International Transport Forum

The Mitigation of Risk in Resilient Supply Chains

Discussion Paper

171 Roundtable

Martin Christopher
Cranfield University

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The International Transport Forum

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Introduction

One of the biggest changes to the business landscape over the last twenty years or so has been the significant increase in the level of risk confronting supply chains. We have moved from a world of relative stability – and hence predictability – to an environment which is characterised by turbulence and uncertainty with a consequently heightened potential for disruption to business activity.

Supply chains are increasingly being impacted upon by external events such as natural disasters and changes in the geo-political arena as well as through events within the supply chain. Whilst natural disasters, seemingly on the increase and attract much attention, often the greatest risk to business continuity is systemic, i.e. risk is embedded in the supply chain because of managerial decisions concerning the design of the supply/demand network.

There can be no doubting that in recent years the business environment has become more turbulent and hence less predictable. Whereas in the past it was standard practice to plan ahead – with a time horizon of months, if not years – now the challenge is to find ways to become much more responsive to events as they happen. Traditionally, businesses have been forecast-driven i.e. they have been run on the basis of projections of future demand, often based on past history. Such an approach works well when the business environment is relatively stable; clearly it is less effective in the volatile conditions that many organisations face today.

It is also the case that many firms are dependent on supply chain networks that were designed some years ago when the world was a more certain place and the assumption was that the future would be much like the past. Now, in the significantly changed circumstances that confront many businesses, it may be the case that those supply chain solutions are no longer fit for purpose.

Conventional supply chain design was often based on so-called 'network optimisation' principles. More often than not the factor being optimised in those exercises was the firm's operating cost. Thus the aim was to design a network which would minimise logistics costs for the organisation, particularly transport and storage costs. Also the analysis was static, not dynamic – meaning that it used the costs prevailing at a single point in time as the basis for the calculation. As a result those companies operating logistics networks designed ten or twenty years ago may need to revisit those design decisions and re-work the analysis to incorporate the major changes that have taken place in the cost parameters.

Understanding Supply Chain Risk

One of the distinguishing characteristics of modern supply chains is that they operate in an environment of heightened uncertainty and business risk. Supply chains today are possibly more vulnerable to disruption than has been the case for many years. Recent events have highlighted once again how vulnerable to disruption are our increasingly global supply chains. Natural disasters such as earthquakes, hurricanes and floods often have tragic consequences and thus capture significant media attention. It is also evident that events such as these can have considerable impacts on supply chains. The effects of the 2011 Japanese earthquake and tsunami were felt in a multitude of companies around the world as a result of disruption to supply arrangements. In the same year severe flooding in Thailand had a major impact on supply chains around the world. However, what is not always recognised is that much of the risk to supply chain continuity is often created by decisions that are taken by managers when determining the design of the supply chain. We could label such risks as 'systemic' because they lie

within the supply chain itself rather than in the wider business environment. Hence it can be argued that the shape of the supply chain risk profile is largely determined by managerial decisions and actions and not just by the exposure to external risk sources.

Why are modern supply chains seemingly more vulnerable to disruption than ever before? There are many reasons but some of the main sources of supply chain risk are:

- The trend to 'lean' supply chains and just-in-time practices: Many companies have actively sought to improve the efficiency of their supply chains by introducing just-in-time arrangements and have sought to 'lean' down their operations. This approach, whilst undoubtedly of merit in stable market conditions, may become less viable as volatility in the business environment increases.
- The globalisation of supply chains: There has been a dramatic shift away from the predominantly 'local-for-local' manufacturing and marketing strategies of the past. Now, as a result of offshore sourcing, manufacturing and assembly, supply chains extend from one side of the globe to the other. As a consequence there can be an exposure to geo-political risk as well as exchange rate changes and longer, more variable lead-times.
- Focussed factories and centralised distribution: In an attempt to capture the economies of scale many companies have rationalised their production facilities and centralised their distribution. Thus instead of many smaller and often local factories and warehouses serving local markets, those companies now seek to serve global markets from fewer but bigger facilities. As a result, the risk to the system as a whole increases if one of those facilities becomes inoperable.

As a result of these and other trends today's supply chains have undoubtedly become more complex. Complexity, properly defined, is not just about how complicated these networks are but rather about how inter-connected they are. The typical supply chain today will often have more nodes and links than in the past. This makes the task of controlling the network more difficult. As an example, Henry Ford 1st producing the Model T Ford owned most of the end-to-end supply chain including steel mills, rubber plantations and component manufacturing factories. Today, Ford is a totally different business reliant on thousands of independent suppliers and partners located in a multitude of countries. As a result, the potential for unexpected events to impact any of the myriad of nodes and links in the system and hence disrupt its continuity is increased.

Supply Chains as Networks

A generally accepted definition of a supply chain is:

"A network of organisations that are involved, through upstream and downstream linkages, in the different processes and activities that produce value in the form of products and services in the hands of the ultimate consumer" (Christopher, 1992)

The notion of a network is particularly important since it has long been recognised that supply chains are not really chains in a linear sense but are in reality a complex web of inter-connected entities. These entities are often independent agents with high levels of autonomy that do not always work to the same agenda. It could indeed be argued that these supply/demand networks are 'eco-systems' or complex adaptive systems in that they are in a state of continuous flux, responding to the wider environment and constantly evolving. By implication, these complex networks are difficult if not impossible to control and their behaviour is hard to predict. Furthermore these complex systems exist against a backdrop of uncertainty arising from the wider geo-political environment, for example the growing pressure from some quarters for a reversal of the philosophy of open global trade towards greater economic nationalism. Recent examples of this trend might be the vote in the UK to leave the European Union and the election of President Trump in the USA which led to the country's withdrawal from the Trans-Pacific Partnership and the re-negotiation of the NAFTA agreement. It is difficult to predict exactly how these – and other – geo-political shifts will play out, but the potential impact of such major changes in the global trading environment is clearly great.

Contagion Risk in Supply Chains

The more inter-connections and inter-dependencies in a supply/demand network the greater is the likelihood of contagion risk. Contagion risk can be defined as the possibility for a failure in one part of the network to have a knock-on effect across the network as a whole. Thus, in the same way that a failure of financial institutions to control sub-prime lending of mortgages primarily in the United States of America led to the global financial crisis of 2007/8, so too can the failure of one upstream supplier cripple an entire supply chain.

