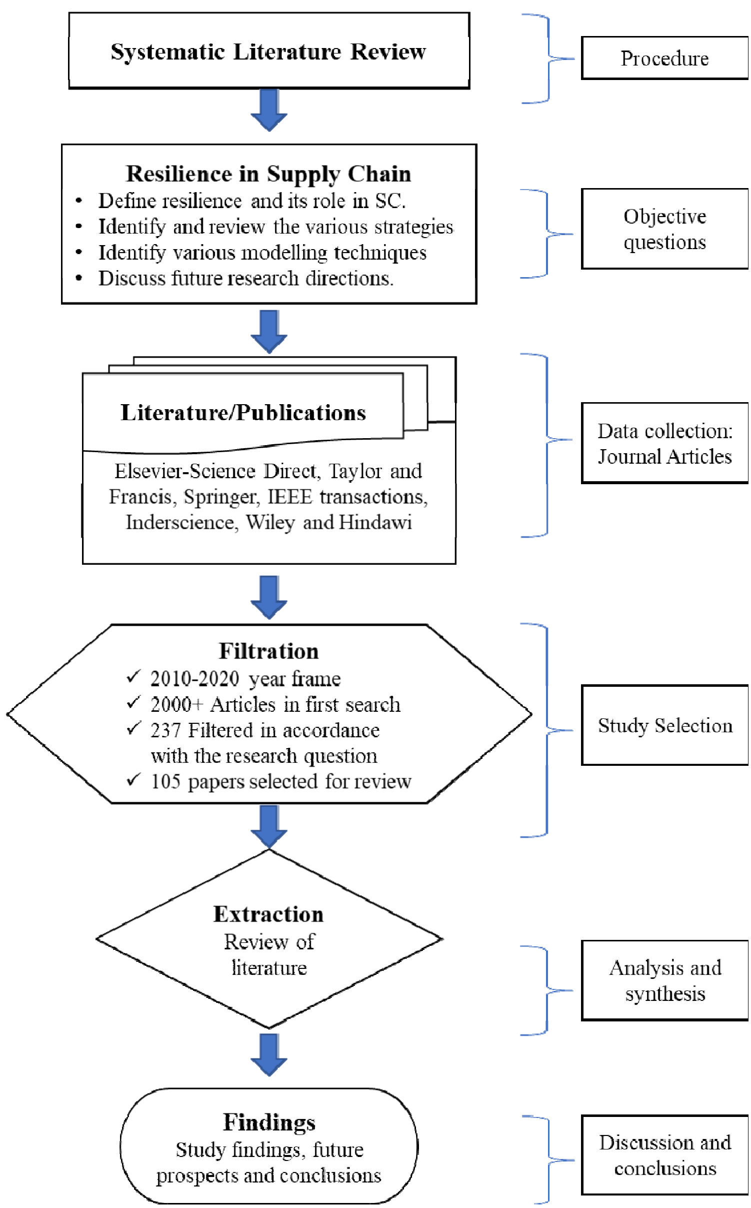
The remaining parts of this paper are organised as follows. In Section 2, methodology of the study with the scope is discussed. In Section 3, previous literature reviews conducted in the past are portrayed. Section 4 contains the study findings comprising of role of resilience and definitions, quantification of resilience, strategies used to increase resilience and the modelling techniques. In Section 5, framework is formulated and presented, illustrating the main contribution of the study. Section 6 depicts the possible future research directions followed by conclusion in Section 7.

2 Methodology and scope

In order to produce a suitable methodology for the review of literature, a systematic literature review technique was employed. The following flow chart (Figure 1) shows the various steps taken into consideration. The literature is taken from the different databases and journals, i.e., Elsevier-Science Direct, Taylor and Francis, Springer, IEEE transactions, Inderscience, Wiley and Hindawi within the time span from 2010 to 2020. The data was collected from the sources by adding 'resilience', 'SC ', 'SC network', 'resilient SC, etc., as keywords in the search and then relevant articles were filtered.

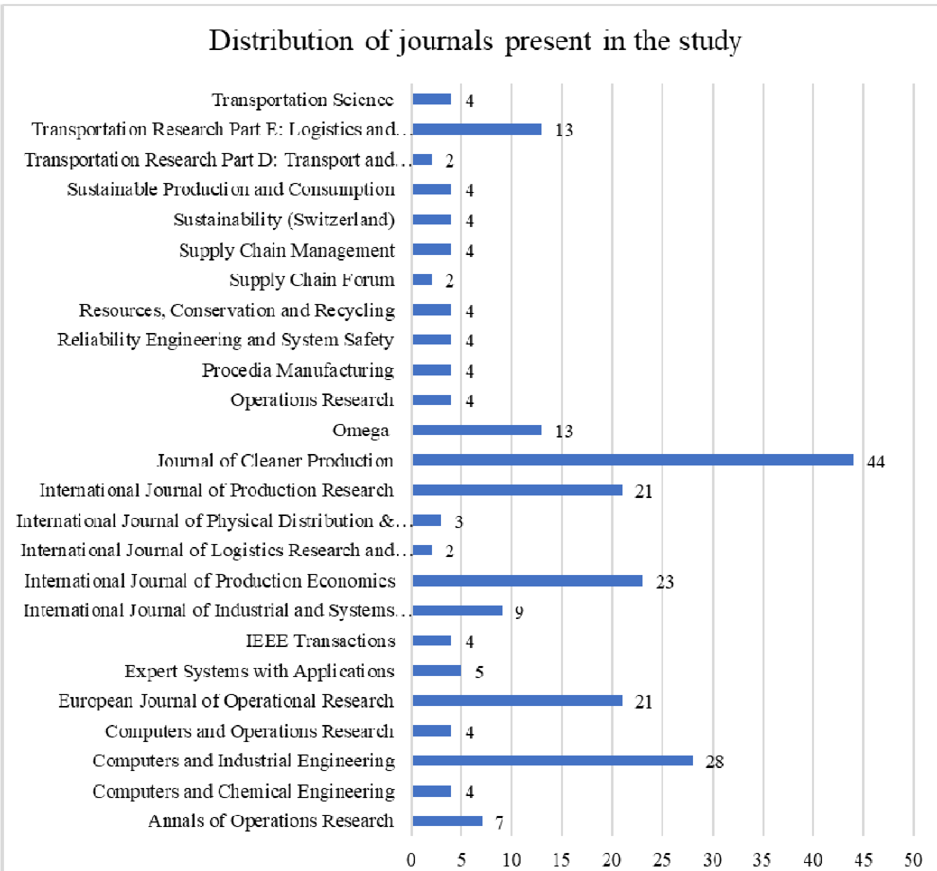
The search results provided a hit of 2,000+ results which are further screened manually, filtering the papers related to the objectives of the study. The distribution of the main papers according to the journals are presented in the Figure 2.

Figure 1 Methodology followed in the study (see online version for colours)



The scope of selected articles considered must include the papers which highlight the need of resilience for the SCN, depicting the role of resilience and principles, incorporating resilience into the model. Figure 3 shows keyword network map resembling the work area according to the number of occurrences of the selected articles, highlighting the information clusters and the coloration between them. It can be observed that none of the study considered in this research is out of the context of scope as no outliers can be visualised from the network made in VOS viewer.

