A Shock to the System – Research Programme of the Cambridge Centre for Risk Studies

Cambridge System Shock Risk Framework

Resilient International Supply Chains

Centre for Risk Studies

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Abstract

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1 The Resilient International Supply Chain

New approaches to RISC Management

Over the past twenty years, multi-national corporations have benefited from turning their businesses global. The science of managing international business networks has rapidly evolved, transforming trans-global supply chains into highly efficient backbones of modern business. But the drive for efficiency has also created vulnerabilities and the potential for systemic failures. Current best-practice in supply chains recognizes how failures might occur, and develops efficient resiliency in operations and system design to optimize protection for the business.

Globalization of business has been a major achievement over the past three decades and management of international supply chains has been developed to a sophisticated science.

Supply chain interruption has become a major concern of global businesses, with disruptions causing serious impacts on a company's long run performance and equity risk. Top executives consider supply chain disruption to be one of the greatest areas of concern in running their business.

1.1 Developing efficient resiliency

Management science is rapidly evolving to understand the threat of disruption, and to develop best practice methods to reduce the impact of disruptions. Managers are increasingly refining their focus on efficiency to incorporate safety margins and incorporate measures to improve the resilience of supply chain operations.

This refinement is the development of efficient resiliency – investing in just-enough safety margin to make a significant improvement on disruption, but not over-investing in wasteful measures. Analyzing and quantifying the value of resilience is an emerging area in the study of operations management.

1.2 Five Steps to Resilience

1. Assess Supply Chain Resilience – understand your supply chain network and identify vulnerable choke-points and concentration risks
2. Determine Risk Exposure – identify the likely frequency and severity of disruption loss from threats
3. Evaluate & Prioritise Mitigation Strategies– select the best operational and structural improvements which have verifiable business benefits
4. Address Supply Chain Resilience Opportunities– manage the implementation of change in your organization and develop a risk management culture
5. Monitor Supply Chain Resilience – develop management routines to track progress and status

The risk assessment process requires a structured framework. Deloitte has teamed up with the Centre for Risk Studies at University of Cambridge, one of the leading centers for operational risk research to review current innovation and translate this into practical action plans for business managers.

1.3 Understanding supply chains as a network

Supply chains are networks of business processes, linked by transportation stages, information flows, financial transactions, and personal interactions.

Supply chains can be seen as 'systems of systems' – they make use of, and overlay, the infrastructure of airports, shipping ports, communications systems, and complex business processes of many other services in the performance of their contribution to business.

Understanding how these networks operate provides insights into their vulnerabilities. The topology of the network – the inter-connections and dependencies – can identify choke-points and concentration risks.

1.4 Threat assessment

Many business managers underestimate their risk. New thinking expects crises to occur. Macro-threats are the most damaging, where multiple systems are impacted at once. A systematic review of potential causes of macro threats identifies over 50 different categories of threat, each of which triggers some level of disturbance somewhere in the world every few months, and an extreme crisis – a "1-in-100" annual event from one of them – could be expected somewhere in the world every two years.

1.5 Five steps to improve resilience

The assessment begins with an understanding of disruption tolerance of the business and the development of a plan that ensures organizational visibility, flexibility in operations, provides a supportive environment for collaboration and establishes good mechanisms to maintain management control.

1. Assess supply chain resilience

Supply chains are more than a collection of bilateral buyer-supplier relationships. Understanding the supply chain as a network of value-add processes and links and connections between them enables an evaluation of the system holistically and topologically. The importance of 'nodes' in the network and key linkage relationships can be prioritized through an assessment of criticality and potential threats to them.

Assessment of network 'density' shows the concentration risk, choke points, and inter-connectedness of the supply chain that may be vulnerabilities to be addressed. Operational logistics and relationships are a key part of the assessment.

2. Determine risk exposure

Risk is the likelihood of disruption loss – the frequency and severity that could occur. Each node can be individually assessed but the greatest threat is the possibility of systemic failures, where a macro-threat causes multiple, correlated impact on many parts of the system at once. Scenario stress tests are useful to evaluate what types of disruption could occur and test potential responses in a preparedness plan.

3. Prioritize Mitigation Strategies

Developing a business case and a road map for action involves the review a range of options for improving resilience in the supply chain. The clearer this can be about the objectives the better, such as setting risk thresholds for delay tolerance.

There are several components of a mitigation plan that can be integrated into a complete road map for improved resilience.

Financial mitigation includes options for insuring loss and fully incorporated into the financial risk management practice of the business.

Operational mitigation involves evaluating options in the design and implementation of the supply chain. Where the risk assessment has identified choke-points, or concentration risks, or over-reliance on individual nodes, alternatives are explored to diversify risk and be less vulnerable to suppliers in higher risk environments.

Operational contingency involves developing a good crisis response plan, which may involve contingencies for rapidly shifting production capacity from one place to another, re-routing supplier capacity, and using alternative transportation methods. Demand management techniques may also help to mitigate disruption impacts.

Tools such as scenario evaluation, cost-benefit analysis and what-if analysis help prioritize the value of the elements of the mitigation strategies.

4. Address resilience opportunities

Having a proactive plan to execute and to take advantages of opportunities enables managers to improve resilience over time. Reaction to an anticipated event, or reaction to an unexpected event are all management challenges but strong relationships with suppliers and customers enables opportunities to be exploited to improve resilience.