One source of contagion risk is in the design of the network itself. Decisions to reduce the supplier base, for example, and to single source the procurement of materials and components can mean that the impact of failure at a single node will reverberate across a company's entire product portfolio. Thus the growing trend in the car industry to standardise platforms, sub-assemblies and components across all of the company's models can lead to disruption across the business in the case of, say, a faulty component. This was the cause of many of the product recalls experienced by Toyota in recent years.

The growing concern for Cyber-Security

A common feature across all supply chains is their growing – sometimes total – reliance on information technology. Perhaps inevitably as supply chains become digital it is disruptions to the flow of data and information that now pose one of the biggest threats to business continuity.

The prevalence of "cyber attacks" has been on the increase in recent years. The source of these attacks is not always known and the motivation for the attack not always clear. The likelihood is that these attacks will continue to rise and that cyber-risk is likely to be the number one concern for business in the future. Sometimes this risk comes from the failure of internal IT systems and a number of businesses have seen significant disruption from this source. British Airways in 2017 suffered a major IT system

failure – with seemingly no back-up in place – that led to several days of cancellations, delays and severe negative customer reaction. However many of the recent examples of breaches of cyber-security have originated externally and have been designed with malicious intent. The impact on business performance of such orchestrated attacks can be considerable as the example below highlights:

Box 1. Reckitt Benckiser hit by cyber attack

In July 2017 a number of major global businesses and government departments were severely affected by the 'Not Petya' cyber attack which was thought to have originated in Ukraine. The attack spread by contagion through inter-linked IT systems and across supply chains. One company hit by the attack was Reckitt Benckiser, one of the world's leading producers of fast moving consumer goods. Some of their factories were closed for days as their planning systems failed, customer orders could not be processed and their enterprise planning systems were crippled. It was estimated that the company lost GBP 100 million of sales revenue as a result of the attack. Even though the company had previously recognised the possibility of such an attack and had reviewed its cyber security systems it still proved vulnerable to this new source of supply chain risk.

A report in The Times on 9 January 2018, stated that on average UK firms each suffered 231 028 cyber attacks during 2018, or 633 attempts to breach their firewalls each day. The company who produced the report – Beaming, a provider of business internet services – was quoted as saying: "2017 was the worst year yet for cyber attacks on British businesses, whose IT security systems are under constant pressure from hackers and malicious computer scripts seeking to exploit any vulnerability. With most attacks targeting simple devices connected to the Internet of Things (IoT), it is possible many companies are already infected and don't know about it."

There is a growing concern that cyber risk may enter through the 'back door' of the business - meaning that the entry point for malware type attacks can be through suppliers. The implication of this possibility is that the procurement and supply management function must be cognisant of these potential issues and become much more concerned with ensuring that supplier partnerships are safeguarded by robust firewalls to reduce or eliminate the possibility of cyber risk contagion.

Supply Chain Risk Sources

It can be argued that there are five generic sources of supply chain risk and these are summarised below:

Supply risk

How vulnerable is the business to disruptions in supply? Many companies are not always fully aware of details for their upstream supply chains which are becoming increasingly global and often there is limited visibility of upstream contractors and sub-contractors. Whilst the majority of businesses will have good insights into their first tier suppliers, not many will have a detailed understanding of their second and

third tier suppliers. An example of how risk may be hidden from view through upstream supply arrangements, is the well documented 'horsemeat scandal' in 2013. Routine analysis by the Food Safety Authority of Ireland (FSAI) revealed that horse DNA had been found in beef burgers and other meat products. Very soon after the initial discovery further testing revealed that the problem was not an isolated instance but rather extended across much of Europe. Supermarkets were forced to recall many processed beef products from their shelves as concern amongst shoppers spread.

It very quickly transpired that whilst retailers and fast food restaurant chains were buying these products from reputable food processing and manufacturing companies, the cause of the problem lay further upstream in the supply chain. For example, Findus – a major producer of frozen beef products – discovered that the beef it had been buying from a French company, Comigel, contained a large proportion of horse meat. Comigel themselves had bought meat from another company, Spanghero, who had sourced from other traders including suppliers in Romania.

Clearly the lack of visibility and transparency in the meat supply chain meant that it was only by chance that this contamination came to light. It follows that to mitigate supply risk a detailed understanding of all upstream sourcing arrangements is required as well as a more pro-active approach to supplier management.

Demand risk

Most markets today are characterised by uncertainty. We have moved over a period of twenty or thirty years from a relatively stable - and hence predictable – business environment to a situation that has been termed by some as a "VUCA world", i.e. Volatile, Uncertain, Complex and Ambiguous.

In this type of world sudden and unexpected changes in demand can expose less agile companies to a greater risk of product obsolescence on the one hand and lost sales through out-of-stock situations on the other. This risk has been exacerbated by the widespread adoption of 'lean management' practices which often have resulted in reduced amounts of 'slack' in the system in the form of buffers of inventory and capacity.

New developments in the fields of what are often referred to as 'Big Data' and predictive analytics may provide the opportunity for greater insight into market trends and enhance the organisation's ability to anticipate and respond to shifts in demand.

Process risk

How resilient are our processes and those of our supply chain partners? Process reliability is critical to supply chain continuity. Processes must be under control to ensure that variability is kept to a minimum. Variation in any process is a problem because variation implies unpredictability.

What is now known as the Six Sigma methodology should be employed to identify and remove sources of process variability. The methodology employs a set of tools, many of which were originally devised for quality control.

Six Sigma is a data-driven continuous improvement methodology that seeks to bring processes under control and to improve process capability. The methodology follows the five-stage DMAIC cycle below:

1. Define: What is it we are seeking to improve?

2 Measure: What is the current capability of the process? What is average performance and what variability around the average is evident.