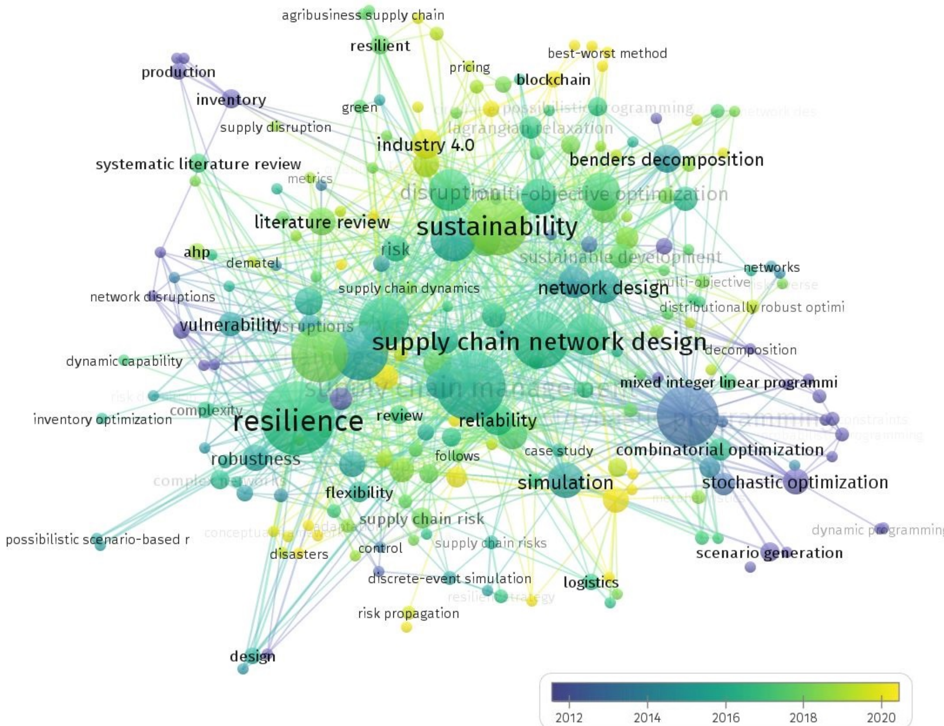
Figure 2 Statistical distribution of the journals (see online version for colours)



3 Previous literature reviews

In the last decade, a lot of academicians have tried to conduct various literature reviews addressing the role of resilience in SC. Some of the literature reviews are presented below.

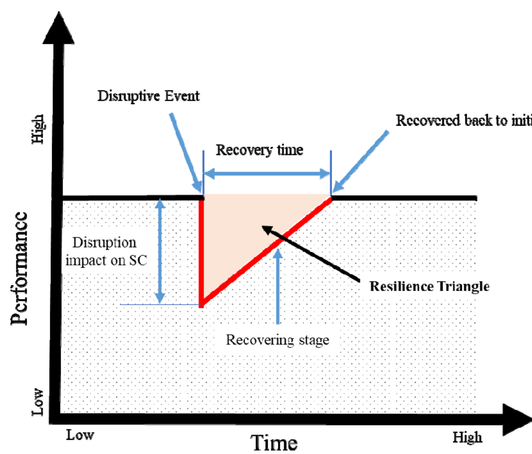
Figure 3 Keyword network map (made in VOS viewer) (see online version for colours)



The key focus of conducting reviews was to identify the link of resilience with SC and understand the role of resilience in SC's. For this many reviewers came up with enablers/inducers/metrics that can enhance/measure resilience. In the work of Pereira et al. (2014), a conducted a systematic literature review and discussed the issues faced by inter-intra organisation in identifying the role of procurement in SC. The authors identified 13 barriers that restrict the performance of a SC and 15 enablers that play an important role in influencing the performance of SC. Moreover, it was found that flexibility is the most discussed enabler and has a significant relationship with all other dimensions. In the research conducted by Hohenstein et al. (2015), a systematic literature review (SLR) was carried out with the centre of attention on SCR and how SCR is defined in the past by the academic community and characterised in different phases. In this research, the authors presented a portfolio of various SCR components in different phases of ex-post disruption and ex-ante disruption with the help of a sand cone model. The authors suggested that robust measures such as inventory management with multiple sourcing technique can be adopted to tackle disruptions and to incorporate resilience. To understand resilience through the aspects of psychology, ecology, economical and managerial insights, Yao and Fabbe-Costes (2018) examined SC network resilience through the prospective of SCM. The authors presented a detailed literature on SCR and how resilience in SC is measured by the different academic community. In this research three capabilities are highlighted, i.e., absorption, responsiveness and capitalisation. SCR adds up complexities in the network decisions, Wang et al. (2016) conducted a research to understand the behaviour of SC network with the aim to build resilience in the network with the help of systematic literature review. In this paper, the concept of SCM and the cost associated with the configuration of network and how resilience is defined in the literature were thoroughly discussed. The authors classified SCN into three types; starlike structure network, tier-based network and the last is based on inter-dependant SC's (a holistic SC). Due to tremendous increase in outsourcing decisions, Gunasekaran et al. (2015) investigated SCR under complexities arose due to global sourcing strategies and presented a framework highlighting the issues related to SC. The authors proposed various components of resilience related to SC such as collaboration, product design, flexibility, speed, visibility, etc. which can enhance SCR.

All the research works discussed above culminate the importance of clarification of resilience in SC s as of immense prominence while dealing on global scale. Yao and Fabbe-Costes (2018) discussed the definition of resilience acknowledging the different fields of psychology and ecology, whereas Wang et al. (2016) discussed in accordance with behavioural sciences. These publications defined the resilience in different fields and thereafter compared them and finishing up with general definition of resilience in SCs.

Figure 4 Performance of SC VS time during and after a disruptive event (see online version for colours)



Due to the importance of defining resilience in SC , this topic will be discussed later in section 4.1 with summary of all the definitions used in the past and the generalised definition. Hohenstein et al. (2015) and Pereira et al. (2014) also focused on defining resilience as a major finding in their research but also defined the issues faced by organisation and various mitigating strategies used by the academicians and practitioners to deal with the problem. Hence, in Section 4.1, the role of resilience in SC will also been discussed to address resilience with the issues faced in SCs.

In most of the past reviews the authors followed qualitative approaches, which further reduce emphases on an important concept of quantification of metrics used to address the resilience. This concept is discussed broadly in this paper in Section 4.2.

In conclusion, it can be specified that SC resilience can hardly be taken as an isolated term, as it is a mix-up of industry and business evolution and needs. To the best of our knowledge none of the study have classified strategies employed to increase resilience and enclosing all the strategies into a single framework which includes the expected costs due to disruption and the parameters considered while designing a network of SC . Moreover, this study has explored SCR by keeping a broad scope, further inclusion of recently published research works.

4 Study findings

4.1 Resilience and its role

Many researchers in the past have integrated the concept of resilience into SC from different perspective as the initial concept of resilience was taken from other fields like psychology, sociology and ecology (Kamalahmadi and Parast, 2016). The first definition of resilience was given by an ecologist, Holling (1973), as a degree of persistence of a system and of their capability to adapt change and handle disturbances while maintaining the same relationship in network. A complete outline of the resilience presented in various studies is shown in Table 1.

The definitions of SCR according to various academicians are presented in Table 2.

Lambert and Knemeyer (2004) concluded that the if resilience is increased in the network, then the SC capability increases and vulnerabilities decreases. Furthermore, as demonstrated in their research, results of different combinations of low-high vulnerabilities with respect to capabilities on the performance of SC can be summarised as shown in Figure 5.

So, wrapping up the definitions from the past, SCR is 'the resistance of a SC to withstand disturbances, anticipate the mitigation strategies and recover back into initial working state after being disrupted'.

The role of resilience is identified as resilience triangle (R-triangle). The triangle shown in Figure 4 is illustrated as R-triangle which is the measure of resilience in a SC (Falasca et al., 2008). The main aim of practitioners is to reduce the area of this triangle as the larger the area of triangle the smaller the resilience of a SC.