5. Monitor supply chain resilience

Monitoring disruption statistics, near-misses, and other indicators of risk potential provides management with status on how the resilience improvement measures are progressing. Monitoring feeds back into the first step in the strategy and provides a virtuous cycle of resilience.

1.6 Embracing efficient resiliency

New management philosophies, analytical tools, and information are available to respond to the challenge of supply chain risk. Best practice addresses the trade-off between cost effectiveness and resilience to unpredictable events, known as efficient resiliency.

2 The Fragility of Globalization

Efficiency vs Resilience

Global business is becoming increasingly and rapidly connected. Connectivity generates huge efficiencies and scaling benefits. But connectivity also increases exposure to shocks and systemic risk. Global businesses need to track and manage disruption threats systematically

Globalization has enabled businesses to derive great benefits from addressing international markets and drawing from global labour pools. Globalization delivers huge efficiencies and economies of scale, facilitated by increasingly sophisticated data collection and sophisticated management methods

2.1 Globalization is only a few decades old

But the phenomenon of globalization is relatively recent. As recently as the 1980s, world markets were regional, poorly linked, and distinct. Globalization was made possible by advances in communication technology and transportation economics that have occurred within the last generation, including the spread of the internet and improvements in telecommunications, widespread air transport and rapidly decreasing freight costs, and greatly improved operations technology.

The pace of growth of international connectivity is illustrated by metrics such as the increase of world air cargo traffic from 40m revenue tonne-kilometers in 1980 to over 200m today. World air passenger travel has increased from 500m revenue-passenger-kilometers in 1970 to over 5 trillion today. International telephone call traffic (TDM and VoIP) has grown from 20 billion minutes in 1981 to over 450 billion today.

2.2 Regional separation to global correlation

This growing interconnectivity has increased correlations between regions. In the 1980s, disruptions and shocks in one region of the world had very little impact on the others – for example a strike in Southeast Asia would disrupt businesses in that region but have very little impact on North American businesses. Now there is close alignment between trends and shocks in all of the major markets in the world. This connectivity can be seen clearly by looking at price changes across all the international stock markets of the world, where their day to day fluctuations have become more aligned. Analysts have measured that correlations between international stock market variations have doubled since the 1990s.

2.3 Frequency and severity of disruption

All businesses and supply chains have unwanted variations and minor disruptions, with the occasional severe disruption. The ratio of frequent small disruptions to rare big ones – the frequency and severity distribution of disruptive loss to a business – is a key metric of supply chain risk management. Globalization and the ability to serve and source across many markets has reduced the vulnerabilities of businesses to local market fluctuations, accidents, and minor shocks – the frequency of smaller disruptive losses is reduced.

2.4 Increased vulnerability to big shocks

But global interconnectivity has created vulnerability to rare, big shocks. The world has always been a chaotic and uncertain place, but when markets and businesses were not connected to each other, shocks were more localized.

Now a major event almost anywhere in the world can have a catastrophic ripple effect on the connections that a global business relies upon. And the ripple effects now impact many more businesses, and have bigger inter-linked consequences that can have cascading and amplifying systemic impacts across multiple parts of a business.

2.5 Globalization has increased 'tail' events

Global interconnectivity has increased positive correlation, which means that when one system goes down, there is an increased likelihood of others going down as well. This network effect has increased the potential for much more severe business losses than many senior managers are expecting or planning for.

In the frequency-severity distribution of disruptive loss, the rare catastrophes form the 'tail' of the distribution. Globalization has increased the likelihood of tail events.

2.6 'Black swans' and emerging risks

Tail events, or unexpected catastrophes, are increasingly being factored into business risk management. Popularized as 'black swan' events or as 'low probability, high impact'

events, these have become important aspects of businesses, occupying increasing business focus on identifying emerging risks.

Globalized businesses have refined their management strategies and operational procedures over only a few decades. The early focus was on optimizing operations for cost reduction and other efficiencies. This may have been justified by relative stability during these few decades, when threats to the entire system in the form of major natural disasters, political upheavals, or other disruptive stresses were perceived to be too infrequent to affect business strategy. However rare a political crisis or a natural catastrophe may be in any individual location on the planet, a globalized business spans many locations and finds itself exposed to crises more often than is generally perceived.

2.7 Efficient resilience

The management of global business and large scale international supply chains is beginning to shift focus from efficiency as a single end goal, to efficient resilience - ensuring that an appropriate measure of resilience is built into the supply chain to protect against rare but severe shocks. The aim is protect against extreme situations that threaten the viability of the business or cause severe loss.

Resilience is often at odds with efficiency. A manufacturing process might be made more resilient to supply disruption by having larger inventory of component parts or finished products, but lean and efficient management practices discourage holding inventory. Building resilience into a supply chain may require some level of additional investment, or allowing some areas of inefficiency, as a safety margin for extreme situations. There is a balance to be made between some level of increased cost to the business, either in capital investment for resilience, or in allowing additional 'inefficient' capacity during operations, or investing in options for response and recovery.

2.8 Judging the right level of investment

The difficulty is to assess how much cost is worth investing to protect business operations against future potentially rare but severe disruptions. This is not a straightforward econometric cost-benefit analysis, but a carefully considered process for understanding the business needs of a company, assessing their exposure, and understanding the true nature of the threats so that senior management can make judgements based on the best-available knowledge.

2.9 A risk assessment framework

The risk assessment process requires a structured framework. The Deloitte framework for developing supply chain resilience is set out in the following sections, and developed into an action plan to develop a resilient international supply chain.