3 Analyse: Map the process, use cause and effect analysis and prioritise for action.

4. Improve: Re-engineer the process and simplify it where possible.

5. Control: Improve the visibility of process performance. Use statistical process control to monitor variability.

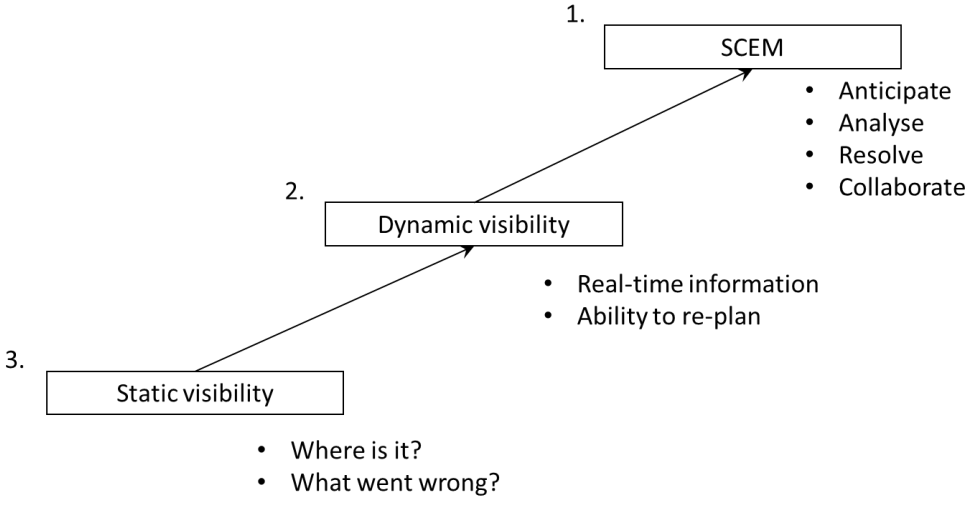
Control risk

Do we have the systems in place to ensure accurate monitoring of performance in the end-to-end supply chain? Do we have early warning systems in place to alert us to problems? How timely is the data we use?

Supply chain event management (SCEM) is the term given to the process of monitoring the planned sequence of activities along a supply chain and the subsequent reporting of any divergence from that plan. Control risk can be mitigated by the effective deployment of SCEM procedures. The internet and, it is being suggested, block chain technology can provide the means whereby SCEM reporting systems can link together even widely dispersed partners in global supply chains, 'Cloud' based computer systems enable independent organisations with different information systems to share data easily.

SCEM enables organisations to gain visibility upstream and downstream of their own operations and to assume an active rather than a passive approach to supply chain risk. Figure 1 below shows the progression from the traditional limited scope of supply chain visibility to the intended goal of an 'intelligent' supply chain information system.

Figure 1. The progression to supply chain event management

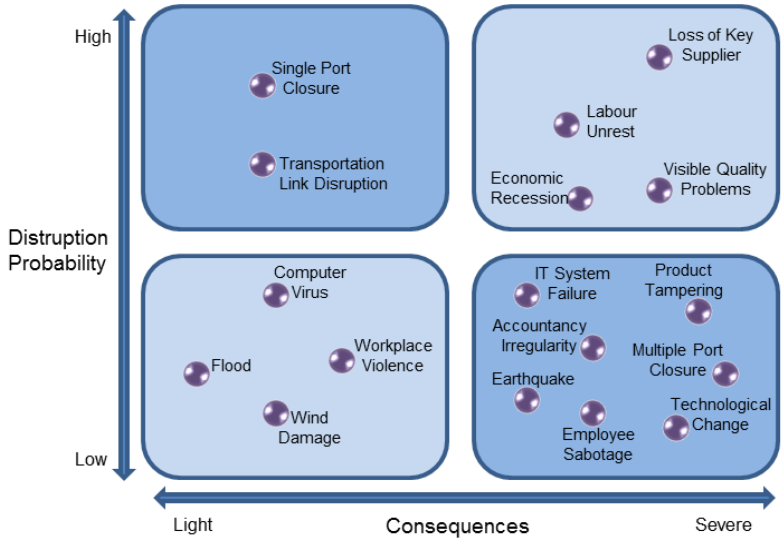


Source: Christopher (2016)

Environmental Risk

Where across the supply chain as a whole are we vulnerable to external forces? Whilst the type and timing of extreme external events may not be forecastable, their impact needs to be addressed. It is sometimes advocated that organisations should seek to categorise particular disruptive events according to the likelihood of their occurrence and the impact on the business if they were to happen. The matrix below is an example of such an approach.

Figure 2. A vulnerability map for a single company



Source: Sheffi and /Rice (2005)

Whilst it might be imagined that the high probability/severe consequence quadrant should be the biggest concern, it is actually the case that the greatest threat may come from low probability/severe consequence events since it is difficult if not impossible to see them coming. The 9/11 attack on the Twin Towers in New York wold be such an example.

Data maintained by reinsurance companies such as Swiss Re and Munich Re highlights the fact that natural disasters are on the increase, be they hurricanes, floods or earthquakes. At the same time geo-political risk has reached extremely high levels according to the Chartered Institute of Procurement and Supply (CIPS) Risk Index – in fact the highest level for 24 years.

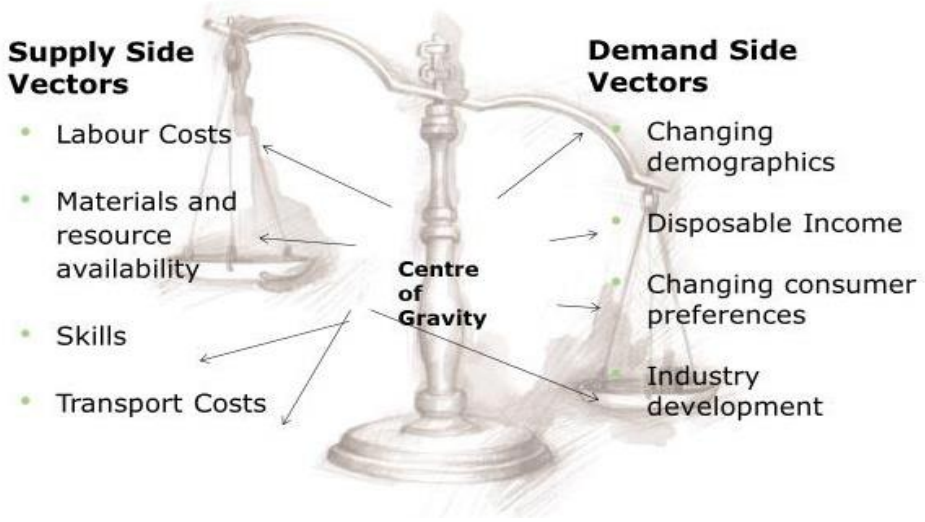
Even though these extreme events cannot be forecast, organisations should subject their supply chain architecture to a form of 'stress testing'. The idea behind this is to look across the supply/demand network and ask the question for each node and link: "If for whatever reason this node or this link were to be disrupted, what would be the impact on our organisation?"