Figure 5 Supply chain resilience relationship with risks and vulnerability (see online version for colours)

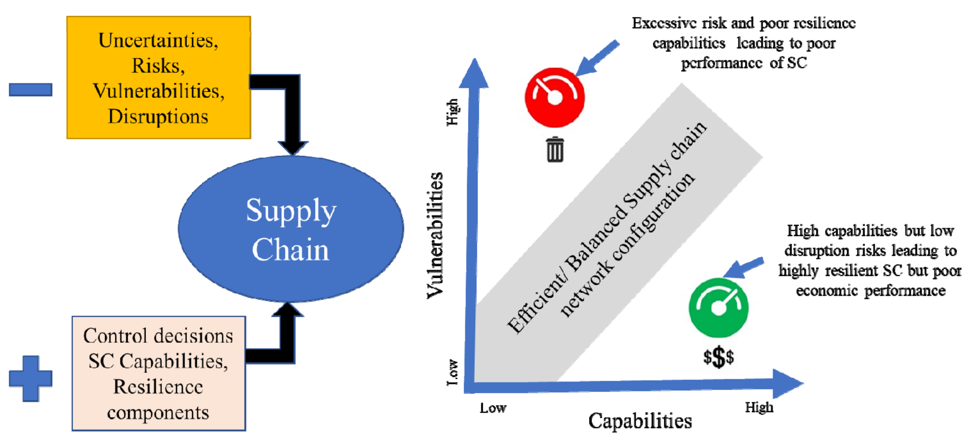


Table 1 Definition of resilience identified by various authors

	Resilience			
Fields	*Resilience in ecosystem science*	*Resilience in psychology and sociology*	*Resilience in economy and management*	*Resilience in supply chain management*
Target impact area	Whole ecosystem; environment, flora and fauna, socio-natural ecosystems	Probabilistic view of human behaviour individual or group	Individual and collective attitudes and behaviours at different levels: individual, organisational, interorganisational system.	Company/industries and supply chain network
Attributes, decision levels	Structure of nature	Child development, post-traumatic stress disorder (PTSD) and mental vulnerability	Macro- meso- micro economics, business processes and operations	Strategic, operational, tactical decisions
Strategies	Resilience and stability through elasticity, amplitude, hysteresis, malleability, and damping	Self-esteem, personal competence, and tenacity, the tolerance of negative impacts, self-control and spirituality	Reactive resilience, proactive resilience crisis /risk management	Anticipation, resistance, absorption, response recovery through elements like robustness, flexibility, visibility, agility etc.
Goals	Restoration of initial equilibrium after being into a disturbance	Self-reconstitution and self-development after disease	Initial/new working state, future resilient to disruptions	Maintain equilibrium in SC, back to initial state or more desired state.

Source: Adapted from Holling (1973), James et al. (1989), Smith (1981), Ponomarov and Holcomb (2009) and Yao and Fabbe-Costes (2018)

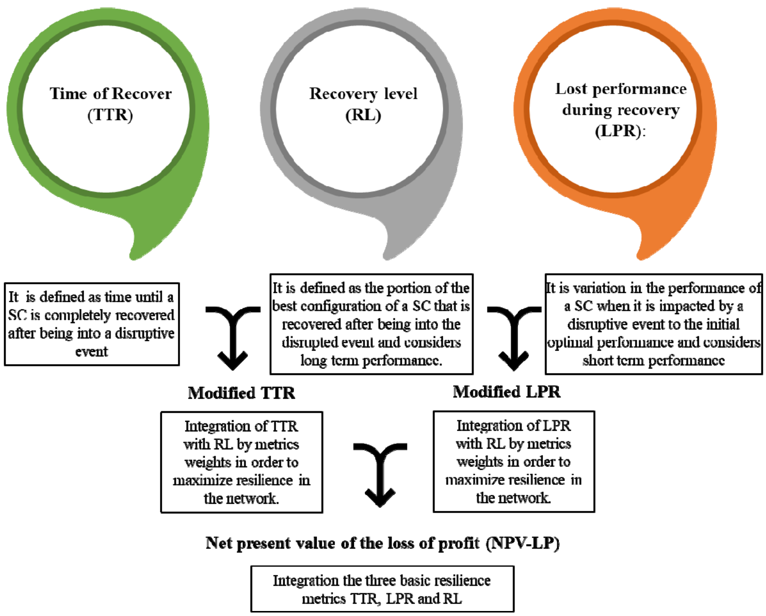
Table 2 Definition of SCR by various authors

Definition of SCR	*Authors*
It is the measure of variation in the system across three 3 dimensions; 'control functions on SCN'; 'the extent to which a SC is capable of self-balancing during disruption' and 'the extent to which the system can develop capacity to learn and adapt'. A SC is resilient when the resilient dimensions/ elements/components fortify the 3 A's, i.e., 'aligned, agile and adaptable.	Sutcliffe et al. (2021)
It is the adaptability of a SC to act in response to disruptive events, react to unforeseen occasions, and then recuperate by continuously maintaining operations at a desired rate.	Bui et al. (2020)
It is an ability of a system or an industry to recover effectively and quickly after being affected by a disruption event, and a resilient SC have the potential to retrieve itself into a more desirable condition.	Fattahi et al. (2020)
An adaptive potential of a SC to prepare and get ready for unpredictable future events and correspondingly retaliate quickly towards disruptions and recuperate back by sustaining continuity of SC processes at the desired level of excellence.	Dixit et al. (2020)
It is a multi-facet concept in the SCM, capability of a firm's SC, to retain back rapidly and effectively from a disruption.	Behzadi et al. (2020)
A resilient SC is efficient enough to minimise the unfavourable effects of disruptions and anticipate significantly to reduce the time required to recover back the normal state or even to a better desired state	López and Ishizaka (2019)
It is a tool capable of diminishing the losses caused by the disruptions	Pashapour et al. (2019)
A resilient SC is able to endure the crisis and able to adjust flexibility to retrieve back to its sustainable state as soon as possible	Dormady et al. (2019)
It is an ability of SCN to resist the impacts of natural disasters and to operate in the face of such disruption and recuperate promptly from its impacts	Woodburn (2019)
It is the inherent and adaptive activities taken to enable SC planners to prevent the potential losses due to disruptions	Sahebjamnia et al. (2018)
The capability of a SC to maintain its functionality during disruption.	Xie et al. (2017)
SCR is an operational proficiency that enables a disturbed or wrecked SC to get repaired itself and become stronger than before.	Brusset and Teller (2017)
It is an ability of a system to absorb changes and to retrieve in a turbulent environment	Chowdhury and Quaddus (2017)
Capability of a SC is to reduce the probability of facing unexpected disturbances, reduce the impression of damage caused by these disturbances by maintaining and react effectively with responsive plans to surpass the disturbance and reinstate the SC to a desired state.	Kamalahmadi and Parast (2016)

The area under the curve shows the performance of a firm which is measured by sales or profit gained by a firm. When a disruptive event occurs as shown in Figure 4, a steep decrease in performance can be observed, if efficient mitigation strategies are applied the SC will start recovering and the time taken by a SC to recover back to the initial stage is coined as time to recover.

It can be seen that optimal configuration of SC lies in the marked area for balanced network. Increase in risks due to the uncertainties lead the SC planners to adopt mitigation strategies and incorporate them to SCN, so that the ability of SC to retrieve back can be increased to adapt the best configuration.

Figure 6 Basic SCR metrics and hybrids (see online version for colours)



Source: Behzadi et al. (2020), Henry et al. (2012), Francis and Bekera (2014) and Nan and Sansavini (2017)

4.2 Quantification/measuring resilience

Mostly, resilience is measured in term of time as there is no reason of conducting resilience when time is not addressed (Ivanov and Sokolov, 2010), as the recovery time, level of recovery and the performance loss for a period of time are the main aspects. Figure 6 shows the 3 basic metrics and their hybrids observed in the literature. These metrics are used in measuring resilience and normalising the resilience into numerical values as indexes, enablers. Moreover, by improving the SC dimensions like flexibility, redundancy, visibility, etc., these metrics can be enhanced.

Recently, Fattahi et al. (2020) introduced a new resilience metric in order to incorporate the two facets of SCR as TTR and LPR. The problem was modelled by a two-stage stochastic program in which first stage decision includes capacity, inventory, locations and allocation of SCN when not in a disruptive stage and second stage decision includes the expected increase in cost when the SC is disrupted. Zahiri et al. (2020)

presented a new resilience metric as net present value of the lost profit. The objective of the study is to maximise the recovery level, expected profit and lost profit during recovery period. The author integrated the three basic resilience metrics TTR, LPR and RL to introduce a new metrics and investigated the importance of resilient backup strategies in SC.