3 Systems of Systems

Supply chains rely on existing infrastructure

Supply chains are 'systems of systems' – they overlay and leverage the networks of infrastructure that have been developed to serve air transportation, marine supply routes, and business communications. These global systems have their own characteristics and vulnerabilities which supply chains inherit. A network can be represented by its topology, which is about the connectivity of the network, provides a foundation for deriving key indicators of vulnerability.

The global networks that underpin modern societies are systems of systems where complex networks are built on top of simpler ones.

For example, in a supply chain, goods are shipped over a transportation network which itself is a network constructed out of separate interlinked air, sea, road and rail systems. Related negotiations, contracts and business communications take place over networks made up of email, voice and electronic payment. All these systems in turn rely on a lower level supply of electricity, fuel, water and built infrastructure.

3.1 Characterizing Networks

Networks can be measured and characterised in terms of vulnerability where a given network will inherit the vulnerabilities of the underlying networks on which it is built. By understanding the vulnerability of simpler individual networks we can assess the vulnerability of a higher level complex network.

A particularly interesting characteristic of a network is its topology because from that it is possible to make general assumptions as to a network's vulnerability.

3.2 Topology and vulnerability

High order star – example air travel network: Whole network is vulnerable to failure at the "hub" node at centre of the star.

Low order "scale free" network – example the internet: Redundancy in the network offers a variety of alternative pathways. Low vulnerability to individual node failure.

Core periphery network – example the global banking network: Core central component network of key nodes with good redundancy. Low vulnerability to failure in the core but widespread failure in the core will bring down whole network.

3.3 Networks on networks

When analysing a network built up from other networks, it can be thought of as three levels, starting with the simplest and working up in complexity:

- Substrate or infrastructure networks, which provide basic needs such as water and electricity. They are characterised by high capital cost and inflexibility.
- Primary systems, such as road and rail networks, are the key systems of a modern economy. They have a high capital cost but have some flexibility.
- At-risk networks are the business networks which companies operate. The cost and flexibility of these networks is within the scope of the decision making of organisations and their advisors.

3.4 Substrate networks

Utilities Electricity generation & distribution

Gas storage & distribution

Oil storage & distribution

Water/sewerage

Telecommunications Wired

Wireless

Physical infrastructure Roads

Railways, terminals

Ports, terminals, canals

Airports

Buildings and structures

Primary networks

Primary systems are built on top of substrate networks and at this level it is useful to characterise the network topology, and from that derive inherent vulnerability and redundancy. This table shows some typical primary networks.

Primary networks	Network topology	Redundancy
Air transport	Star	Low
Cargo shipping	Medium order	Medium
Data	Scale free	High
Telephone	Scale free	High

Broadcasting	Star	Low
Energy distribution	Core periphery	Medium
Water and waste	Core periphery	Medium

3.5 At-Risk networks

Supply chains are the networks that risk managers control. Supply chains make use of a wide variety of substrate and primary networks. Companies use the air transport and shipping networks to move their goods, and rely on telecoms networks for the information flows that the business depends on. Supply chains inherit the vulnerabilities of the underlying networks.

Risk assessment for a given supply chain involves understanding the vulnerabilities of the primary and substrate networks that it relies on.

3.6 Primary Networks

Air transport

Air transportation networks are routes between major hubs of expensive airport infrastructure. The 20 largest airports handle a third of all passengers worldwide. The dependence of so much traffic on a small number of hubs makes it a 'high-order' network and vulnerable to disruption from the loss of a few nodes.

Shipping routes

Cargo shipping routes concentrate in busy sea lanes and favor major international ports, but are not as concentrated as air networks. There are major choke points of sea routes – 8% of the total world shipping trade passes through the Suez Canal.

Communication networks

Telecoms and data traffic are less vulnerable to disruption as they utilize multiple routing technology, making them a scale free network. But the system relies on physical infrastructure of server farms, transmission networks, and communication exchanges. This figure of data volumes transmitted through the internet shows the importance of transatlantic connectivity, and the data hubs in different parts of the world.

3.7 Consumer electronics supply chain example

The skills and labour pools required to manufacture consumer electronics, combined with the high cost of high technology manufacturing and low transport costs tend to favour the clustering of assembly processes in centralized locations. This produces overall a high-order star topology for this industry, with intrinsic vulnerabilities to localized disruptions. The supply chain is the at-risk network making use of the primary networks of air transport, cargo shipping, communications and many other networks.

Manufacturing supply chain for consumer electronics computer products. Components are sourced from all over the world and assembled in stages of increasing complexity, to a final assembly. In this example the final assembly plant is in Shanghai, China. Completed products are then flown to markets in North America, Europe, Southeast Asia and elsewhere.

The consumer electronics manufacturing supply chain viewed topologically, showing assembly stages migrating towards the central final assembly hub.

The network resembles a high order star, with each stage of assembly dependent on timely delivery from suppliers upstream. The process is vulnerable to disruption from many points of supply failure. The system is vulnerable to any disruption to the central hub.

Production is managed by a tight turn-around of orders from regional managers in 20 different countries, with the largest markets being US, Europe, China and Japan. Completed units are flown from the main assembly plant in Shanghai to main airports in each country, and from there to regional distribution centers. Sales are seasonal and deliveries are time-critical to meet peak demand times.

The supply chain is vulnerable to disruption to the main assembly hubs, air transport networks, or regional distribution networks.