The maintenance of a regularly up-dated risk register which reviews all the above five sources of risk is an essential pre-requisite for the creation of a resilient supply chain.

Changing Centres of Gravity

All supply chains have a 'centre of gravity' which is determined by the combined effects of the 'pull' of various forces on the demand side and the supply side of the firm. The resultant centre of gravity influences decisions on where factories should be located, where materials should be sourced and where strategic inventories should be positioned. Figure 3 below suggests that a number of important issues need to be weighed within the balance when supply chain design decisions are taken.

Figure 3. The centre of gravity is shifting for supply chains



Source: Christopher (2018)

On the demand side the forces or vectors that will impact the centre of gravity include:

Changing demographics

As a result of population growth dynamics and changing age profiles some markets are growing more rapidly globally whilst others are shrinking. Equally, some countries are getting older whilst others are getting younger with consequent impacts in spending patterns.

Differences in disposable income

A major change is taking place regarding the relative growth in spending power in different countries. Traditional markets in the West which once dominated global spending are now being overtaken by the emerging economies in terms of expenditure. For example, Unilever now reports that over half its turnover comes from developing countries.

Changing consumer preferences

As populations transition from being predominately rural towards increasingly urban and as disposable income rises, so too does the pattern of consumption change. The massive growth in the demand for

cars in China and India provides a good example of this as does the changes in diet now occurring in many emerging economies with a consequent rise in the demand for dairy and meat products.

Industry development

The major shift in industrial production away from Western economies to low-cost countries has had a major impact on trade flows and the level of demand for raw materials. Serving these fast growing markets whilst still needing to maintain a presence in static or declining markets is a challenge many companies face today.

Similarly, on the supply side a number of factors will act as countervailing forces impacting the centre of gravity. These include:

Labour costs

Many sourcing decisions in recent decades have been motivated by the desire to take advantage of lower labour costs. So-called 'low-cost country sourcing' has been based on the desire to improve competiveness by manufacturing or sourcing in locations where labour costs are a fraction of more traditional locations. However what were once significant differentials in labour costs has often been eroded through wage inflation. Likewise new potential contenders for the description of low cost countries have emerged.

Material and resource availability

Inevitably the availability and cost of key input materials and resources such as metals, energy, chemicals and other commodities are a major influence on location decisions. With rising demand and, in some cases, declining supply, the availability and prices of these critical input factors can be dramatically affected. There is a growing realisation amongst some established manufacturing companies that they will have to re-assess their current supply chain arrangements as production economics that prevailed in the past may no longer apply.

Skills

As industries continue to become more knowledge-intensive and dependent upon specific skills and capabilities, access to them becomes ever-more critical. Even in times of high unemployment, companies in many sectors find that they face skills shortages, for example: information technology specialists, software designers and engineers. Whereas once it was the Western world that pre-dominated in the supply of these skills, this is rapidly changing as the levels of education and training in the newly emerging economies accelerates.

Transport costs

Because most transport is still dependent on oil-based fuel it is inescapable that transport costs will be impacted by rises in the cost of oil. When many of today's supply chains were originally designed, the cost of oil was a fraction of what it is today. For example, in December 1998 a barrel of crude oil sold for about USD 9.64 (United States Dollars); in July 2008 – ten years later – it rose to an all-time high of USD 147.27. Since then the cost of crude has been highly volatile and currently is exhibiting a steady upward trend. Certainly the future for transport-intensive supply chains does not look good.

Creating sustainable solutions through structural flexibility

Because the likelihood is that the centre of gravity of a supply chain is going to change more frequently in the future, given the volatility of the business environment, the need for flexibility in the supply/demand network increases. Many companies find themselves in a situation where they have invested in specific supply chain solutions which are often fixed for a period of time e.g. factories, distribution centres, supply arrangements etc. As a result they may find it difficult to re-configure the network as conditions change. This ability to quickly change the shape of a supply/demand network can be called *structural flexibility*.

What are the key enablers of structural flexibility?

Perhaps the most critical enabler, but the one most difficult to achieve, is a corporate culture and 'mindset' that is open to change and is comfortable with frequent changes to processes and working practices. Also, because some of the enablers of structural flexibility – discussed below – involve much higher levels of collaborative working across organisational boundaries, there needs to be a willingness to actively create 'win-win' partnerships across the supply chain.

Given that this co-operative approach to working across the extended enterprise can be achieved, the main elements that underpin structural flexibility include:

Visibility and information sharing

The ability to see from one end of the pipeline to another is essential. It is important to be able to see the changes that are on the horizon both upstream and downstream. Information sharing provides a powerful platform on which to build collaborative working relationships across the supply chain.

Access to capacity

An important facilitator of flexible supply chain management is the ability to access additional capacity when required. Capacity here refers not only to manufacturing but also in transport and warehousing. Furthermore that capacity may not be owned by the firm in question, it could come from partners across the network, third party providers or even competitors.

Access to knowledge and talent

Given the rapid rate of change in both markets and technologies, a major challenge to organisations today is ensuring that they have access to knowledge in terms of the potential for product and process innovation. Equally critical is access to people who are capable of exploiting that knowledge. 'Open innovation' and technology sharing agreements are ideas that are rapidly gaining ground. Once again, companies are increasingly turning to external sources of knowledge and talent to provide adaptive capabilities.

Inter-operability of processes and information systems

In an ideal world organisations would be able to alter the architecture of their physical supply chains in short time frames with minimal cost or disruption involved. Equally, those same companies need the ability to manage multiple supply chains serving specific market segments. To enable this re-configuration it greatly helps if the nodes and links of the supply chain are 'inter—operable'. In other words they can be plugged together in a variety of ways to enable specific supply chain solutions to be easily constructed. Standard processes and information systems help greatly in creating inter-operability.

