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## Coping with uncertainties via resilient supply chain framework

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**Abstract:** Supply chain resilience (SCR) is a promising area budding from the emergent admiration to minimise supply chain disruptions by practitioners and by researchers across the globe. To inflate monetary earnings, many organisations execute initiatives such as comprehensive reach of supply chains, amplified outsourcing, shorter product life cycles, reduced buffers and centralisation. These initiatives are effective in stable surroundings, but they could make supply chain vulnerable to various types of disruptions. The main thrust of this research is, to propose a conceptual model for endowing deeper knowledge of how uncertainty from suppliers, customers and existing supply chain structure amplifies vulnerability and consequently increases supply chain risk exposure. In accordance with fitness landscape theory, this paper accepts a complex systems perspective to view supply chain organisations and understand their capabilities. It focuses on diminishing the vulnerability of supply chain systems and the ability to design systems to be more resilient to change.

**Keywords:** supply chain management; supply chain resilience; vulnerability; supply chain risk.

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## 1 Introduction

Today's supply chains appear increasingly susceptible to unexpected disruptions. Organisations are exposed to internal risks such as fire at a manufacturing plant, loss of a critical supplier, operational contingencies, labour strike etc., and external risk such as environmental hazards and terrorist attacks. In order to remain competitive, many companies foster the streamlining of their supply chains by implementing concepts such as just-in-time and just-in-sequence (Childerhouse et al., 2003, Svensson, 2004). Recently, the earthquake and tsunami that struck Japan on March 2011, confirmed how globalised supply chains are exposed to unpredictable events (Matsumoto and Inoue, 2011). From General Motors Company's technical centre to the headquarters of package delivery giant FedEx Corporation, teams of employees jumbled to evaluate the impact on organisation, industrial units and commodities. Plant shutdowns across Japan following the earthquake, tsunami and nuclear crisis threaten supplies of everything from semiconductors to car parts to the manufacturers across the globe. A Hitachi factory that makes 60% of the world's supply of airflow sensors was shut down. Two Japanese plants accounting for 25% of the world's supply of silicon wafers for computer chips were closed (Cooper et al., 2011). The physical destruction and nuclear power shut-downs caused Toyota production to drop by 40,000 vehicles, costing \$72 million in profits daily (Kachi and Takahashi, 2011; Pettit et al., 2013). This is analogous with the observation by Christopher and Holweg (2011) that managers consistently recognise their business

environment as inherently unstable and find supply chains to experience the 'age of turbulence' (Wieland and Wallenburg, 2013). To manage with such turbulences and the inherent changes in today's supply chains, enormous deliberation, has been given to strategies that minimise supply chain risks (Bakshi and Kleindorfer, 2009; Hendricks et al., 2009; Kern et al., 2012; Sodhi et al., 2012; Wieland and Wallenburg, 2013).

Consequently, all these have resulted in supply chains facing increasing risks and becoming more vulnerable. In such a multifaceted business surroundings, traditional risk management approaches do not effectively manage risks across the supply chain.

Under such circumstances, risk analysis and risk management alone are not adequate. An improved consideration of design for resilient, coupled and complex systems must be featured (Park et al., 2011). The predominant approach to enterprise risk management requires risk identification and quantification, which are not always possible in the absence of empirical data (Pettit et al., 2013).

The global supply executives have accomplished several supply chain proposals to enhance profits (e.g., increased product variety, frequent launch of new products) and cut costs (e.g., single sourcing, outsourcing, just-in-time inventory system, vendor-managed inventory (Zsidisin and Smith, 2005; Wagner and Bode, 2006; Tang, 2006; Craighead et al., 2007). Such measures have capability to build lean and efficient supply chains in a stable environment, but these measures make supply chains more prone to disruptions (Hauser, 2003).

Traditional risk management processes have been developed and applied to supply chain risk management (e.g., Juttner et al., 2003; Harland et al., 2003; Gaonkar and Viswanadham, 2004). But minute thought has been dedicated to the problems of how those frameworks can be ingrained with existing organisation progression. The above background provides the motivation to propose a holistic framework that differs from traditional forms of risk assessment which do not take vulnerability and adaptive capability of an organisation in relation to its supply chain.

Remaining part of the paper is organised as follows: Section 2 explains vulnerability analysis of supply chain. Need for SCR is demonstrated in Section 3. A resilience framework is proposed in Section 4; fitness landscape concept is presented in Section 5. managerial insights are given in Section 6. Finally, Section 7 concludes the paper.