3.8 Automotive supply chain example

The high cost of transport makes it more efficient to have localized assembly plants close to each major market. The complexity of the product requires many thousands of components to be produced. Different manufacturers have taken different approaches, some prefer using standardised components to make use of a more open market approach to procurement from their suppliers. Others prefer specialized design and develop deep relationships with their suppliers in a mode of ‘coopetition’ and shared business risk.

Distribution supply chain for European auto manufacturer, with major assembly operations distributed to each of the major markets for the products. In each regional market, there are a large number of component suppliers that serve the regional production center. Major

complex assemblies, such as engines, are built in a few specialized locations and then shipped to assembly plants around the world.

The topological network diagram of an automotive supply chain has several main assembly hubs, served by component manufacturing plants and large numbers of component suppliers. Component suppliers are mainly market-specific, but some larger component suppliers provide to multiple markets. The turn-around speed of unit manufacture from initial order is lengthy and is more tolerant of delay than other product sectors.

The network represents a core-periphery network, with several star networks linked by a core set of relationships. The dependency on very large number of components means that the process can be disrupted by delays in the supply of any of them. The supply chain is highly efficient, with minimal inventory, due to sophisticated inventory control and ordering systems.

Recent shocks to the system from delivery delays have prompted measures to improve resilience, such as closer partnering with suppliers, diversification from single suppliers, and increased safety margins in business planning.

4 Shocks to the System

Keeping track of emerging threats

There are many types of threats that can potentially cause disruption to international supply chains. Recent years have seen a succession of highly disruptive events. Knowing what threats can pose challenges to international business systems is the key to preparedness. Monitoring emerging risks is an important part of managing resilience

Over the past few years a number of events have caused surprisingly severe and wide ranging consequences to international businesses. This has caused a shift in attitudes to managing supply chain risk. Managers expect that events like these could be more frequent than they had previously thought, and that worse events may be possible. Some are reviewing their business systems to make them more resilient to potential future shocks.

4.1 Monitoring emerging threats

While it may never be possible to predict every type of possible event, it is becoming standard practice to monitor emerging threats and to perform ‘what-if’ stress tests of how a business system might fail under potential future scenarios. Scenarios can be used to explore how different strategies will improve the resilience of a network.

Match threats to vulnerabilities

Knowing what types of threat would pose the biggest challenge to a supply chain network helps managers decide what resilience strategies they can best pursue.

A company that has mapped out its business processes, both geographically and topologically, the vulnerabilities of the network become apparent, and the likely threats to those vulnerabilities can be identified.

A structured framework for threat assessment helps identify the biggest threats to a supply chain's vulnerabilities.

4.2 Japan Tohoku earthquake March 2011

The unexpectedly large magnitude earthquake off the coast of Sendai in Japan caused a major tsunami and a meltdown of a nuclear reactor, causing consequences with Japan's trading partners and interrelated business activities all around the world.

Consequences included:

- Extended power disruption to Japanese manufacturing production
- Major Japanese corporations found production and sales severely curtailed, leading to major share price devaluation
- Production of products in other parts of the world disrupted by shortfall of critical components from suppliers in Japan
- Auto production was halted in some car plants in different countries
- Electronics consumer goods were delayed reaching market
- Manufacturing production has been relocated by some companies from Japan to other countries
- Energy sector and nuclear industry severely impacted by political consequences of the disaster

Examples of disruptive events to global business

- SARS outbreak in 2003 disrupted airline passenger traffic for five months, depressing tourism, travel and other business
- Hurricane Sandy 2012 impacted eastern United States causing severe disruption to a region that generates 40% of US economy. Flights from many airports were disrupted and eastern sea port closures disrupted international shipping traffic for weeks
- Volcanic eruption of Eyjafjallajökull, Iceland, 2010, closed airports across Europe for two weeks. Business sectors worst hit, included fresh produce providers, pharmaceuticals, and electronics

- Arab Spring uprising in multiple Middle Eastern countries 2011-12 had impacts on many international businesses, including increased fuel prices. More than 22% of businesses globally reported that the unrest has a negative impact on their business
- In 2010 piracy activity around Horn of Africa reached an unprecedented level of 490 acts of piracy, and an estimated $12bn in costs incurred, leading to re-routing, delays, and cost escalation for shipping routes between Europe and Asia
- Unprecedented multi-national General Strikes were coordinated across Portugal, Spain, Italy and Greece in November 2012, leading to impacts on air travel, telecoms, and many other business sectors
- Mexican Swine Flu Pandemic 2009 caused international panic with initial reports of a high virulence virus, leading to travel and business disruption for many weeks
- 7/7 2005 terrorist attack on London caused the closure of the City's financial center, airports and local travel systems, and impacted international business activity
- North American Blizzard of 2010 affected most of US with record snow levels, suspending travel services, international flights and shipping with waves of snowfall through Feb and March
- Deepwater Horizon oil spill in 2010 made large parts of the Gulf of Mexico unnavigable, caused damage to local industries and disrupted international business connected to the region

4.3 A taxonomy of threats

There are many different types of threat that could cause business disruption to international networks. A classification system is useful to define the different categories of threats that might be planned for.

The threat taxonomy shown here is the result of a detailed study of a thousand years history of disruptive events to society, populations, and business activities. Events have been identified from historical records, population statistics and economic data. The study has concentrated on the most severe events – the 'macro-threats' that can cause substantial disruption to businesses across more than one country for more than a week, and that have a greater than one-in-a-thousand chance of occurring somewhere in the world each year.