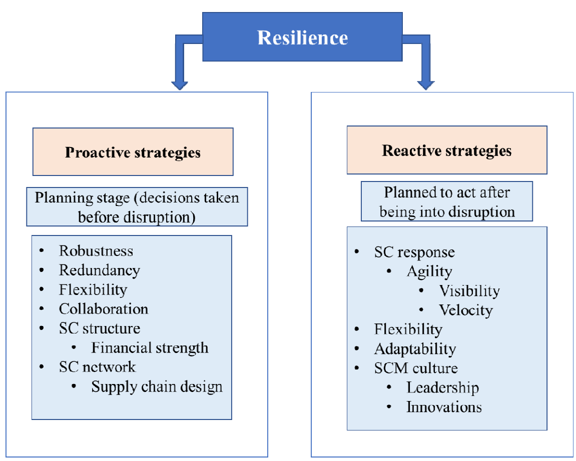
Table 3 Generalised view of approaches used to measure resilience

Equation	*Approach*
$R_{SC} = \left(\frac{1}{n}\right) * R_i$	It is based on linear additive model followed by decision maker to have comparative assessment when the resilience measurement units are similar. In this approach expectation of all the resilience indices (R_i) of an echelon (i) is analysed and best dimensions are selected while designing a SC network.
$R_{SC} = \prod_{i=1}^{n} R_i$	It is based on linear additive multiplication of resilience indices depending upon firm's prospective while dealing with risk's vulnerability. From reliability perspective, this approach is widely used as most of the time measuring units are not constant.
$R_{SC} = F(R_i)$	It is based on additive weight implication in which system resilience is function of resilience index. The resilience index (in network perspective) is determined by the relative characteristics (strength/weakness) of an echelon's link in the network.
$R_{SC} = \prod_{y=1}^{c} R_y$	It is based on constraint approach when a firm has several echelons. The SC resilience index is calculated by considering only critical 'c' subsets of echelons. In this approach, if performance of one echelon fails, then whole SC fails.

Notes: *R_i = Resilience indices, R_y = Resilience indices of a firm, R_{SC} = Resilience of a SC.

Source: Adapted from Barroso et al. (2015)

Figure 7 SCR strategies (see online version for colours)



It is a very tough task to integrate resilience and quantify resilience in a SC. Strategic decisions in the SC are taken in the design phase of network and it is found that aggregation is always a crucial area of methodological controversies in the indexing aspects. From the metrics discussed above; the resilience indexes, indices, inducers, enabler are numerically measured and used by practitioners for further analysis. Various approaches used by decision makers for measuring resilience of a SC comprising of many echelons are shown in subsequent Table 3. Linear method such as addition, multiplication of weights of SC indicators / elements are mostly used for aggregation.

4.3 Strategies

In the literature, most of the studies followed two types of research directions while developing strategies to combat disruptions. One is the proactive, where optimum SC network structures are taken into consideration, in which most of the academicians worked in building proactive strategies to combat the impact of disruptions at the planning stage. The other is reactive, where the optimum control policies are managed and applied when suffering from worst-case scenarios or disruptive events (Mikhail et al., 2019). Wang et al (2016) provided a direction for identification of risks via anticipation strategies that adds vulnerabilities concerns and awareness of the events. It is noted that anticipation strategies act in collaboration to proactive and reactive strategies. The two approaches and their different types of strategy applied to increase resilience are shown in Figure 7.

4.3.1 Robustness

Robustness helps a SC to resist the perturbations by incorporating strategical planning into the model and with an acceptable loss of performance (Behzadi et al., 2018). A lot of work has been done on increasing resilience through robustness.

Strategic planning is required to build robustness in the SC s. SC s basically have two major objectives; one is to minimise costs and the other is to maximise the customer satisfaction. Moreover, in today's world a lot of disruptive events have been encountered, which create uncertainties. Recently, a non-linear stochastic model was proposed by Nezamoddini et al. (2020) for profit maximisation with an improvement technique linked with artificial neural network making SCN robust to handle uncertainties. The authors considered uncertainties of facilities, inventory positioning, operations, demand and proposed a new genetic algorithm to handle these uncertainties. Moreover, they introduced a risk-based optimisation framework to cope up internal and external risks in SC handling while considering short, medium and long-term decisions.

As risks in SC affects the performance and may degrade the profit output, hence, various authors introduced models to formulate a robust SC to help increase resilience. For instance, Dehghani et al. (2018) developed a hybrid robust scenario-based optimisation model and formulated a resilient SC. The model proposed in the research is capable of handling the uncertain parameters and maintaining the level of conservatism in the solutions. The authors established a framework in two phases; firstly, a mathematical approach was used to evaluate the risk and secondly a fuzzy c-mean algorithm was developed to reduce and cluster huge disruptive scenarios. In the conclusion, they found facility allocation is the most powerful resilience strategy to mitigate disruptions.

Due to the complex nature of SC and multiple facet structure comprising of enormous levels/echelons the disruption propagation phenomena is seen causing ripple effects. In order to deal with this effect, Ojha et al. (2018) examined the propagation phenomena of SC risks at each node by the use of Bayesian network theory merged with K2 algorithm to make a robust SC. The author implemented a discrete event simulation model with consideration of factors like fragility, lost sales, service level and total costs. Also, introduced resilience index to capture the behaviour of SC under the impact of disruptions. Another work of Li and Zobel (2020) explored the network resilience in conjunction with risk propagation by introducing a quantitative framework considering a trade-off between long term and short-term impacts of disruption. To measure resilience the authors conducted a detailed analysis of 3 resilience dimension viz robustness, recovery time and a new dimension which covers the other two, i.e., average functionality. For the analysis of demand side and supply side uncertainty a simulation and regression analysis-based methodology is presented.

Thus, a lot of efforts has been made to make robust SCs which can work despite a few unsettling influences with the ability to resist and adapt accordingly to stuns by holding its reliability when disrupting events happen.

4.3.2 Flexibility

Flexibility provides capabilities to a SC for maintaining requisite internal and external conditions when disrupted accordingly though effective responses with the ability to face, resolve and exploit emergencies (Bode et al., 2011).

Some authors used flexibility as a mitigation strategy to increase resilience like Ishfaq (2012), who explored the traditional approaches focusing on efficiency and responsiveness. The research examined the consequences of including multiple modes of transportation to combat disruptions with superior efficiency by increasing flexibility as a resilience measure. The author constructed a dual mixed integer linear program based on shortest path problem and found that alternative routes for transportation under disruption will help increase resilience of SCN.

Simulation techniques have also been used to design flexible network as in the work of Carvalho et al. (2012) in which a 3 echelon SCN was redesigned for resilience using simulation techniques. To measure the performance of the SC, lead time ratio and Total SC cost were evaluated by various scenarios which are further characterised by disruptions. The disruption considered affects the delivery of a material between two SC entities, trigging an interruption in flow. To mitigate these risks, the authors introduced flexibility by selecting of route of transportation and redundancy in network using alternative transportation mode.

To increase flexibility in SC, several attempts have been made by many authors like Rajesh (2020b) who focused on flexibility as key element for building resilience in SC and encapsulated the co-relation between resilience, complexity and flexibility. A framework considering 5 business strategies was used to incorporate flexibility in SC was presented which includes multiple suppliers strategy and flexible supply contracts strategies for supply side; flexible manufacturing processes strategies and postponement strategies for product side; and flexible pricing strategy for responsive pricing. The indicators of flexibility were measured and were identified as co-related strategies and fit into Variance Inflation Factors (VIF). The research is found helpful for the practitioners as it may enable them to select the right strategy under uncertain environment.

From past literature it can be depicted that flexibility in operations can reduce the risks of failures and can lead to superior resilience in SC but the literature still uncovers flexibility strategies which can improve the network such as flexible transportation, flexible game plans, supply base, etc.

4.3.3 Redundancy

Redundancy is generally having excess capacity throughout the entire SC to maintain functions and prevent a slowdown or failure of facilities in the instance of an unforeseen disruption. It enriches the proficiency of a SC by providing extra resources which include utilisation of multiple suppliers and slack resources while suffering from disruption which acts as 'shock absorbers' (Bode et al., 2011).

It is the most employed resilience strategy by the academicians and it can be achieved by managing properly the strategic decisions. It has been found in literature that accurately managing sourcing decision help to achieve redundancy strategy. Ivanov (2017b) presented a simulation-based model focusing on increasing redundancy by considering sourcing strategies as potential drivers of resilience in SC. This research was first to analyse single vs. dual sourcing strategies considering capacity disruption and big data with perturbed demand patterns. The author used two approaches while designing the discrete-event model; proactive as prediction of execution plan and reactive as adjustment of SC operations, and formulated scenarios to run various models under various situations.