## **2 Vulnerability analysis of supply chain**

Most of the inventory management and production planning in supply chain management is habitually carried out under stable working conditions, rather than taking uncertainty into account. Unexpected incidents may occur in supply chain, which might affect the normal or expected flow of materials and components. This has led to an increasing vulnerability in the supply chain. Thus, vulnerability is a principal concern in supply chain management. Vulnerability is defined by Svensson (2002) as 'unexpected deviations from the norm and their negative consequences'. Christopher and Peck (2004) defined supply chain vulnerability as the susceptibility of the supply chain to the likelihood and consequences of disruptions. Sheffi and Rice (2005) explained mathematically that vulnerability can be measured in terms of risk as the combination of the likelihood of an event and its potential severity. Thus, it incarcerates the risk revelation of the supply chain. Wagner and Bode (2006) stated that by addressing the vulnerability of the supply chain, the supply chain risks are addressed. Logistical

complexities also add to the vulnerability of a supply chain (Chaudhuri and Singh, 2012; Chaudhuri et al., 2013). Organisations necessitate recognising how much vulnerability does exist in a supply chain and what drives that vulnerability, so that they can knowingly modify these drivers to achieve the level of supply chain vulnerability that matches the desired risk-reward trade-off (Trevelen and Schweikhart, 1988). Vulnerability is maximum when probability of occurrence of an event and the impact of disruption are high, whereas, low consequence events represents the lowest level of vulnerability and requires little planning or action.

The drift towards lean supply chains results in low inventories accomplished by close collaboration with customers and suppliers leads to high vulnerability (Thun and Hoenig, 2011). A supply chain may be vulnerable with respect to as various threats such as technological malfunctions, human faults, environmental impacts, accidents, loss of key human resources, lockouts, etc. An example of a contemporary aspect that could have tremendous impact on the long term vulnerability of supply chain systems are the environmental impact and related sustainability of the systems, e.g., as denoted through new carbon footprint measures (Asbjørnslett, 2008). Vulnerability of modern supply chains can subsequently result in supply chain disruptions and detrimental effects for firms (Hendricks and Singhal, 2005; Wagner and Bode, 2008). Now the question which appears is how much risk one is ready to abide to improve efficiency of supply chain, in proportion to increased vulnerability? Supply chain experts suggest that the key to managing disruptions risk evolves understanding and accessing company's vulnerabilities. This evaluation engross answering questions like: what can go wrong? What is the probability of that happening? What are the consequences if it does happen? (Kaplan, 1997). Hollnagel (2004) raises concerns around the search for effectiveness and efficiency, and has given it the acronym ETTO, for the efficiency-thoroughness trade-off. This ETTO principle can be correlated with normal accident theory (NAT), which provides theoretical support for exploring structural categories that might be related to supply chain vulnerability. The theory states that under conditions of high interactive complexity (i.e., systems in which two or more single or isolated failures can interact in unexpected ways) and tight coupling (i.e., systems with components which can have prompt and major impacts on each other) organisations may be prone to accidents (Perrow, 1984, 1999; Weick, 2004).

Globalised supply chains can be represented as such interactively complex and tightly coupled systems. An incident at automotive supplier Robert Bosch illustrates that the Bosch's supply chain faced a high degree of vulnerability because the little and apparently independent failure was not predicted by the employees at either of the firms and not identified until product failures in the field were reported. The incident was: in January 2005, Robert Bosch failed to detect a defect in the Teflon coating on a 1.5 cm small socket built into diesel-injection pumps supplied to automotive manufacturers (e.g., Audi, BMW and Mercedes). The defect can be traced back to DuPont in the USA which produced and delivered contaminated Teflon to Federal Mogul, which in turn manufactured and delivered the socket to Robert Bosch (Wagner and Bode, 2006). The powerful dependence on suppliers and the inflexible coupling between the organisations in the supply chain is often due to the lack of buffer inventory, and delivery concepts such as just-in-time or just-in-sequence. These are paradigm of complex and tightly coupled systems as proposed by NAT. Promoters of the high reliability theory (HRT) claims that, organisations can apply various strategies and organisational remedies to

manage interactive complexity and tightly coupled processes in order to create reliable organisations. These strategies involve the concern about failure, redundancy and slack in the systems, sensitivity to operations, decentralisation of authority, and commitment to resilience (Weick, 1987; La Porte, 1996; Roberts, 1990; Weick and Sutcliffe, 2001).

Thus, to augment the efficiency, organisations have complex systems because they want to take advantage of the prospects the complex systems give, but at a cost of increasing vulnerability. There is universal harmony that global supply chains are tormented from the disruption of supply chain function and reduced supply chain efficiencies (Myers et al., 2006; Tang, 2006; Bogataj and Bogataj, 2007). Thus, obscurities with any member of a chain inflate to give penalties for all the other members. This sets the landscape for supply chain risk, where each member not only is susceptible to its own risks, but also can be hit by risky events affecting other members. Another typical example: the fire at Philips' Albuquerque plant, a supplier of radio-frequency chips for mobile phones, demonstrates how vulnerable nodes in supply chains can influence a firm's performance. As a consequence of the drop in the supply of radio-frequency chips from Philips, mobile phone manufacturer Ericsson suffered a loss of about \$400 million (Norrman and Jansson, 2004). Thus, susceptibility of the supply chain to the disruptions is of considerable importance. This leads to the concept of supply chain vulnerability. The fundamental principle is that supply chain attributes are milieu of supply chain vulnerability and impact the possibility of occurrence and severity of supply chain disruptions.