4.4 Macro threat checklist

This classification helps concentrate on the more severe threats to multiple businesses, rather than on threats that may still be significant to an individual business network, such as a major fire in an important factory. The focus is on correlated events that impact many sectors of business together, which can lead to cascading effects and consequences. The threat taxonomy provides a useful checklist for evaluating supply chain vulnerabilities – which of these threats pose the greatest risk to the weakest links in the system? – and enables a prioritization for monitoring emerging risks.

4.5 Understanding the threats

Each of these threats has different characteristics, such as where in the world they are most prevalent or the risk of occurrence is highest. The effects that they have is different – some trigger mainly a financial impact, others cause destruction, some have the effect of debilitating personnel or reducing demand for services. Most of the threats cause some different mixture of all these types of effect at once. There is a body of knowledge available about each threat type.

4.6 Scenarios for stress tests

The networks at risk can be analyzed by applying a stress test of a hypothetical threat scenario, and assessing how the system is likely to behave and what management response would be, to that event.

Scenarios are useful to identify key weaknesses in the architecture of a system or in the procedures and business operations. They can help identify how best to make improvements that reduce the likelihood or severity of disruption.

4.7 Correlation of events

In the worst type of events, more than one thing goes wrong at once. Severe events can trigger other types of events to occur, and these often cause the main surprise. The likelihood of one type of event to trigger another is captured here. It is worth considering scenarios of multiple, cascading events.

4.8 How some threats may trigger others

Cambridge Framework of Macro Threats to Global Supply Chains

The macro threat assessment framework enables organizations to check the resilience of their business systems to the occasional occurrence of extreme events. Although each individual threat poses a very low likelihood of triggering a major disruption in a supply chain, collectively they demonstrate that there are many potential causes of disruption that should be expected in the management of global businesses. One or more of these 55 macro threat categories triggers some level of disturbance somewhere in the world every few weeks. An extreme crisis – a "1-in-100" annual event from one of them – could be expected somewhere in the world every two years. Each threat has very distinct patterns of occurrence, geographical prevalence, types of impact, and likelihood of occurrence. Managers of supply chains should expect to have to manage these types of crises routinely.

5 Five Steps to Resilience

Assessing the risk and reducing it

Improving supply chain resilience can have major pay-offs for businesses in protecting against extended periods of disruption. This section describes an approach to reviewing your risk of supply chain disruption from localized extreme events. It describes how to go about reducing risk and improving resilience.

Increasing the resilience of efficient supply chains is a complex task involving many participants at different levels in an organization.

Aligning priorities and processes requires thoughtful conceptual guidance. Accompanying sound governance principles and resources management across people, processes, and technology are four key pillars that offer a targeted approach to building efficient, resilient supply chains.

The four pillars of visibility, flexibility, collaboration and control, provide a conceptual overview of the characteristics that underpin a resilient supply chain.

5.1 Visibility

Resilient companies have good visibility into their entire business networks, know the weaknesses and vulnerabilities of their system, and fully understand the threats to it. They identify major weaknesses – the chokepoints and concentrations, over-reliance on single suppliers, and other elements, and have strategic plans to address them.

Many companies have a good understanding and set of processes in place to manage operational threats, such as the impact of localized disruptions. Managing macro threats is less systematic in many companies. Some take the view that events that could cause extreme levels of disruption are so rare as to be of no concern to their short term business objectives.

Leading companies are developing comprehensive visibility into all their risks, and monitor any emerging threats.

5.2 Flexibility

Companies that can maintain flexibility can adapt to crises. Flexibility requires sound preparation and clear communication. Having more than one option to respond to an unexpected event involves contingency planning, scenario analysis, and clear decision-making protocols for key managers.

The central goal is to minimize disruptions as quickly as possible at a cost appropriate to the value of the affected operation.

5.3 Collaboration

Critical to attaining cost-effective flexibility is collaboration. Supplier relationships based on trust helps lower transaction costs and reduce uncertainty – this is particularly valuable in times of crisis but needs to be fostered and developed in times of calm. Developing a thorough understanding of the supply chain helps identify the key supplier relationships and critical, strategically significant networks.

Dealing with supply chain crises also requires a more modern approach to strategic activity. The principles of 'coopetition', where competition and co-operation exist concurrently, can offer insulation from business interruption. However, it is a concept that, in practice, requires clear boundaries and time frames and a high degree of trust between organisations.

5.4 Control

The final pillar, control, is the capacity to implement and execute the policies and plans designed to provide resilience. It enables organisational processes to occur in a timely fashion and in accordance with the analysis provided. Transparency is critical. Clear information, sound analytical and detection frameworks, knowledge of consequences and alternative options, and a fast and engaged decision-making process allows the company to utilise the appropriate people, processes and technology to prevent or minimise disruption.

6 Five Steps to Resilience

The pillars of resilience can reduce vulnerabilities and risk exposure through a five-step process:

1. Assess Supply Chain Resilience

There are a number of ways of assessing supply chain resilience. Operational assessments often focus too closely on personnel and resource assessment at a highly granular level, which has been criticized as sometimes missing the big picture of broader aspects of supply chain risks . Current thinking urges that organisations evolve beyond a tactical conceptualisation of the supply chain, where analyses are rooted in bi-lateral buyer-supplier relationships , to embrace more strategic relationships.

Various approaches embrace a holistic understanding of the supply chain to enable mutually beneficial cooperation both vertically and horizontally , to improve risk management protocols , and move the company closer to establishing efficient resilience.