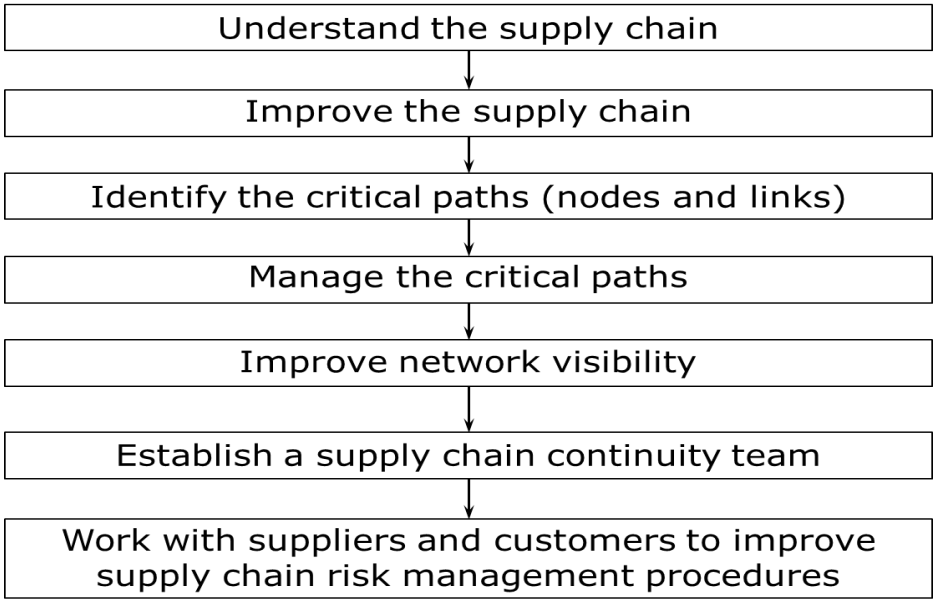
Network orchestration

Because the achievement of higher levels of adaptability generally requires inputs from a variety of other entities in the wider supply/demand network, the need for co-ordination across the network arises. As supply chains become more 'virtual' than 'vertical' there is a growing requirement for orchestration. Whether that orchestration task is performed by the firm itself or by a specialist external logistics service provider or a Fourth Party Logistic Model (4PL), the ability to structure appropriate networks and to synchronise activities across the nodes and links of those networks is paramount.

Managing supply chain risk

Figure 4 below suggests a seven-stage approach to the management of supply chain risk.

Figure 4. The supply chain risk management process



Source: Christopher (2016)

Each of the seven stages is described in more detail in the following sections.

Understand the supply chain

There is in many companies an amazing lack of awareness of the wider supply/demand network of which the organisation is a part. Whilst there is often a good understanding of the downstream routes to market, the same is not always true of what lies upstream of first tier suppliers. First tier suppliers are often dependent themselves on second and even third tier suppliers for their continuity.

One company that has invested a significant amount of resources in improving their understanding of upstream risk is John Deere, a manufacturer of agricultural equipment. The company has developed a tool to monitor supplier performance which provides regular reviews of any possible problems not just with their immediate suppliers but reports on any issues, potential or actual, with second and third tier suppliers.

It is this detailed level of supply chain understanding that is necessary if risk is to be mitigated and managed. For complex supply chains or where complete mapping of the entire network is not practical it would be appropriate only to look in detail at the 'critical paths' – how these are identified is dealt with later.

Improve the supply chain

'Improving' the supply chain is all about simplification, improving process reliability, reducing process variability and reducing complexity. For long-established businesses it is probably true to say that rarely have their supply chains been planned or designed in a holistic way. Rather they have developed organically in response to the needs and opportunities of the time. Suppliers may have been chosen because of their ability to meet the demands for lower price rather than because of the reliability of their supply chains for example.

Process variability can add to supply chain risk in a number of ways. Variation implies unstable processes with outcomes that are not always predictable. The use of Six Sigma methodology can be a powerful way to reduce variability in supply chain processes.

Identify the critical paths

Supply networks are in effect a complex web of interconnected 'nodes' and 'links'. The nodes represent the entities or facilities such as suppliers, distributors, factories and warehouses. The links are the means by which the nodes are connected – these links may be physical flows, information flows or financial flows. The vulnerability of a supply network is determined by the risk of failure of these nodes and links.

As there will potentially be thousands of nodes and links, the challenge to supply chain risk management is to identify which of them are 'mission critical'. In other words, how severe would the effect of failure be on the performance of the supply chain? Companies need to be able to identify the critical paths that must be managed and monitored to ensure continuity.

Critical paths are likely to have a number of characteristics:

- Long lead time, e.g. the time taken to replenish components from order to delivery.
- A single source of supply with no short-term alternative.
- Dependence on specific infrastructure, e.g. ports, transport modes or information systems.
- A high degree of concentration amongst suppliers and customers.
- Bottlenecks or 'pinch points' through which material or product must flow.
- High levels of identifiable risk (i.e. supply, demand, process, control and environmental risk).

Manage the critical paths

Once the critical nodes and links have been identified the first question is how can the risk be mitigated or removed? At its simplest, this stage should involve the development of contingency plans for actions to be taken in the event of failure. At the other extreme, re-engineering of the supply chain may be necessary. Where possible, Statistical Process Control (SPC) should be used to monitor the critical stages along the pipeline.

If bottlenecks are the cause of the problem then decisions will have to be made about the options. Can the bottlenecks be removed? Can they be reduced by adding capacity or by holding inventory? Sometimes the bottleneck may be a key supplier who is capacity constrained. If alternative sources are not available at short notice then it will be necessary to manage the bottleneck by carrying strategic inventory to enable the flow through the downstream nodes to be maintained.

One feature of critical paths in a supply chain is that they often are subject to the risk of failures in infrastructure. Supply chain infrastructures include not only the means of enabling physical movement e.g. ports, airports, road and rail networks but also information systems and the systems to facilitate trade and exchange. When failures in infrastructure occur, whether through Acts of God or human intervention (e.g. strikes, cyber attacks etc.), the effect on business continuity can be severe. Many companies have developed contingency plans to mitigate the risk of infrastructure failure. These contingency plans are often based on the analysis of different scenarios and increasingly use sophisticated modelling and simulation exercises.

Improve network visibility

Many supply chains suffer from limited visibility. What this means is that a particular entity in the network is not aware of the status of upstream and downstream operations of the levels and flow of inventory as it progresses through the chain.

In such a situation it can often be weeks or months before problems become visible, by which time it may be too late to take effective action. One way to resolve this problem is to establish a supply chain 'control tower'. The idea behind the control tower is that complex global supply chains need to be constantly monitored in a systematic and formal way to ensure that intended events and outcomes happen as planned. Information on inventory levels, delivery lead-times, supplier performance and so on will also be available through the supply chain control tower. The purpose of the control tower is to enhance visibility across the supply chain and to provide a basis for more effective decision making.