### **3 What is the need of supply chain resilience?**

The conventional way to handle uncertainty is risk management which is mostly challenging when the threats are unpredictable. At the same time organisations are accepting broader responsibility for the social and environmental impacts of their supply chains. The complete organisation has a role to play in creating and maintaining SCR. Supply chain risks can even result from poor environmental and social performance by firm and its suppliers which can result in costly legal action. Spekman and Davis (2004) stated that dimension of risk relates to the notion of corporate social responsibility (CSR) and the extent to which supply chain members reputation and image can be tainted by the actions of another member.

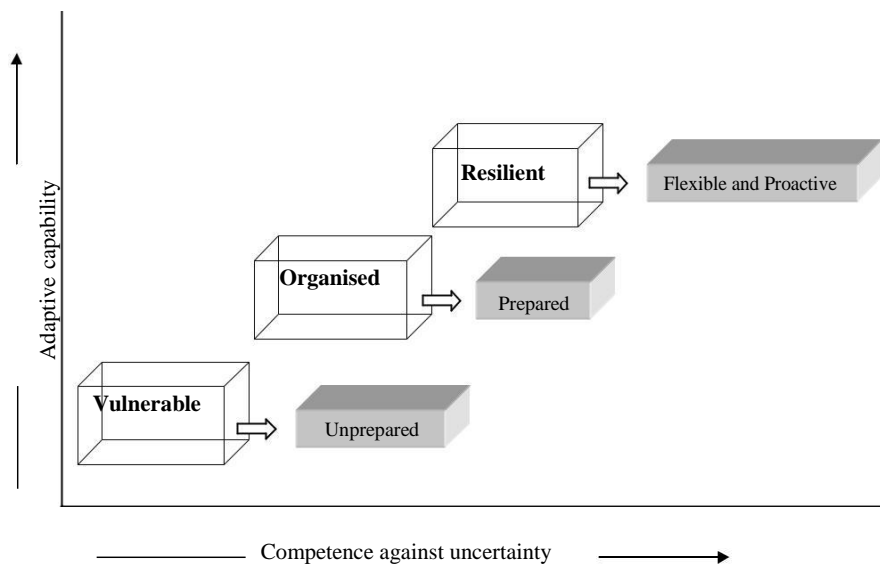
Supply chain disruptions can occur from external sources like natural disaster and internal sources like unsuccessful integration of all functions in a supply chain. Ponomarev and Holcomb (2009) explained the urge for companies to have better understanding of resiliency in supply chains and logistics processes that can enable them to be competent of providing an efficient and effective response.

Thus, a resilient supply chain has the capacity to overcome disruptions and continually transform itself to meet the changing needs and expectations of its customers. SCR aims at developing the adaptive capability to prepare for unexpected events and respond to disruptions and recover from them (Robert, 1997). It is based on the basic assumption that not all risk events can be prevented. Resilience should be on every manager's must-have list 'because anyone who is really in the game messes up at some point' (Jüttner and Maklan, 2010). Supply chain resilience is the dynamic capability, which is competent to absorb the negative effects from a range of diverse risk sources (Teece, 2007; Briano et al., 2009). In the ecological sciences, the standard definition of

resilience is “the ability for an ecosystem to rebound from a disturbance while maintaining diversity, integrity and ecological processes” (Merriam-Webster, 2007).

A very basic definition of resilience established in engineering is: “the tendency of a material to return to its original shape after the removal of a stress that has produced elastic strain” (Peck et al., 2003). SCR addresses the supply chain’s ability to cope with the consequences of unavoidable risk events in order to return to its original operations or move to a new, more desirable state after being disturbed (Christopher and Peck, 2004). Robert (1997) defined SCR can as “the adaptive capability of the supply chain to prepare for unexpected events, respond to disruptions, and recover from them by maintaining continuity of operations at the desired level of connectedness and control over structure and function”. Thus, resilient systems have maximum adaptive capability and competence against uncertainty (Figure 1).

**Figure 1** Comparison of resilient system over other systems



SCR focuses on the system’s adaptive capability to deal with temporary disruptive events. Depending on the magnitude of the hostile events, the terms disruption, crisis or even disaster are used in the literature. The adaptive resilience capability has been structured along the three distinct disruption phases into the supply chain ‘readiness’, ‘responsiveness’ and ‘recovery’ (Sheffi and Rice, 2005). Besides, all definitions share the view that resilience means to respond and recover at the same or better state of operations and thus includes system renewal (Hamel and Valikangas, 2003). Folke et al. (2003) proposed the four major characteristics of resilient systems as: diversity, efficiency, adaptability and cohesion.