Mapping the supply chain network

Mapping a company's network – logging the sources, links, processes, and value of the various links in the chain – has become a key first step in assessing supply chain resilience.

It is not always necessary to go into extremely high levels of resolution for supply chain assessment. A review of the top tiers of suppliers is a good initial analysis. Where a supplier situation appears to pose a risk, it may be valuable to go into more detail and review their next tiers of supply points and connections.

Visualisation tools assist in understanding network connections both geographically and topologically, enabling greater appreciation and more accurate assessments of the vulnerabilities of, and risks to, a company's supply chain.

The supply chain can be assessed both structurally (the design of the network) and operationally (how the processes are managed in running the network).

Structural assessment of supply chain

A structural assessment means an analysis of the geography and inter-relationships of the supply chain network, as described in Systems of Systems.

If a supplier or assembly process is considered as a 'node' in the network, then a structural evaluation assesses the 'density' and 'criticality' of each key node to highlight the impact it might have on the severity of disruptions . Whereas operations optimization is concerned with assessing maximum flow (between two nodes), the shortest path (in terms of time or distance), or potential transportation problems (connecting customers with facilities) , resilience assessment involves judging choke-points (single-point constraints on flows), concentration risk (multiple key elements that are too closely interconnected), and overall supply chain density (susceptibility from close grouping) .

Network density

The 'density' of a network – the interconnectedness – is closely related to the severity of disruptions that it might suffer. The assessment identifies high-value clusters and areas of geographic concern.

Node criticality

The importance of each node in a supply chain is assessed from the linkages it has and if possible, from the value that it contributes to the overall process or revenue it generates. Assessing node criticality identifies vulnerable nodes, such as unique suppliers, and provides a value hierarchy for prioritizing risk management actions.

The resilience of two different supply chains can be contrasted by comparing their densities and the number of critical nodes that they each have.

Operational assessment of supply chain

The processes that enable the supply chain to operate are an essential part of the review of the resilience of the system. Operation assessments begin with the communication flows and information exchange that enables the processes. The culture of the management staff, their risk awareness, trust and governance are essential components of a full assessment.

Operational logistics

Much of operations management science, is devoted to operational logistics. Operational assessment of logistics resilience entails understanding standard procedures for managing disruptions and delays, making up shortfalls, and tolerance of failures.

Disruption tolerance

Records of disruptions that have been experienced in different parts of the network can help to establish operational volatility. 'Interruption windows' – the duration of supply delivery delays that can be tolerated at the key nodes – are indicators of the current resilience of the supply chain process.

The supply chain as a complete system

The structural and operational assessments of the supply chain are integral to its overall performance. The supply chain is a complete system, and needs to operate as process, including the important ancillary processes. Assessing it holistically is a key input into the risk assessment process.

2. Determine Risk Exposure

There are various approaches to assessing risk in supply chains. Risks can be distinguished between endogenous (internal failures of the system), exogenous (shocks that come from outside), and shared risks . Others take the approach described here of distinguishing between localized risks (the failure of a single or small number of closely related nodes) and systemic risk (the widespread failure of multiple parts of the system due to an external shock, perhaps as a result of a macro-threat).

Risk as likelihood of loss

Risk is generally expressed as a threat or hazard (events that might occur) combined with vulnerability (the impact on the supply chain if it did occur). Risk exposure is a combination of assessing the likelihood of threat occurrence with the vulnerability of the system to the threat. Risk is the likelihood of loss – in this case the disruption of a business system through supply chain failure.

Approaches to risk assessment in supply chains

A number of conceptual approaches have been proposed to understanding risks, threat and vulnerability in supply chains. Several approaches provide lists of threats as checklists or typologies for consideration, for example conceptualized as maps of concentric vulnerability from financial, operational, strategic and hazard layers . Others present lists of varied risks combined with practice-based vulnerabilities or a transaction cost-based risk typology , or framed as professional management risks (such as cost, quality, lead-time, and security) .

Risk assessment for key nodes

For each critical node in the supply chain, a threat-impact 'traffic-light' matrix can provide a relatively straightforward and meaningful visualisation of risk severity. Threats are typically categorized into low, medium and high threat, combined with the impact that the threat would have, assessing the vulnerability of the node to that threat. A risk assessment matrix a useful technique to prioritize critical nodes where high impact potential and high threat likelihoods place them at risk.

Systemic risk assessment

The greatest threats to a supply chain are those in which a macro threat causes multiple, correlated failures in many nodes of the system. Macro threats can impact large geographical regions and, more importantly, cause failures simultaneously in several of the primary networks that supply chains depend on. Contingent failure – the disruption to a supply chain from failures that propagate throughout a system – is more complex to anticipate and assess. It is often difficult to assess the risks to the output continuity of an assembly plant when it is dependent on components being delivered from other parts of the world. The risk to the assembly plant includes the risk of disruption from all its suppliers in other countries.

The systemic risk for a supply chain involves looking at how the network might behave as a whole. A disruption to one part of the network can spread to other parts, for example if air traffic is substantially disrupted in one region of the world with planes being grounded for several days due to extreme weather, then aircraft routing all over the world can be affected that may cause transportation difficulties and supply delays in regions unaffected by the original cause.

Using scenarios for risk assessment

Macro disruptions that have occurred to the international supply chains over recent years have increasingly caused companies to review their risk assessments of their supply chain as a system.