In another work, multi-sourcing policy as a redundancy strategy was incorporated to deal with uncertainty. Bottani et al. (2019) modelled a bi-objective mixed integer program to develop a resilient SC of demand and supply. The authors used Ant colony optimisation as a metaheuristic approach to maximise total profit (TP) and minimise the total lead time (TLT) so as to increase resilience in SC. The proposed resilient SCN is able to self-adapt with the changes and self-coordinate when facing disruptive events.

However, there is a lack of research works in literature on increasing flexibility with redundancy together to maintain a balance of these two dimensions in a resilient SC.

4.3.4 Agility

Agility is an ability of a SC to quickly respond to deviations by adapting its initial steady SCN configuration (Wieland and Wallenburg, 2013). The agility is a broad strategy which leads to the following two subsets:

4.3.4.1 Visibility

Visibility is the proficiency of a SC which helps managers to detect early warnings due to turbulence/ disruption in a SC and give managers an opportunity to see through entire SC and react quickly (Blackhurst et al., 2011).

It portrays the need for simple structures, measures to recognise requirements and interruptions instantaneously to have the ability to rectify changes in an efficacious way. Visibility is one of the most significant factor that affects SCR. Azadeh et al. (2014) designed a SC with a simulation-based model and identified various resilience factors and their concurrent effects on SC. A simulation framework was established to present 13 different scenarios mapped with associated resilience factor. The authors focused on the disruptions based on delays in the transportation system.

4.3.4.2 Velocity

Velocity is the speed or rate at which mitigation strategies of a SC act in response to disruptions while advertising positive changes (Jüttner and Maklan, 2011).

The three prime foundations for improving SC performance are optimisation of valueless time reduction, rationalisation of the operations and reduced inbound time. Hence, time management is one of the eminent resilience features that practitioners must focus to improve performance. SCR dimensions such as velocity and agility were addressed and incorporated in methodology by many publications. Kristianto et al. (2014) designed a SCN with a two-stage program with first stage as inventory allocation and total costs as second. The authors used a Bender's decomposition algorithm to solve the model with higher efficiency of computing. Using the concepts of Pareto optimality, the labelling algorithm is used to find the shortest path.

It was found that increase in agility, visibility, information sharing, trust, technological capability, strongly increases SCR. Jain et al. (2017) conducted an empirical analysis to construct an integrated framework and a hierarchy-based model to depict the relationship between the SC resilience enablers. The authors classified 13 key enablers by structural prospective analysis and a comparative analysis was done to explore the relationship based on coefficient of similarity. Moreover, statistical analysis was also conducted to see the co-relation, interaction and level of significance of the resilience enablers.

Recently, mitigation strategies like visibility and velocity were implemented for increasing agility to combat disruption and were further investigated to indicate significant improvements when blockchain technology was incorporated. Lohmer et al. (2020) probed the impact of blockchain technology on SCR by using an agent-based simulation model under consideration of disruptions. The authors used different potential applications of block chain technologies on SC and explored the managerial insights of this technology on resilience of a firm.

It is observed that flexibility necessitates agility to react quickly to uncertain disruptive events and fuzzy environments. Moreover, improving redundant stocks and management of suppliers play an important role in increasing agility. The current literature lacks integrated studies which includes agility, flexibility, redundancy together.

4.3.5 Collaboration

Collaboration is an establishment of relation between two or more autonomous firms to share vital information and execute SC operation jointly (Kamalahmadi and Parast, 2016).

Lohmer et al. (2020) introduced factors like collaboration through smart contracts to incorporate resilience in the network.

Some authors utilised a dynamic approach and found that through collaboration and SC integration, flexibility can be increased which plays a crucial role in resilience. Brusset and Teller (2017) defined the role of dynamic and organisational capabilities to analyse a trade-off between lower order capabilities and resilience of a firm.

Levalle and Nof (2015) explored a collaborative control theory (CCT) approach to develop a resilient SC. The authors characterised resilience under the influence of disruption due to supply network in the agents which can take place randomly. By applying this CCT approach, it was found that the new proposed team collaboration is more resilient to disrupting fluctuations.

Collaboration helps to anticipate the disruption and manage uncertainties in the network very efficiently. A lot of works is published under this segment but still application of new disruptive information sharing technologies have not been explored so far to increase resilience in the firm.

4.3.6 Other strategies

4.3.6.1 SC structure

Complexities in handling related to SC infrastructure, geographical locations, inventory management, service, SC financial costs, integration of different components are characterised under this dimension (Rajesh, 2020c; Bode et al., 2011; Jain et al., 2017; Lohmer et al., 2020; Wu et al., 2013; Nezamoddini et al., 2020).

Recently, Rajesh (2020a) integrated multi-criteria decision aid with artificial intelligence as a new capability to overcome structural complexities. The author used a grey based decision support model to acknowledge resilience in SC by incorporating 21 strategies to mitigate 12 major risks. An analytical network process (ANP) with the combination of grey prediction mode has been presented to quantity attributes of resilience.

A simulation-based approach was used by Dixit and Tiwari (2020) and CVaR was used to capture worst- case performance of SC. In this research, SCR was assessed based on network structural parameters which significantly determine the after-effects of a disruptive event. This research would guide the practitioners to incorporate resilience in the network as CVaR is found to be responsive and easy-to-use and handles risks.

4.3.6.2 SC network

Network characteristics of a SC such as node density, centrality, connectivity, and network size can be improved to increase resilience (Dixit et al., 2020). Hosseini and Ivanov (2019) explicitly included ripple effect in SC of a manufacturer to fuse resilience at disruption stage as well as at recovery stage. The authors quantified resilience in a multi-tier SCN by a new metric based on Bayesian network and identified disruption of critical suppliers in the network by plotting a graph as the ratio of recoverability to vulnerability.

4.3.6.3 SCM culture

It includes employees training and education, likewise total quality management (TQM) in which the various risk mitigation strategies are imparted for establishment of leadership skills and new innovation skills within people for long term survival of a SC in the market (Blackhurst et al., 2011). It helps to improve reactive phase of SC when disrupted.

Bode and Wagner (2015) examined SC complexities and the structural drivers under the shadow of supply side disruptions. The authors classified SC complexity using a framework of organisational theory which considered three aspects, i.e., horizontal (suppliers), vertical (tiers) and spatial (links).