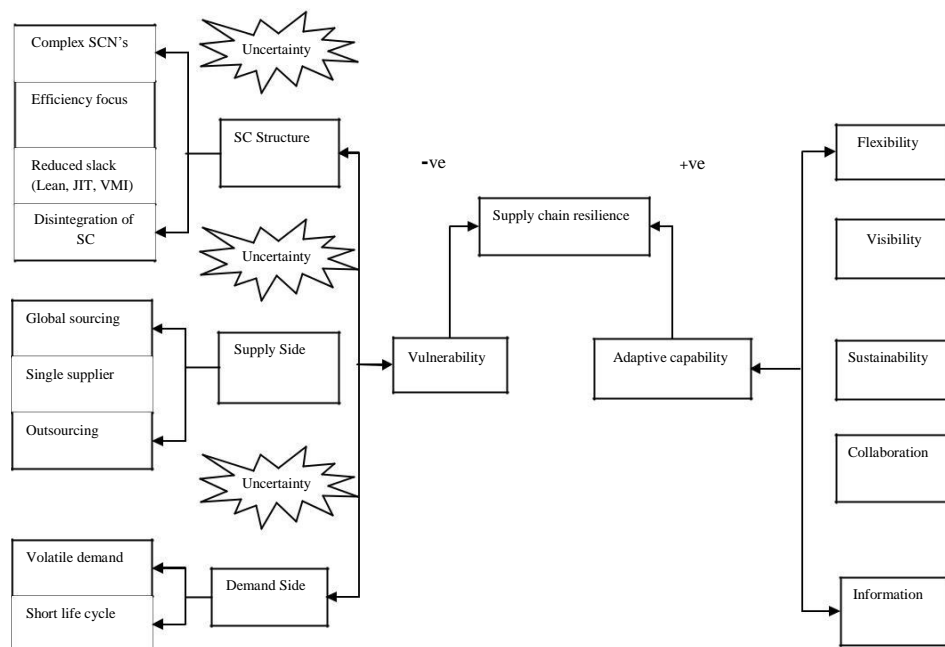
Thus, to reduce the risk, supply chains must be designed to incorporate event readiness, provide an efficient and effective response, and be capable of recovering to their original state or even better post the disruptive event. This is the essence of supply chain resiliency (Ponomarov and Holcomb, 2009). Colicchia et al. (2010) suggested that organisations that respond quickly to disruptions have the prospect to coalesce their

leadership position and this will help to build their brand value. The venture in resilience for such organisations is defensible due to the high margins allied with well-built market spot and gaining competitive advantage. Some authors propose ‘redundancy’ as a separate formative resilience capability (Sheffi and Rice, 2005). Organisations can build up their resilience by either building in redundancy or building in flexibility. Redundancy means keeping a few resources in reserve to be used in case of a disruption, like using safety stocks, multiple suppliers, etc. Whereas, flexibility is the concept of building capabilities that can sense threat and respond to them quickly.

#### 4 Supply chain resilience framework

Today’s global supply chain requires dynamic intangible capabilities that can, not only contain supply chain disruptions but, moreover, generate competitive advantage in normal, routine operating times. The SCR framework explained in Figure 2 demonstrates that, to enhance the resilience of a supply chain it should have five basic capabilities viz flexibility, collaboration, visibility, sustainability and information.

**Figure 2** Supply chain resilience framework



Flexibility is defined as ‘being able to bend easily without breaking’ and, as such, has been defined as an inherent part of resilience (Fiksel, 2006). Flexibility entails creating capabilities to respond when needed and designing production systems accommodating multiple products and real time changes (Rice and Caniato, 2003). It ensures that changes caused by the risk event can be absorbed by the supply chain through effective responses. In the supply chain literature, flexibility is seen as a reaction to environmental uncertainty (Giunipero et al., 2005). Visibility refers to the capability of ‘being perceived by the eye



or mind' (Christopher, 2005). It has been also defined as "the identity, location and status of entities transiting the supply chain, captured in timely messages about events, along with the planned and actual dates/times of these events" (Jüttner and Maklan, 2011). Supply chain visibility addresses information about entities and events regarding end-to-end orders, inventory, transportation and distribution as well as any events in the environment (Sheffi, 2001). Visibility ensures confidence into the supply chain and prevents over-reactions, unnecessary interventions and ineffective decisions in a risk event situation (Francis, 2008). As such, visibility is related to effective disruption response and recovery, effective responses supported by supply chain visibility helps companies to offset non-availability and mitigate the negative impact on cost targets.

Collaboration means 'to work jointly on a common project'. Since SCR is a network-wide, inter-organisational concept, its influential potential has to adopt the attitudinal inclination of the parties to line up forces in the case of a risk event. Collaborative partnerships help to manage risks effectively (Sinha et al., 2004). Collaboration is related to visibility in the sense that it includes the parties' keenness to share even sensitive risk and risk event-related information (Christopher and Lee, 2004). As such, collaboration contributes to reduced uncertainty and event readiness. Hellstrom et al. (2011) proposed a framework for identifying potential risk and gain sharing challenges in collaborative change initiatives, and used it to explore risk and gain sharing in an inter-organisational implementation of radio frequency identification technology. Kang et al. (2012) examine the sourcing risk management issues faced by foreign invested small companies. Palaniswami et al. (2010) highlighted existing issues in supply chain security and proposed framework for improving the overall security in supply chain networks.