A common technique is to apply scenarios as a stress test to the supply chain system. Hypothetical scenarios such as an extreme weather event enable managers to explore

potential consequences across all sides of their business: supply chain, manufacturing process, fulfilment, and consumer demand. It enables risk assessment for the business system in addition to the vulnerabilities of individual nodes or processes.

Scenario stress test on a supply chain

In this example, an extreme winter scenario of an extended multi-week freeze across northern Europe and the American northeast is applied to the supply chain of a consumer electronics company.

Airports operate at low capacity for several weeks, disrupting airline routing worldwide, delaying component supplies. Assembly plants in the impacted region suffer reduced outputs from diminished staffing levels with local travel conditions. Distribution of product within the important markets of US and Europe face logistical challenges, and consumer demand is suppressed over an important retail sales period. The freeze causes economic consequences for many other businesses that impact the overall business environment.

3. Evaluate & Prioritise Mitigation Strategies

Once the resilience of the supply chain has been assessed and the risk to the supply chain has been evaluated, the company may want to consider improving the resilience of their supply chain system.

This involves assessing the costs and benefits of potential resilience strategies and developing a business case and a road map for best course of action.

Setting risk threshold objectives

An important part of risk management is to try to articulate the performance goals required. This is usually a tolerance level for the amount or duration of disruption for key business processes, such as delivery delays for product at the primary distribution centers for the major markets served by the business. The objective of mitigation strategies might, for example, be to try to ensure that supply interruptions do not exceed one week. In reality measures to mitigate future interruptions come at some level of cost, and the balance between investment and risk mitigation will be a business judgement. Making this decision as informed as possible is the aim of good risk management.

Prevention strategies and impact limitation

Most delays are relatively short in duration. A small increase in delay tolerance can greatly increase the resilience of the business to moderate disruption. It may be possible to improve resilience to a level where moderate delays have no impact on a business, or that moderate disruption is eliminated. A prevention strategy might involve maintaining redundant

sources of suppliers, or achieving higher levels of quality management throughout the supply chain.

Short term: Inventory as a resilience strategy

Delivery delay impacts can be mitigated through maintaining redundant inventory. Operations management has greatly improved operational efficiency of supply chains through techniques such as just-in-time (JIT) delivery and lean business processes to eliminate wastage and cost that is entailed in maintaining inventory. However it is increasingly argued that JIT increases the vulnerability of supply chains to disruption . Maintaining some level of inventory provides a safety buffer for delivery delays. Balancing the efficiency of the overall system with the need for resilience requires important judgements of how much to invest in safety margins. The need to manage this trade-off is increasingly being recognised in risk management for supply chains. This trade-off is an issue of efficient resiliency.

Long term: Recovery planning

Where delays are inevitable, or the costs of preventing them are uneconomic, the focus of mitigation is on rapid recovery from a disruption. Contingency planning aims to have measures in place to maximize the speed of restoring productivity after disruption.

Restoration time after disruption can be improved if the potential for disruption has been recognized and pre-determined contracts, for example with alternate suppliers or transportation alternatives, have been put into place.

Components of a mitigation strategy

Risk mitigation strategies to improve supply chain resilience have been characterized into three broad categories : Financial, operational mitigation, and operational contingency.

Financial mitigation

Financial mitigation is the practice of building margins for disruption into the economics of the business, and planning for a mixture of small disruptions occasionally and for rare occurrences of extreme disruptions. Business interruption (BI) insurance may provide some protection, although most forms of BI are linked to damage to property that the company owns. Contingent business interruption insurance, where the cause may be transportation disruption or power failure, is less common and may be expensive.

Ensuring that supply chain risk is properly represented in the financial risk management practice of the business will ensure that the company's investment strategies, currency exchange hedges, and other measures, help maximize protection against supply chain failure consequences.

Operational mitigation and supply chain design

In addition to considering increasing inventory storage to offset disruptions, operational mitigation includes evaluating options in the design and implementation of the supply chain itself. Where the risk assessment has identified concentration risks, choke-points, and over-reliance on individual nodes, alternatives can be explored to diversify risk and be less vulnerable to failures in unique suppliers. Low cost country sourcing (LCCS) may offer considerable cost savings, but may increase the risk in the form of capacity limitations, higher threat environment, and financial instability. Changing sourcing strategies may involve shifts to more reliable sources or the implementation of multiple sourcing strategies.

Operational contingency

When a major disruption occurs, companies that are able to respond flexibly are able to minimize the business impact. Shifting production capability from one place to another, re-routing supplier capacity, and using alternative transportation systems can recover quickly from an unexpected crisis. A number of blue-chip companies have avoided significant losses in a crisis through successful rerouting policies. These kinds of mitigation measures usually require contingency plans to be put in place before a crisis occurs. Improvization during a crisis may be the least-best option.

Demand management and product design

Where a crisis results in production shortfall, it may be possible to use demand management techniques, and incentivize buyers to favor replacement products that are more available to offset the disruption impact.

In the design of products, several companies have pursued the use of more standardized components to enable multiple sourcing from the open market, improving both the competitiveness of supply economics and the ability to switch suppliers in a crisis.

Evaluating and prioritizing mitigation strategies

In most cases developing resilience in a supply chain will be a combination of several of these strategies. The implications of each, the benefits they provide and the costs they entail, is an assessment exercise. A successful mitigation plan will prioritize the biggest gains for the least costs, and identify the business case for change. Tools such as scenario evaluation, simulations, modelling and cost-benefit analysis are useful evaluation techniques.