We referred earlier to the potential of supply chain event management (SCEM) to enable better identification of the occurrence of unplanned events (or the non-occurrence of planned events). Tools such as these can significantly reduce supply chain uncertainty and thus reduce the need for additional inventory buffers. Another emerging technology that is enabling dramatic improvements in visibility is Radio Frequency Identification (RFID).

RFID tags enable a supply chain 'track and trace' capability to be created. Tags are either 'active' or 'passive'. Active tags transmit information to receiving stations and passive tags are read by scanners as they move through the chain. As the cost of these tags falls, and as more and more organisations require their suppliers to use them, then the adoption of this technology will accelerate.

A parallel technological development that will greatly assist the global management of assets in the supply chain is satellite tracking. Containers and trucks can be fitted with devices that enable the geographical position of the asset to be monitored by satellite, including information on variables such as temperature.

The challenge, as ever, is not technological but is the need to engender a greater willingness amongst supply chain entities to share information with each other, even if that information may not always be good news.

Establish a supply chain continuity team

All the foregoing stages in the supply chain risk management process require resources to undertake them. One way to do this is to create a permanent supply chain continuity team.

Many companies already have business continuity teams in place but often their focus is more limited and largely Information Technology (IT) / Information Systems (IS) focused. Other companies look at risk mainly from a financial perspective. All of these activities are necessary and essential but the argument here is that these teams should be expanded in their scope to take account of the fact that the biggest risk to business continuity lies in the wider supply chain.

Ideally these teams will be cross-functional and will have access to all the skills necessary to undertake the detailed analysis and implementation involved in the supply chain risk management process. The team should maintain a 'risk register', which identifies the possible points of vulnerability along with the actions that are to be taken to mitigate that vulnerability.

To ensure that high priority is given to supply chain risk management, the team should report to a board-level executive – ideally the Supply Chain Director or Vice-President if that person is on the board.

Work with suppliers and customers

Given the complexity of most supply networks, how can risk be better managed upstream and downstream of the focal firm? Ideally, if each entity in a network took responsibility for implementing risk management procedures of the type advocated here with their immediate first tier suppliers and customers then a far more resilient supply chain would emerge.

There are some good examples of collaborative working with both suppliers and customers to develop a greater understanding of the potential vulnerabilities in specific industries. At BAe Systems – a major aerospace company – they have a strategic supplier management process with about 200 key suppliers based upon an industry initiative 'Supply Chain Relationships in Action' (SCRIA). BAe Systems put small

teams into these key suppliers to find ways of aligning supply chain processes and improving visibility. With their biggest suppliers such as Rolls-Royce there is ongoing contact right up to board level.

This approach is akin to the idea of *supplier development*, which has been quite widely adopted in the automotive sector. Going beyond this there is an opportunity to draw from the experience of companies who have insisted that their suppliers meet rigorous quality standards in terms of the products that they supply. The same practice could be applied in supply chain risk management by requiring suppliers to monitor and manage their supply chain vulnerabilities. In this way a 'snowball effect' might be achieved, with each supplier working with their first tier suppliers to implement supply chain risk management procedures.

Target Stores, the North American retailer, requires its suppliers to sign an agreement that they will comply with Target's requirements on supply chain security and risk management. Pfizer, the pharmaceutical company, also has clearly established performance standards for its suppliers in terms of supply chain risk management which are audited continuously.

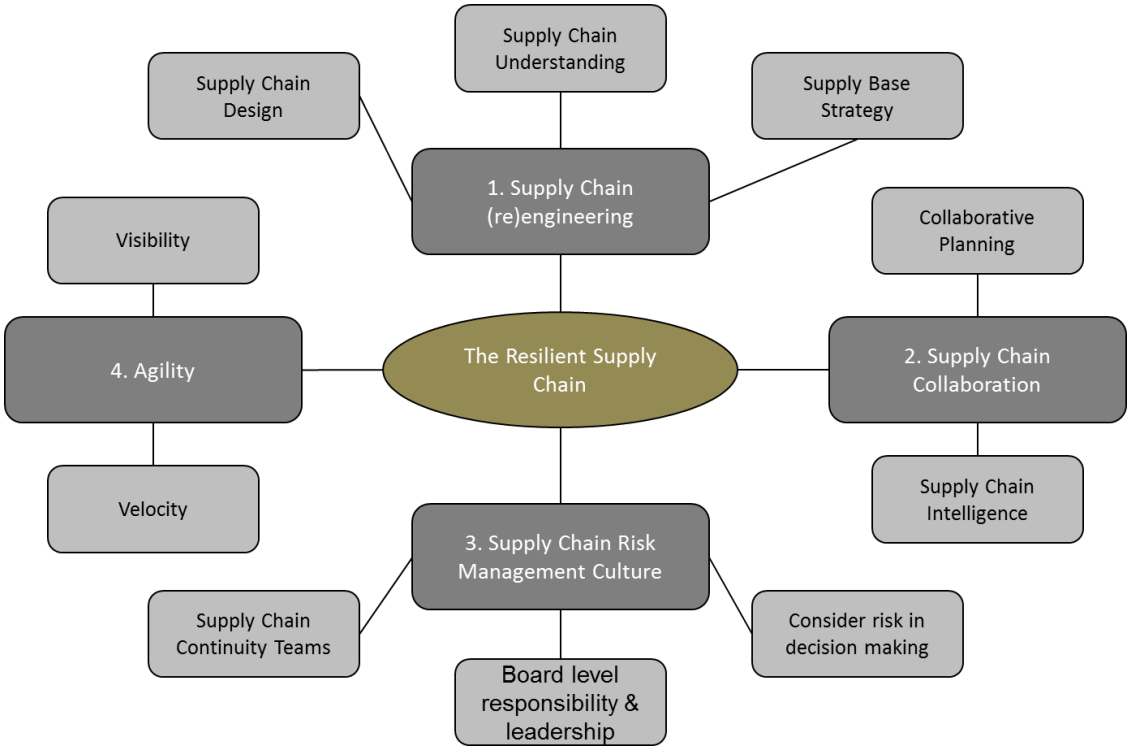
Achieving supply chain resilience

Because even the best managed supply chains will hit unexpected turbulence or be impacted by events that are impossible to forecast, it is critical that *resilience* be built into them. Resilience implies the ability of a system to return to its original or desired state after being disturbed. Resilient processes are flexible and agile and are able to change quickly. In this latter respect it is important to realise that velocity alone is not enough – it is acceleration or the ability to ramp up or down quickly that matters so far as resilience is concerned. Supply chain resilience also requires 'slack' at those critical points that constitute the limiting factors to changes in the rate of flow.