Furthermore, collaboration has been suggested as the 'glue that holds supply chain organisations in a crisis together' (Faisal et al., 2006). It prevents opportunistic behaviour on behalf of individual parties which would adversely affect the whole system's response capability. For example, decision synchronisation and incentive alignment as two of the architectural elements of supply chain collaboration are essential for effective system-level disruption responses (Richey and Chad, 2009). Collaboration has been suggested as the glue that holds supply chain organisations together in crisis (Richey and Chad, 2009). Thus, collaboration is equally important after a disruption is overcome, in order to share experiences among the parties. Such post disruption collaboration is likely to have an effect on the system's ability to deal with future disruptions along all three phases: before, throughout and after the event.

Lack of trust and collaboration are major barriers to successfully introducing flexibility into the supply chain. Decision synchronisation and incentive alignment as two of the architectural elements of supply chain collaboration are essential for effective system-level disruption responses (Simatupang and Sridharan, 2008). Pettit et al. (2010) suggested that a global supply chain must create strong capabilities in the fields of collaboration, visibility and flexibility in order to effectively manage their huge number of interconnected operations between several tiers of suppliers and customers, consequently contributing to balanced resilience. Resilience plays a key role in sustaining dynamic capabilities and maintaining the link between dynamically integrated capabilities and sustainable competitive advantage (Ponomarov and Holcomb, 2009). Sustainability is not an end state that we can reach; rather, it is a characteristic of a dynamic, evolving system (Fiksel, 2006). Individual products or enterprises cannot be

deemed sustainable in isolation, although they can make important contributions to the fulfilment of specific human needs. Sustainability is a key enabler for resilience of supply chain (Faisal, 2010).

Improved understanding about what constitutes sustainability in a supply chain helps to make better decisions and decreases the risks of both a single organisation and the whole network (Carter et al., 1998; Geldermann et al., 2007; Brown, 2009). Achieving a sustainable society will require cooperative efforts among industry, government and public interest groups to ensure not only sustainable production systems but also sustainable consumption patterns on the part of individuals and institutions and perhaps the essence of sustainability is resilience, the ability to resist disorder (Robert, 1997). Establishment of a supply chain community to facilitate the exchange of information among players of that community is the key precedence for supply chain risk. The implications of resilience extend beyond process redesign to fundamental decisions on sourcing and the establishment of more collaborative supply chain relationships based on far greater transparency of information (Christopher and Peck, 2004). Datta and Christopher (2011) who investigated information sharing via an agent-based simulation model pointed out that centralised information structure without widespread distribution of information and coordination is not effective in managing uncertainty of supply chain networks. Lee et al. (1997a, 1997b) concluded that information sharing can significantly minimise the consequences of the bullwhip effect. Lee and Whang (2000) suggested that “information is a basic enabler for tight coordination in a supply chain. The lack of collective information is a focal source of vulnerability because most organizations are driven by forecast rather than demand”. Fantazy et al. (2011) empirically tested the relationships amongst environmental uncertainty, internal integration, external integration and performance. He concluded that information sharing is essential for supply chain performance since it offers the specifics that help supply chain managers to make decisions.

## **5 Fitness landscape concept**

The fitness landscape theory was first recognised by Wright (1932) who created the first mathematical model of Darwinian evolution. He examined a link between a micro property of organisms and a macro property of evolutionary dynamics. To explain this epistasis (the effect of one variable on another) Wright proposed a fitness landscape metaphor in which a population of organisms would evolve by moving towards a higher fitness peak. In this paper, authors have attempted to draw the analogy with the fitness landscape, by comparing a distribution of possible fitness values mapped to its fitness level, assuming that supply chains will evolve by moving towards higher resilience peak.

Fitness landscape theory has been used to examine various life science problems including the structure of molecular sequences (Lewontin, 1974), mathematical models of genome evolution (Macken and Perelson, 1989) and to model the dynamic behaviour of the supply network evolution with the dynamic interaction among the firms and the environment (Li et al., 2009). The SCR framework proposed in this research will provide a new means to evaluate supply chain fitness.

### 5.1 The NKC model

The NK model was devised by Kauffman and Weinberger (1989) to examine the way that epistasis controls the ‘ruggedness’ of an adaptive landscape. Kauffman proposed a stochastic procedure to design fitness landscapes, which argues that a landscape can be more or less rugged depending on the distribution of fitness values and interdependences among the parts – the more complex a system, the more rugged the landscape. Kauffman’s concepts have been applied in modelling organisational decision problems (Levinthal, 1997; McKelvey, 1999; Gavetti and Levinthal, 2000; Rivkin, 2000, 2001), new product development (Frenken, 2001), organisational design (Levinthal and Warglien, 1999; Rivkin and Siggelkow, 2003), strategic analysis (Gavetti et al., 2005), industrial collaboration (Schuh et al., 2008), supply chain management (Choi et al., 2001; Choi and Krause, 2006) and sustainable supply chains (Matos and Hall, 2007; Hall et al.,

2012).