Table 4 Methodologies identified in the study

Methodologies	*Authors*
	Empirical studies
Based on empirical observations, experience and surveys.	(Rajesh, 2020c, 2020a; Behzadi et al., 2020; Singh et al., 2020; Fang and Zio, 2019; Hosseini and Ivanov, 2019; Ravulakollu et al., 2018; Saghafian and Van Oyen, 2016; Nan and Sansavini, 2017; Chen et al., 2017; Jain et al., 2017; Rajesh, 2016; Aqlan and Lam, 2016; Cardoso et al., 2015; Scholten and Schilder, 2015; Raj et al., 2015; Kim et al., 2015; Francis and Bekera, 2014; Azadeh et al., 2014; Carvalho et al., 2012)
	Simulation based studies
Exact method	(Chen et al., 2017)
Heuristics	(Azad et al., 2014)
Sample average approximation (SAA)	(Snoeck et al., 2019)
Discrete-event model (DEM)	(Macdonald et al., 2018; Ojha et al., 2018; Ivanov, 2017a)
Ant colony	(Bottani et al., 2019)
Genetic Algorithm	(Nezamoddini et al., 2020)
	Mathematical models
Stochastic programming	(Nezamoddini et al., 2020; Dixit et al., 2020; Snoeck et al., 2019; Fattahi et al., 2020; Gao et al., 2019; Govindan and Fattahi, 2017; Behzadi et al., 2017; Gülpınar and Çanakoğlu, 2017; Kelle et al., 2014; Kristianto et al., 2014; Chen and Miller-Hooks, 2012)
Mixed integer linear programming	(Bottani et al., 2019; Azad and Hassini, 2019; Sawik, 2017; Adenso-Díaz et al., 2018; Khalili et al., 2017; Sadghiani et al., 2015; Sawik, 2013; Azad et al., 2013; Qin et al., 2013; Losada et al., 2012; Ishfaq, 2012; Huang et al., 2010)
Mixed integer non-linear programming	(Wang et al., 2016; Poudel et al., 2016)
Robust optimisation	(Dehghani et al., 2018; Gülpınar and Çanakoğlu, 2017; Sadghiani et al., 2015; Shabbir et al., 2021; Lotfi et al., 2021; Mehrjerdi and Shafiee, 2021)
Fuzzy programming	(Dehghani et al., 2018; Pavlov et al., 2018; Talaei et al., 2016; Tavakkoli-Moghaddam et al., 2015; Zhang et al., 2020)
Goal programming	(Aqlan and Lam, 2016)
Monte Carlo simulation	(Chen and Miller-Hooks, 2012)
Dynamic programming	(Day, 2014)
Pareto optimality	(Gong et al., 2014; Kristianto et al., 2014)
Bender's decomposition	(Azad and Hassini, 2019; Poudel et al., 2016; Kristianto et al., 2014; Azad et al., 2013; Chen and Miller-Hooks, 2012)
CVaR	(Dixit et al., 2020; Snoeck et al., 2019; Gülpınar and Çanakoğlu, 2017; Khalili et al., 2017; Sawik, 2013; Huang et al., 2010)
Grey prediction model	(Rajesh, 2020a)
Bayesian network	(Hosseini and Ivanov, 2019; Ojha et al., 2018)
Machine learning – neural networks	(Nezamoddini et al., 2020; Aamer et al., 2020; Akbari and Do, 2021)
Machine learning for optimisation	(Bengio et al., 2021; Abbasi et al., 2020; Kurtz and Bah, 2020; Chang et al., 2007)

Table 4 Methodologies identified in the study

Methodologies	*Authors*
Theory based models	
Contingency theory	(Boone et al., 2013)
Control theory	(Levalle and Nof, 2015)
Structure theory	(Ivanov et al., 2014)
Organisational theory	(Bode and Wagner, 2015)
Statistical Theories	(Brandon-Jones et al., 2015; Blackhurst et al., 2011)
Graph Theory	(Hosseini and Ivanov, 2019; Kim et al., 2015; Soni et al., 2014)
Structural dynamics	(Chowdhury and Quaddus, 2017; Ivanov and Sokolov, 2013)
Miscellaneous	
Quality function deployment	(Ramezankhani et al., 2018; Chowdhury and Quaddus, 2015)
Analytical Hierarchy process (AHP)	(Chowdhury and Quaddus, 2015)
Analytical network process (ANP)	(Rajesh, 2020a)
Variance-based structural equation modelling (VBSEM)	(Brusset and Teller, 2017)
Big-data analytics	(Seyedan and Mafakheri, 2020)
Blockchain technologies	(Lohmer et al., 2020; Kamble et al., 2021; Esmaeilian et al., 2020; Saurabh and Dey, 2021; Sundarakani et al., 2021; Dubey et al., 2020)

4.3.7 Integrated strategies

Many strategies are intertwined to each other and acts together to increase resilience. Like in the study of Scholten and Schilder (2015), the authors explored the role of collaboration in enhancing resilience in SC by an empirical model and found that the resilience enablers; i.e., visibility, flexibility and velocity, can be improved by collaboration.

Ravulakollu et al. (2018) constructed a risk-based framework to measure resilience in SC under the influence of domino effect. Various risks, potential indicators and counter measuring strategies were explored and representation of these were done by bow-tie framework. The framework includes 4 phases; i.e., identification (collection of data), analysis (selection of performance indicators), evaluation (assessment of robustness, agility and building of resilience triangle) and decision making (selection of countermeasure strategies); which intertwined to each other.

Brandon-Jones et al. (2015) explored the relationship between the complexities of SC and frequency of disruptions. This research highlighted visibility and stack resources (emergency stock or extra capacity) as key performers of SCR. The authors postulated 8 hypotheses to represent four dimensions of resilience and to test the hypothesis for relation, co-relation with each other.

All these strategies are important for a firm to adapt and achieve SCR. After the surge of plentiful value adding processes and globalisation of industry, numerous challenges are confronted in SC operations and this is the root cause of vulnerabilities in SC. It can be depicted in the literature that strategies like collaboration should be adopted by the firms to initiate proper understanding of the risk between the members of the SC by building inter-firm trust and information sharing. Various academician worked on analysing the factors which enhance the resilience but application of these factors is very scarce. Empirical studies on these strategies are also not been explored which can become a potential research area of future studies.

4.4 Modelling techniques in supply chain

SC models dealing with resilience are completely new and require a lot of effort from the academic community. With the increase in research as well as knowledge, new models are adding a particular relevance to the resilience in SC.

From Table 4, it can be seen that empirical studies contribute most in the literature with the focus to evaluate and synthesise the various approaches to the concept of resilience in the SC. Some authors proposed the role of collaboration in enhancing resilience in SC by an empirical model and found that the resilience enablers; i.e., visibility, flexibility and velocity can be improved by collaboration (Scholten and Schilder, 2015).

In case of mathematical models, stochastic programming as a modelling tool has been used by various academicians, followed by mixed- integer linear programming. Snoeck et al. (2019) developed a two-stage stochastic program to model mitigation strategies for a SCN with high risks considering disruption costs and presented a trade-off between various costs and SC risks by exploiting distinction between business-as-usual periods and disruption period. CVaR is further used to increase robustness and sample average approximation was used as solution technique. Gao et al. (2019) developed a robust mixed integer quadratic 2-stage stochastic program and designed a new novel approach to measure resilience and capture the cascading effect of disruptions by integrating probabilistic assessment of risks with a risk-exposure index. The authors used a conic copositive program to analyse the lost sales experienced during disruptions. For quantification of risks due to disruption, a worst-case CVaR was used.

There is a significant increase in the models opting robust optimisation to deal with resilience and multi objective decision-making problems. Recently, Fang and Zio (2019) introduced a novel resilient structure with an adaptive robust optimisation model for the system network's improvement against natural hazards. In this research, the authors referred lost performance during recovery as the ratio of the cumulative performance at the time of disruption to the cumulative performance when not in a disruptive stage of system network during the recovery periods. This research fills the gap between the troubles of accurately predicting the disaster information in the classical probability theories and the built resilience while the SC is affected by worst-case scenarios.

Models with fuzzy programming are capable of handling cognitive uncertainties of decision making in realistic working environments. Many hybrid models were used to tackle uncertainties like the one proposed by Dehghani et al. (2018), which developed a hybrid robust-scenario based optimisation model and formulated a resilient SC. The proposed model was capable of handling the uncertain parameters and maintaining the level of conservatism in the solutions. The authors established a framework in two phases; firstly, a mathematical approach was used to evaluate the risk and secondly a fuzzy c-mean algorithm was developed to reduce and cluster huge disruptive scenarios. In the conclusion, they found facility allocation is the most powerful resilience strategy to mitigate disruptions.

Simulation based models have been a hot topic to work on in recent years., A lot of studies are developing simulation-based models to combat with large scale problems and find the nearby optimal solutions. Heuristics and meta-heuristics methods are used barely in the literature. Recently, Singh et al. (2020) designed a simulation model for a network of public distribution system to make a resilient SC. The authors focused on COVID-19 pandemic as a serious disruption affecting good and healthcare industry throughout the globe. They considered 3 scenarios as normal operation, during shut down of facility and backup facility to derive a resilient measure.

Theory based models were used to evaluate the co-relations between the different resilience strategies and providing conceptual frameworks for the practitioners. In the study of Chowdhury and Quaddus (2017), statistical interferences were used and hypotheses testing was performed to test the level of significance of various SC dimensions. They authors raised an issue of increased susceptibility in SC due to increase in disruptive events and identified 12 dimensions of SC and further characterised into proactive, reactive capabilities and SC design quality.

New technologies like block chain have also been used to deal with resilience as in the study of Lohmer et al. (2020) in which the impact of blockchain technology on SCR was examined by using an agent-based simulation model under consideration of disruptions. The authors used different potential applications of block chain technology on SC and explored the managerial insights of this technology on resilience of a firm.