One way to look at supply chain resilience is to consider it as having two key components: resistance and recovery. Resistance refers to the robustness of the supply chain which enables it to avoid the shocks that inevitably impact it. Think of it as a feature akin to a shock absorber in a vehicle. We might hit a rut in the road whilst driving the car but the effect on the driver and the passengers is mitigated by the shock absorber. Recovery relates to the ability of the supply chain to get back on its feet quickly after the occurrence of a disruptive event. Thus for example if a key supplier was no longer able to supply us – for whatever reason- could we quickly access an alternative source?

Figure 5 below suggests that enhanced supply chain resilience is based upon four key elements. Let us consider each in turn.

Figure 5. **Creating a resilient supply chain**

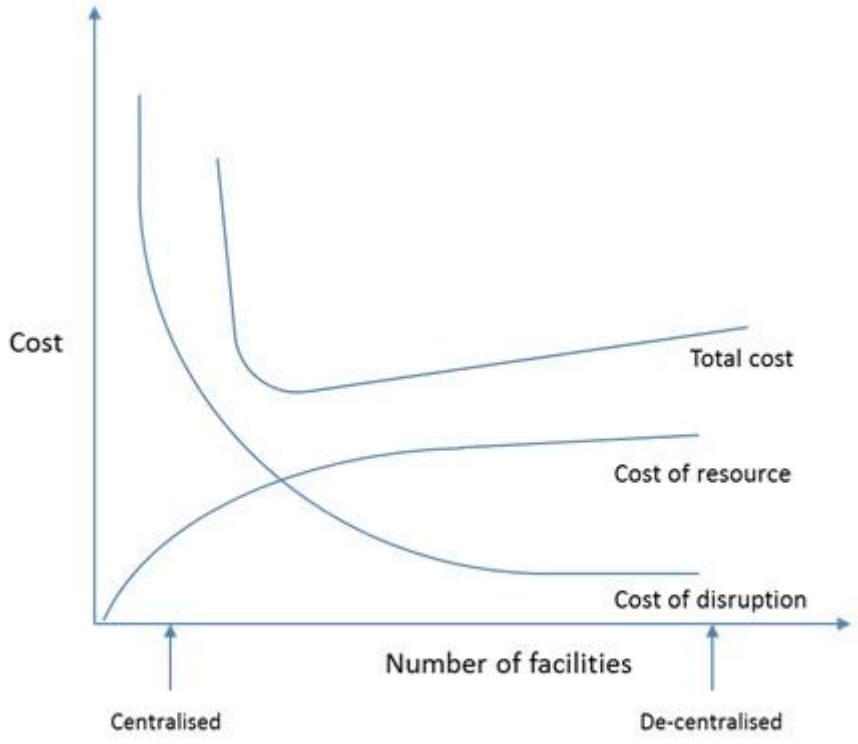


Source: Christopher (2016)

Supply chain (re-) engineering

Much of supply chain risk is systemic; the risk is there because of the design of the supply chain. Many decisions may have been taken in the past that have shaped the current supply chain design. Thus decisions to centralise production or to consolidate local warehouses into bigger regional distribution centres will likely reduce the overall costs of the system but could have an adverse effect on the risk profile of the business. If supply chains can be designed, wherever possible, to avoid the reliance on a single facility or source of supply then resilience will be enhanced. In a sense there is a trade-off between the cost savings resulting from consolidation and centralisation and the resulting risk implications. Figure 6 below highlights this trade-off.

Figure 6. Resilience vs. centralisation

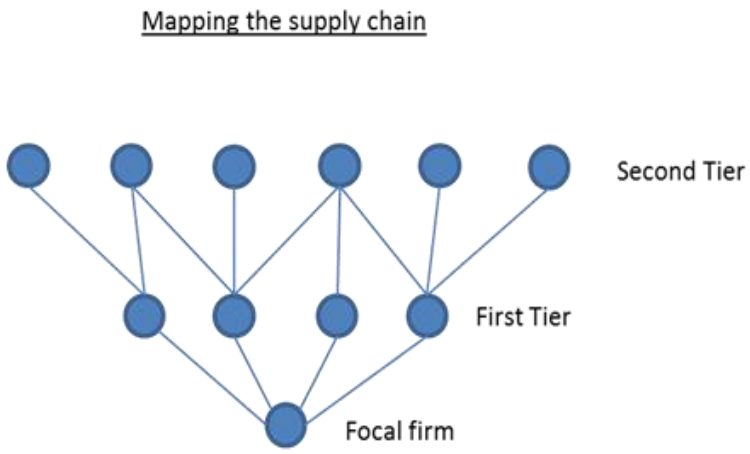


Source: Based on Chopra and Sodhi 2014

Thus even though system costs increase with the number of facilities (e.g. inventory) the associated risk costs come down. It has been suggested (Chopra and Sodhi, 2014) that the system costs go up with the square root of the number of pools of resources while the costs of disruption go down as the inverse of the number of pools. Hence the supply chain design principle that is implied by this relationship is that too high a level of centralisation or consolidation could actually have a higher total cost than a solution with a slightly lower level. The same principle would apply to decisions on the number of suppliers or the level of commonality at the bill of materials level in a product family.

Organisations seeking to create a more resilient supply chain need to ensure that they understand the 'architecture' of their current supply/demand network. This supply chain understanding is facilitated by a detailed mapping of the network. Essentially, the purpose of the supply chain map is to determine the 'as is' status of the network, looking for specific bottlenecks or 'pinch points' and identifying opportunities for re-engineering the system to remove unnecessary complexity. It is particularly important to extend the map as far upstream as possible into second – or even third-tier suppliers to look for critical suppliers who may be hidden from view. Figure 7 provides an example where three first-tier suppliers share the same second-tier supplier. If that second tier supplier were to fail it could be the cause of a major disruption to the supply chain.

Figure 7. Mapping the supply chain



Source: Christopher (2016)

Supply chain collaboration

Because of the inter-dependencies that exist in global supply chains a key driver of resilience is a high level of collaboration between supply chain partners. The reason why creating a collaborative environment is so critical is that visibility and shared information are fundamental to the development of a resilient supply chain. We have already discussed the role of supply chain event management in monitoring critical stages in the supply chain to check for deviations from the plan. Effective event management will only be possible if there is a willingness amongst supply chain partners to share information. A further beneficial spin-off from shared information between different entities in the supply chain is a likely reduction in 'bullwhips' where disturbances are magnified because of a lack of visibility.