In NK model, N represents the number of elements in a system and K represents the number of linkages each element has to other elements in the same system. Kauffman’s NK model was originally a fixed structure model, in that the system under study was not be influenced by factors outside of its system boundary. In other words, it was a closed system in a static environment. In practice, this assumption is simplistic and invalid for complex systems. Therefore, Kauffman introduced a C parameter, to indicate coupledness between the system and other systems in the environment. Coupledness means that any system will not just depend on internal factors, but also the behaviour and performance of the systems in the same environment. This notion is central to competition, because if the fitness of one firm’s supply chain strategy is increased, it is almost certain to affect the fitness of other firms’ supply chain strategies. This formal, but simple representation allows the model to be applied to other complex systems. Thus, in NKC model, for any element  $i$ , there exist a number of possible states which can be coded using integers 0, 1, 2, 3, etc. The total number of states for a capability is described

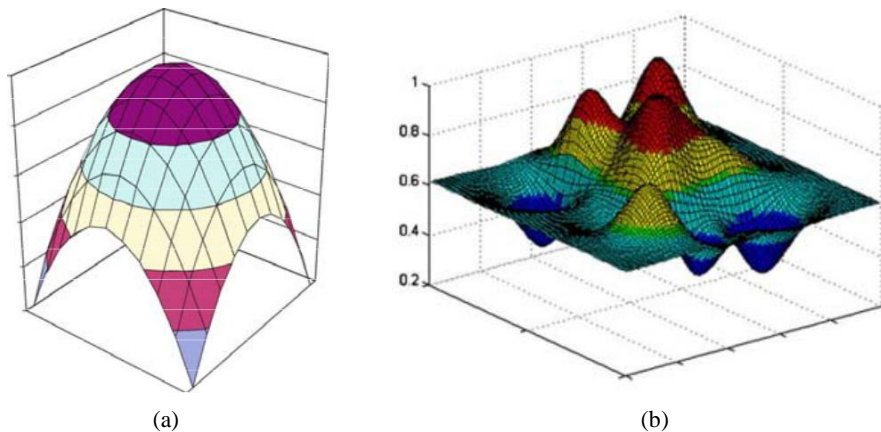
as  $A_i$ . Each system,  $s$  is described by the chosen states  $s_1, s_2, \dots, s_N$  and is part of an N-dimensional landscape or design space (S).

**Table 1** NKC model notation

<i>Notations</i>	<i>Evolutionary biology</i>	<i>Supply chain strategy</i>
N	The number of elements or genes of the evolving genotype. A gene can exist in different forms or states.	The number of capabilities that constitute the supply chain strategy. In the resilient framework defined in this paper there are five capabilities: flexibility, visibility, collaboration sustainability and information.
K	The amount of epistatic interactions (interconnectedness) among the elements or genes.	The amount of interconnectedness among the capabilities defined.
A	The number of alleles (the alternative forms or states) that a gene may have.	Number of possible states a capability might have.
C	Coupledness of the genotype with other genotypes.	Co-evolution of one strategy with its competitors.

The  $K$  parameter in the NKC model indicates the degree of connectivity between the system elements (capabilities). It suggests that the presence of one capability may have an influence on one or more of the other capabilities in a firm's supply chain strategy and can range from  $K = 0$  to  $K = N - 1$ . The former being the least complex system, where each element is independent from all other elements and the latter being the most complex system where each element is connected in some way to all other elements. For  $K = 0$ , the resultant landscape is relatively simple and smooth, except for one single global peak. This proposes that one single strategy dominates the competitive landscape [Figure 3(a)]. As  $K$  increases from 0 towards its maximum of  $N - 1$ , the fitness landscape transforms to an increasingly rugged, uncorrelated, and multi-peaked landscape [Figure 3(b)]. This level of connectivity indicates disturbance in the system, because it can lead to many local fitness maxima on the landscape.

**Figure 3** Fitness landscape for different  $K$  values, (a)  $K = 0$  (b)  $K = N - 1$  (see online version for colours)



Source: Caldart and Oliveira (2010)

If NKC model is applied to the process of supply chain strategy formulation, it is assumed that the contribution of any capability to the overall fitness of a supply chain strategy depends on the status of that capability and its influence on the status of the other capabilities in the strategy. In summary, supply chain firms are complex adaptive systems that aim to consciously evolve by seeking new strategic configurations. Fitness landscape theory and the NKC model suggest an approach to map, quantify and visualise supply chain strategy formulation as a search process that takes place within a design space of strategic possibilities, whose elements are different combinations of supply chain capabilities.

In the framework described in this paper we have:  $N = 5$  (five capabilities: flexibility, visibility, collaboration, sustainability and information);  $A = 2$  [two possible states such as the presence (1) or absence (0) of a capability];  $K = N - 1 = 4$  (each capability will affect the other four capabilities in the strategy). With these parameters the design space is

$A^N = 2^5 = 32$ , which provides thirty two possible supply chain strategies, each of which is allocated a random fitness value between 0 and 1 [Table 2, where few strategies (6 out of 32) are explained for reference].