There is a huge hype in development of new prediction models and adaptation of SC disruptions management practices with the use of prediction algorithms, big data analytics (Seyedan and Mafakheri, 2020) and machine learning. They were found very efficient for demand forecasting/prediction. Bayesian networks for building resilience are also growing area. They can be used to handle impact of uncertain/unforeseen events (Hosseini and Ivanov, 2020).

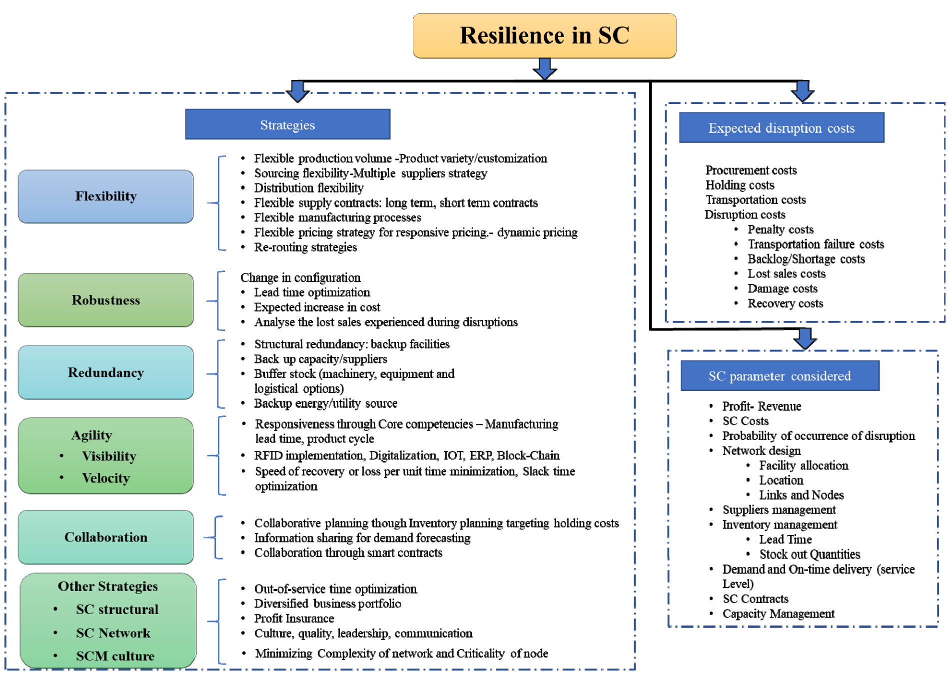
5 Supply chain resilience framework

Frameworks have been extensively employed by various academicians while reviewing literature to help readers and practitioners to understand the research areas and provide an overview of the characterisation process (Aldrighetti et al., 2021).

Recently, Singh et al. (2019) defined resilience indicators used by the academic community in the past by reviewing 55 articles during the time span from 2000 to 2018. The reviewers, after careful analysis of various journals, prepared SCR framework acknowledging 17 indicators and provided a framework incorporating all these SCR elements. The framework includes 3 phases, i.e., anticipation, resistance and response and recovery.

Many literature reviews (discussed in Section 3) have proposed frameworks with the perspective to provide a comprehensive knowledge of resilience in SC but none of them have provided a framework in terms of classified strategies employed to increase resilience. So, in this study we provide a framework comprising of the strategies employed by the academic community to increase resilience in SC as shown in Figure 8. Moreover, the framework also includes various expected disruption costs identified in the literature and the parameters considered while designing a network of SC.

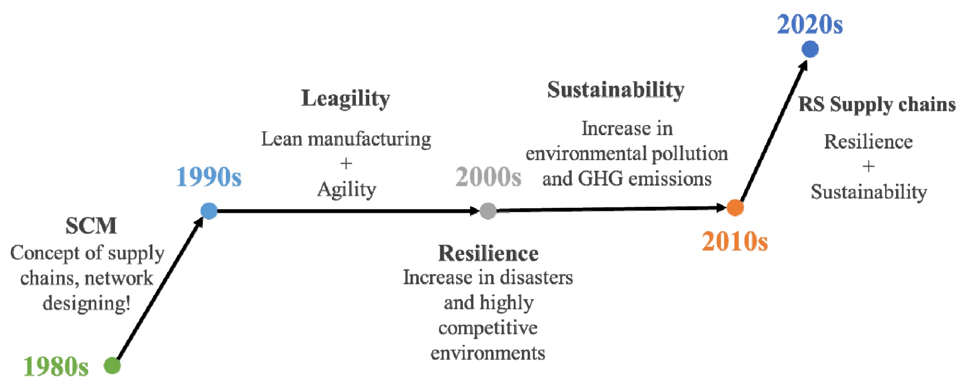
Figure 8 Framework of supply chain resilience (see online version for colours)



The proposed framework stipulates an insight into various classified strategies for increasing resilience and how they are employed. For an instance, to increase resilience by redundancy strategy; backup facilities, suppliers, buffer stock can be considered as a mitigation strategy.

For expected disruptive cost and SC parameters; the mentioned costs were identified in the literature which are introduced while planning the proactive investments. For example, a disruptive event can lead to change in predefined SC parameters like, supply/demand quantities, lead time, etc., resulting in penalties of transportation failure, procurement costs, extra holding costs, backlog costs for not satisfying the demand.

Figure 9 Timeline of SCS (see online version for colours)



6 Future research directions

A significant increase in the complexity of the SCs led to increase of competition between firms and exposure to risks. The timeline of the trends and evolution of research works done recently and, in the past, can be visualised by Figure 9.

Various research directions and paths for future research, analysed by reviewing literature are elaborated in the subsequent paragraphs.

6.1 SC strategies

In the literature, SC dimensions such as redundancy, flexibility, agility, visibility, velocity, collaboration, etc., were found as key enablers for increasing resilience and future works can be done on these enablers to have shorter recovery time when being into a disruptive event and to have a better SC performance.

It is observed that most of the industries that managed well were already building redundancy into their networks or were more aware of their bottlenecks. Since 90s, disruptive events have significantly increased mostly because of climate change and frequency and severity and concurrency. The COVID pandemic has made firms realised that there is a need to create some redundancies in different geographical areas. Excess capacity/inventory leads to increase in costs, hence, there is always a scope for superior optimisation tools to achieve optimality. Future works can be carried out to explore new redundancy elements to improve resilience metrics and co-relate with other enablers to find trade-off between them. A research can be conducted on introducing a series of metrics that can increase redundancy by better optimisation of multiple sites, multiple suppliers and substantial reduction in inventory, holding costs, inventory turns, supply base rationalisation and reducing the number of suppliers. Flexible logistics solutions can also be developed to build low-risk redundancy SCN, which can react quickly when a disruption occurs, and modernise the SC to manage new operations and workflow.

Moreover, a multi-objective model can be introduced to examine flexibility and decision efficiency together as none of the study have considered these together. A detailed study can be carried out with consideration of different industrial domains as well as micro-analysis to cope up operational decision's flexibility by simulation-based models.

A research can also be conducted to analyse the trade-off between the different dimensions. A suitable gap is observed in increasing flexibility or either by increasing redundancy but not with taking both the aspects together to maintain a balance of these two dimensions in a resilient SC. Incorporate sourcing strategies while modelling a multi-facet decision in more detailed scenarios can deal with more flexibility.

Financial costs and taxation have not been studied jointly while focusing on resilience. Hence, incorporating taxation policies in the network in dealing with cost reduction and resilience enhancement are needed.

Increasing robustness is always a vital enabler to corporate resilience in the SCs. Pricing strategies, quality, SC costs, dependability can be fused to make a robust resilient SC as these aspects have not been explored together in the past. Additionally, robustness and survivability can be handled together to build resilience and increase robustness in the SC.

Customer allocation decisions, capacity flexibility, SC contracts, backup-sourcing decisions, production planning, responsive pricing and facility fortification decisions were some of the mitigation SCR strategies used in the past. Hence, further works can be done to analyse a better strategy by having a comparative study of various mitigation strategies as they were found very important in designing resilient SCs.