Supply chain 'intelligence' can also be enhanced if the key players in a supply chain are prepared to sit down together to pool their knowledge and insights concerning possible sources of risk in the wider supply/demand network. Ideally the business should establish a 'Supply Chain Council' comprising key upstream and downstream entities in the network to regularly review risk profiles and to agree risk mitigation strategies.

Building a supply chain risk management culture

Because of the potentially massive damage that can be caused to the business through supply chain failures and disruption, it is vital that top management recognise the need to provide leadership in supply chain risk management. Regular reports on the risk profile of the business and its supply/demand network should be reviewed by the board of the company. As previously highlighted, a supply chain continuity team should be established which as well as establishing contingency plans also should have a responsibility for engaging with all levels of the business and the supply/demand network to spread the message that supply chain risk mitigation is everyone's responsibility.

This latter point is particularly relevant in the light of the growing concern with cybersecurity. Because every supply chain today is so dependent upon information systems and because of the way in which the

internet and mobile communications drive a great deal of supply chain activity, the opportunities for cyber attacks are much greater. Paradoxically, whilst sharing information across supply chain boundaries is a pre-requisite for effective supply chain management this might also provide more points of entry for those intent on malicious attacks.

Finally, when any decision is taken – by the board of the company or by anyone – there should be a pause before the decision is implemented to ask the question: "how might this decision affect the risk profile of the business?" Thus decisions to change the sourcing strategy or to close a distribution centre for example should be only taken once the potential supply chain risk impact is understood.

Investing in agility

Since the idea of resilience is about being able to 'bounce back' quickly when things go wrong, it will be apparent that the more agile the supply chain is, the quicker it is likely to recover.

Whilst agility has a number of enablers, two of the most critical are visibility and velocity. Superior visibility enables the organisation to see things sooner and velocity reduces the time to respond to the event in question. Essentially, firms need to identify the investment in and the changes to the supply architecture and its supporting systems that would enable a 'sense and respond' capability to be developed. Earlier we introduced the idea of 'structural flexibility' – the ability of the supply chain to adapt quickly to new conditions. At the heart of this concept is the recognition that many traditional supply chains are too rigid because previous decisions have 'locked' the company into a structure with arrangements that are hard to change. It can be argued that if resilience is to be improved then every decision that is made should be screened in terms of how many options this decision will remove or add. The implication being that the best decisions in an uncertain world are those decisions that keep the most options open.

Insurance or options

Conventionally when individuals or organisations are faced with risk they may consider insuring against its potential impact. Today many of the major commercial insurance companies offer various products which enable the mitigation of some of the effects of supply chain disruption. Typically in the past supply chain risk insurance has been linked to property insurance. There are generally two types: Business Interruption (BI) insurance and Contingent Business Interruption (CBI) insurance. BI insurance covers events happening at the property owned by the insured organisation e.g. a fire at a factory. CBI insurance relates to events happening at a property owned by suppliers or customers of the insured business.

These types of insurance would typically cover the costs of recovery but not compensation for lost sales, loss of market share, loss of reputation or loss of shareholder value. By definition this insurance only covers events at properties but not elsewhere across the supply chain. However, new forms of insurance cover are now starting to be offered which may cover the wider risks in a supply chain e.g. infrastructure failure, labour disputes etc.

As an alternative – or at least as a complement – to insurance is the potential for investing in options. It can be helpful to borrow the idea from corporate finance known as 'real options analysis'. In finance an option provides the right but not the obligation to buy or sell an asset at some future point in time. In supply chains there are also options that can be acquired to provide flexibility in the face of uncertainty. The idea is that if real options can be created at a cost less than the benefits to be derived from them, the exposure to 'downside' risk is decreased whilst the opportunity to exploit the 'upside' risk is enhanced. Ways in which real options can be created in supply chain design include making arrangements to access additional capacity if required through third-party logistics service providers or contract manufacturers or by negotiating more flexible supply arrangements with vendors. These options may come at a price but the benefits could be considerable.

Efficiency versus resilience

Perhaps the most prevailing trend across all industry sectors in the last fifty years has been the emphasis on creating a 'lean' enterprise. Because of a continuing need to reduce costs and improve efficiencies the focus in many supply chains has been on how 'to do more with less'. To achieve this objective organisations have sought to reduce inventory, to improve capacity utilisation and to outsource activities which it was believed that others could do more cheaply.

The combined effect of these actions has meant that often there is little to fall back on if unexpected changes in the operating environment occur. Thus it can be argued that in these cases efficiency may well have increased but at the expense of a reduction in resilience.

The challenge to business is how can supply chain strategies be devised which avoid this trap? Is it possible to design a supply chain which is both efficient and resilient? One possible way forward which is slowly gaining traction is the idea that by sharing assets across different supply chains a higher level of resilience can be achieved but at less total cost. For many years companies have increasingly used third party logistics service providers (3PLs) to manage transportation and warehousing. Similarly the use of contract manufacturing has become widespread across a diversity of industrial sectors.

This emerging philosophy has been termed by some as 'the sharing economy'. The idea basically is that it often isn't necessary to own an asset but rather it may be better to have access to it when required. Sometimes these assets may be owned by service providers or they may even be owned by competitors or the ownership can be shared amongst a number of organisations. Thus for example competing companies could share inventory of slow moving but high value service parts thus enabling access at a greatly reduced cost.

As turbulence and uncertainty continue to increase across the business environment resilience and responsiveness become ever more critical to sustainability. New ways of thinking are required and existing mind-sets must be challenged. Those companies most likely to survive and succeed in the Volatile, Uncertain, Complex and Ambiguous (VUCA) world we have described will be those who are prepared to accept the need for fundamental change in the way supply chains are designed and managed.

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The Mitigation of Risk in Resilient Supply Chains

This paper examines the sources of supply chain risk and suggests ways in which higher levels of resilience can be achieved. Recent years have seen a significant increase in the risk of supply chain disruption and the need for resilience across the supply/demand network has become imperative. The paper discusses the focus on agility and flexibility required to achieve higher resilience, which in turn will require new ways of working across organisational boundaries.

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