**Table 2** Supply chain strategy as five bit string

<i>System (strategy)</i>	<i>Element 1 (capability 1)</i>	<i>Element 2 (capability 2)</i>	<i>Element 3 (capability 3)</i>	<i>Element 4 (capability 4)</i>	<i>Element 5 (capability 5)</i>	<i>Assigned random fitness value</i>
00000	Absent	Absent	Absent	Absent	Absent	0.33
10000	Present	Absent	Absent	Absent	Absent	0.42
11000	Present	Present	Absent	Absent	Absent	0.53
11100	Present	Present	Present	Absent	Absent	0.62
11110	Present	Present	Present	Present	Absent	0.73
11111	Present	Present	Present	Present	Present	0.86

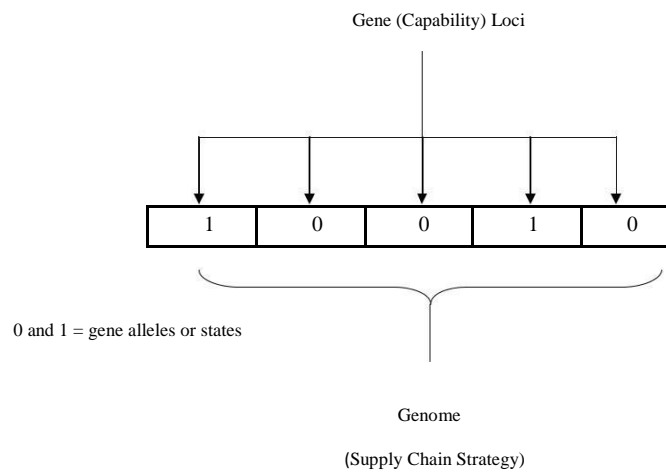
A value close to 0 indicates poor fitness, while a value close to 1 indicates good fitness. The fitness values can then be plotted as heights on a multidimensional landscape, where the peaks represent high fitness and the valleys represent low fitness.

In Kauffman's model, the fitness function  $f(x)$  is the average of the fitness contributions,  $f_i(x)$  from each locus  $i$ , and is written as:

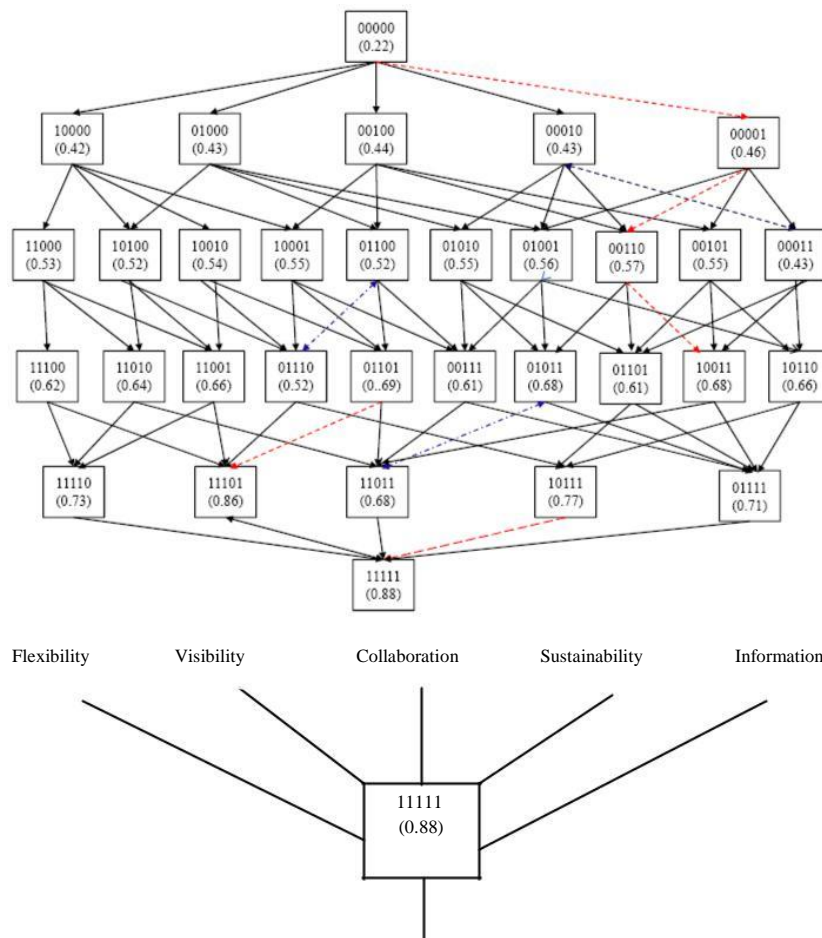
$$f(x) = \frac{1}{N} \sum_{i=1}^N f_i(x)$$

Strategic change is assumed to be a process of moving from one strategy to another in search of an improved fitness. This can be called as *resilient walk* towards high fitness (Soni and Jain, 2011).