It is observed that value of information is very important, and proper and accurate flow of information can significantly reduce bullwhip effect. At proactive as well as reactive stages, an anticipation control and adaptation, real-time monitoring, intelligence and self-assessment of SC by the use of digital technologies like big data analytics, RFID, internet of things (IoT) and ERP systems can increase resilience by detecting the information loss or detection of disruptions (visibility), demand prediction and forecasting. They can be used to reduce dependency of demand based on pricing decisions and customer sensitivity due to delivery lead time uncertainty.

An interdisciplinary approach such as SC collaboration, digital technologies in SC, and control theory can be potential works to reduce response time. Research can be done on estimating the trade-off of various SC costs with Bayesian networks and the use of digital technology.

Recently, works on blockchain technology have increased a lot and a huge potential is present to increase transparency, visibility and securities in SC by the use of blockchain technologies. A new resilience strategy can be formed by use of blockchain technology to tackle resilience elements such as visibility, transparency, security and traceability and can be incorporated into a multi-objective model. Hence, investigating the role of block chain technology in improving SCR by uncovering potential barriers is a potential research direction.

6.2 Measuring disruption probabilities, risk exploration and uncertainty handling

Disruption risks are having very low chance of occurring but have capability of damaging the whole network of SC, and hence, there is an important need to measure these risks. These risks are dynamic in nature as the parameters used for quantifying these risks change with time. Uncertainties due to natural disasters, political crises, financial crises, human-created disasters, pandemic are disruption causing factors which are analysed in most research works by estimating probability of occurrence. Discrete scenarios generation or probability distribution were used in the literature, which were further normalised through different modelling approaches like Fuzzy logics, stochastic programming, robust optimisation, analytical hierarchy process, mixed-integer programming with multiple objectives, heuristics, etc. In order to compete better, prediction accuracy and information acquisition are required which can be an imperative research direction. Furthermore, a future research can be carried out:

- To handle uncertain disruption probabilities of events occurring in SC network as many studies were limited to known disruption probabilities and investigate these probabilities to increase network immunity for long term sustainability.
- To capture individual facility disruption and investigate local disruptions in the network with inclusion of multiple factors like transportation loading activities and identify new potential threats that affect a company's SC as well as new capability-resilience enablers to highlight the role of higher order capabilities in SCR.
- To handle SC complexities and challenges of incorporating dynamic lead time or dissimilar disruption probabilities of failure by imposing a dynamic modelling approach as in the literature many studies have used static lead time. As the disruptions are dynamic in nature, aspects like better anticipation, estimation of the risks involved in the SC and defensive approaches for proactive and reactive decisions must be quantified in terms of resilience metrics.
- To identify information patterns of ripple effects to create recovery policies and to make new coordinated contingency strategy. Regulation and coordination of SCN are crucial aspects as world is prone to disruptive failures and by investing on these aspects; operations and recovery process can be improved significantly.
- To identify the new potential parameters and evaluate the impact performance of these parameters based on financial and operational performance of a SC with consideration of disruption propagation, degradation of capacity and recovery policies.

Keeping COVID-9 as a focus, modelling SCN taking probability of disruption as poisson distribution as recently considered in the study of Shahed et al. (2021), can be taken into account while designing proactive strategies can be a significant research direction.

Moreover, uncertainty demand handling by Chebyshev variant goal programming as recently applied by Wang et al. (2021) can be implemented for new objectives.

6.3 Optimisation and solution techniques

Cost minimisation and profit maximisation are the most used objectives while designing SC, and because of dynamic nature of uncertainty the modelling of SC is very tough task. Modelling for real life conditions including uncertainties in operations/disruption risks, optimisation of objectives and time efficient resilient metrics makes the problem NP-hard. Future studies can be done on handling large scale problem in a more compact way and handling large complexities.

For these problems many authors have tried to develop hybrid techniques i.e., by combination of mathematical models or simulation with meta-heuristics. New hybrid techniques/algorithms to handle uncertainties and make SC resilient, robust and reliable are nowadays trending topics of research.

A future research can be carried out:

- To derive meta-heuristic models for large size problems or scenario-based programming approach to deal with disruption scenarios and handle real world complexities. Besides, incorporate multiple risk factors into the network with focus on reducing financial costs.
- To capture ripple effect visualisation by hybrid techniques or simulation models and increase agility and visibility in SC for better resilience of network.
- To handle more disruptive scenarios with more in-depth analysis so that resilience metrics can be incorporated into the objective function in order to make SC resilient.
- To develop simulation-based models to improve strategic fit and incorporate SC strategies such as distribution and sourcing.

Moreover, using of machine learning and artificial intelligence as a new prominent tool for optimisation and prediction models in the realistic environment can add to new improvements and huge scope for academicians.

6.4 Resilience and sustainability

Resilience and sustainability both are vital elements while designing a SC network. This research direction is possible by integrating the elements of both resilience and sustainability like leagile SC, green SC, robust SC, flexible SC, environment friendly SC and collaborative SC. These elements can be merged into a unified framework to find out the trade-off between all those integrated elements.

Related to SCND, no past research works has taken disruption probability as an uncertain parameter for the design of a network. Most of the SCND research papers considering resilience and sustainability have used discrete probabilities of disruption which is easy for computing but not worthy for realistic environment. Moreover, probabilistic programming approach for this concept has not been explored in the past and can be an interesting topic to work on. Works can also be done on developing a chance constraint fuzzy programming model to tackle uncertainties for improving these two dimensions.

7 Conclusions

The goal of this paper is twofold: the first is to deliver a literature review on recent works related to incorporating resilience in SCs via various methodologies and the second is to stipulate a framework of classification of different applicable resilience strategies used by academic community to deal with uncertainties and disruptions. The procedure followed is systematic literature review and the focuses are emerging topics and gaining huge momentum because of the increase trends of disruptive events recently. Considering more than 100 papers in the time frame of 2010–2020 with inclusion of some recent studies of 2021, the study covered a broad spectrum providing an evolution of concept of resilience throughout the decade and highlighting various potential areas where future works can be focused on. Moreover, the contribution of this study is to summarise different strategies used in the past into a single framework with inclusion of various costs due to disruption and various parameters of SC considered.

This research started with exploring the definition and role of SCR, then followed by various approaches used by the different academicians to address resilience. In this regard, our findings illustrate that most academicians have focused on reactive aspects of SC to uncertain disturbances in their definitions, while preparedness and growth have been less included in their views. The generalised definition was presented with addition to introduction of quantitative metrics used to address the resilience.

By employing a comprehensive approach to review the literature, several strategies were enlisted which facilitates incorporation of resilience in SC. Each strategy was briefly discussed to uncover the basic ideology of its application. We found that proactive strategies such as redundancy, flexibility and collaboration are the key enablers for increasing resilience, although a few works are carried on building reactive strategies such agility, visibility, velocity, adaptability in SC which are found much prominent while dealing with uncertainties. In this regard, improvement or development of new sourcing strategies can be considered as a significant contribution to SCR. Our findings suggest that a huge research gap is observed in analysing flexibility with respect to redundancy in SC with determination of which strategy could be emphasised first.

Over the decade, disruptive events throughout the world have significantly increased with inclusion of firm's internal and external risks. This led to development of a novel framework, comprising of various strategies, cost components and parameters which can meet the current and future challenges. The proposed framework has huge potential for delivering management insights. Our framework provides an excellent managerial guideline to build resilience in SC s. The strategies included in the framework can be used to increase the organisational resilience in order to apply practices to reinforce resiliency and to address key SCR areas for improvement.

It can be specified that implementation of discussed resilience practices can be one effective and significant strategy for firms to create competitive advantage. Moreover, the relationship between the role of resilience and uncertain, disruptive risk events was acknowledged. A prominent set of challenges and future works was presented to guide the academicians on new ideas to explore the potential of such an interesting field. Moreover, works can also be done on identifying the new strategies and their combined effect and conducting targeted review on a narrow spectrum to guide academician on specific methodology.

Last but not least, a strong need for the improvement of strategic decision making was identified with development of solving tools so as to stipulate better and reliable information to decision makers. Throughout this review, it can be seen that SCR is a field of study that creates a positive impression on industries, demanding more thorough research works to meet the recognised challenges.

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