**Figure 4** Formulation of supply chain strategy



**Figure 5** A Boolean hypercube of five supply chain capabilities (see online version for colours)



As  $N = 5$ , Boolean hypercube can be used to map the strategic design space (Figure 5). The binary notation is used to represent the presence (1) or absence (0) of a capability. For example, strategy 00011 indicates that the capabilities information and sustainability are present, while the capabilities flexibility, visibility and collaboration are absent. The base strategy 00000 is at the top of the diagram, while the maximum strategy 11111 is at the bottom of the diagram. As a supply chain firm's strategy aggregates additional capabilities, it descends into the lower parts of the diagram. The assigned fitness value for the various combinations of capabilities is represented by the bracketed figure. Lines are used to connect two immediate neighbours and the direction of the arrowhead indicates an increase in fitness. The dotted lines represent the route from 00000 to 11111 that have the greatest gain in fitness with each move. The dashed lines with double arrows indicate two neighbouring strategies with the same fitness. When all the arrowheads are directed to a single strategy, this is considered an optimal strategy (either local or global). The framework thus developed will help organisations in improving the resilience and reducing the vulnerabilities.

## 6 Managerial insights

The research findings provide couple of managerial implications. First, insights from the study provide supply management personnel a method for categorising different sources of vulnerability from supply stream, demand stream and the existing structure of supply chain. Thus, it will assist managers to track the vulnerabilities and to perk up the resilience of their supply chain.

Second, the proposed model suggest an approach to map, quantify and visualise supply chain strategy formulation as a search process that takes place within a design space of strategic possibilities, whose elements are different combinations of supply chain capabilities. It advocates the consideration of resilience aspects in supply chain design and endows with a deeper knowledge of how uncertainty from various aspects decrease resilience and consequently affect supply chain risk exposure.

Third, the proposed framework has great potential for providing management insight for understanding the topology of a fitness landscape. Which can help supply chain managers to address the questions that strengthen their strategy process?

- 1 Strategic examination: what is their current position on the fitness landscape?
- 2 Strategic alternative: where to move on the landscape?
- 3 Accomplishment: how to reach there?

Finally, the supply chain strategies discussed here will also provide corridor to managers in the performance metrics that should be developed to review the success or failure of global supply chain risk management. This study also provides significant information to the managers for enhancing the adaptive capability of the supply chain.

It is significant for supply chain managers to consider the degree of uncertainty in their various global supply chains, and the ability of their organisations to partially improve this by adopting inter-organisational learning processes. Although the exact nature of the impact of complexity and learning on performance outcomes still needs further research, managers can begin to adopt the strategies discussed and cited here.

## 7 Conclusions and future scope

Supply chain disruptions can have long-term negative effects on an organisation's performance. Organisations need to implement a proactive supply chain risk management towards their vulnerabilities (Christopher and Lee, 2004; Oehmen et al., 2009; Trkman and McCormack, 2009; Lockamy and McCormack, 2010). Effective disruption-management strategy is an obligatory module of organisations overall supply chain strategy. The proposed SCR framework in this paper will provide critical insights for decision making by minimising the destructive impact of unavoidable risk events. Firms that submissively accept the risk of disruptions leave themselves open to the danger of severe loss, as evidenced by the Japan disruptions and Philips' Albuquerque plant cases discussed in the Section 1 and Section 2 respectively. Active disruption management strategies rely on mitigation and/or contingency actions. In this article, we have focused five capabilities that constitute the supply chain strategy and how the

presence of one capability may have an influence on one or more of the other capabilities in a firm's supply chain strategy.

A complex supply chain network is a compilation of firms that look for maximising their individual profit and business by exchanging information, products and services with one another. Therefore, the strategy formulation among firms adjacent in a supply network determines the type of behaviour the network as a whole exhibits and the level of control that any one firm has over another. However, a larger component of such strategy formulation is embryonic, dynamic and unpredictable, and the issue of which capabilities to select and how much to materialise becomes a serious managerial consideration. Thus the main contribution of our research is by using fitness landscape theory and the NKC model, the authors suggest an approach to map and visualise supply chain strategy formulation as a search process that takes place within a design space of strategic possibilities, whose elements are different combinations of supply chain capabilities.

The paper contributes to a better understanding of the concepts of vulnerability and resilience and of related issues in supply chains. The supply chain resilience framework supports the analysis of different supply chain's strategies and helps in finding and categorising strategies. As with most research; there are limitations with this study. First, characteristics of supply and demand risk may differ according to the type of industry, so different risk characteristics may exist in other industries as well, which were not obtained in this research. One avenue for future research would consist of taking the initial findings from this research and to examine the effects of factors such as industry, organisational size, supply management experience, and tier within the supply chain on resilience perspective. The proposed model offers a preparatory stage for further research on how factors such as landscape topology, population and the dynamics would affect supply chain strategy formulation. Also the associated costs and time involved to search type and number of searches. Further, more research may be needed to extend and validate our findings.

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