4. Address Supply Chain Resilience Opportunities

While much of the technical complexity exists in the analytical stages, it is the execution of the mitigation strategies that determines whether efficient resiliency is achieved.

Three types of opportunities present themselves for action to improve resilience in the supply chain: proactivity, anticipated events, and unexpected events.

Proactivity

Proactive strategies may emerge as the optimum plan from the analysis of risk. These require management direction and commitment to implement. Managers who understand the dangers posed by disruption crises, who identify the key threats and vulnerabilities, and who act to put a corrective plan into action are able to take advantage of opportunities to manage their risk. Implementing a plan carefully and incrementally over time is a more cost-effective approach than having to respond in a crisis.

Reaction to an anticipated event

Some measures can anticipate future disruptions and have a crisis roadmap in place ready to respond —a series of steps known to logistics teams and senior managers. It is important to detect that a crisis is occurring or about to, and to properly identify the nature of the threat and the nodes affected. From there, the mitigation strategies can be implemented.

Reaction to an unexpected event

Unexpected crises are the greatest management challenge. Improvising a crisis response is more difficult and costly without pre-planning, but rapid action can contain and minimize losses, and speed the restoration of normal processes. A defining feature of a crisis is that information is imperfect and management decisions often have to be made without a clear picture of the scale of the problem. Waiting until all the facts have been established may not be an option, as reaction time may be a key factor in controlling losses.

Information management is a key part of crisis management, and establishing situation reports and information feedback loops has proven vital in restoring management control and business recovery.

Having strong relationships with suppliers and customers winners is known to be important when managing a crisis. Management response is both conditioned by a need for restoration of business processes and searching for opportunities to improve or strengthen those processes.

Using opportunities to improve resilience

In some cases a crisis is an opportunity to implement resilience measures that might not have been possible beforehand. A crisis is often a catalyst for change, and in the aftermath of a loss, the argument for the need for improved resilience is clear. Management support can be more easily rallied for proposals to implement plans for improved resilience.

The road map for resilience depends on people, processes and technology. If these are prepared, then opportunities can be used to move the road map forward incrementally over time.

5. Monitor Supply Chain Resilience

Risk is not static. The final stage in developing a strategy for improving resilience in supply chains is to evaluate the effectiveness of the plan put into place and to monitor the status of resiliency.

Monitoring disruption statistics

The objective of improving resiliency is to reduce the frequency and severity of localized disruption and to be less vulnerable in the event of a more extensive crisis. It may be possible to monitor the effectiveness of resiliency measures put into place from metrics such as statistics on how often minor disruptions occur and how severe they are. It is also important to monitor 'near-miss' events, where disruptions could potentially have occurred if protection measures had failed.

Any major crisis will be rare and the company should not have to face many of them or often. When a crisis does occur, a post-event evaluation will provide valuable lessons to feed back into management.

Monitor the vulnerability of the system

The assessment of supply chain resilience involves mapping the system, a structural and operational assessment and other evaluations, as in the first step of the methodology. Monitoring these routinely provides status updates on the key vulnerabilities that have been identified, and can identify changes that could potentially be degrading the resilience of the system, or providing management feedback on the pace of improvements from the resilience implementation plan.

Monitor emerging threats

As new threats emerge, either internal issues, or external macro-threat developments, operational checks, stress test scenarios and other contingency plans can be developed to mitigate these impacts. Many companies have emerging risk committees dedicated to monitoring the rise of new threats and developing management responses to them.

Monitor internal and external trends

Monitoring should be trend-focused, with clear indicators and reporting structures, and should rely on clear and transparent communication between all those involved in supply chain management, from logistics to senior executives.

It is important to communicate the risk issues involved to all members of the organization who may be involved in improving and maintaining resilience. There are several studies of the importance of developing a risk management culture within an organization. Advanced analytics and visualisation tools can help facilitate understanding and communicate the essence of supply chain disruptions to different audiences in the organisation.

The virtuous cycle of resilience

Monitoring – the last step in the five step methodology – feeds back into the assessment of supply chain resilience – the first step. The process is a virtuous cycle that iterates and improves.

Risk management should mirror the pursuit of efficiency in the business operations. Improving resilience is an important additional dimension of business management, and one that will entail resources and management focus, but as a result the business process will be made more secure and managers will achieve truly efficient resilience.

7 New Approaches to RISC Management

Developing efficient resiliency

Management of supply chains has progressed from a narrow focus on efficiency to developing new methods for improving reliability. The lessons of recent crises have taught supply chain managers the importance of measures to prevent downtime losses. This has generated new approaches to partnering with suppliers, investing in contingency, and allowing for safety margins. The new management focus is on efficient resiliency.

The best practice for supply chain management is evolving. Supply chain management has been an integral part of business management science for three decades . Its early emphasis was on extending successful within-firm approaches to increasing efficiency and decreasing cost while moving towards better understanding of the customer. These approaches are best represented by the lean business process philosophy that grew out of the success of manufacturing systems like total quality management and just-in-time.

7.1 Initial focus on efficiency

Sophistication in supply chain data and models has grown in parallel with the increasing recognition of the value of global sourcing. National industries serving highly developed, largely western, consumer markets increasingly linked themselves with overseas suppliers that could provide cheaper raw materials or component parts. As global outsourcing grew there was stronger investment in building trust and sharing knowledge between buyers and suppliers. The focal point of this effort was efficiency, i.e., how to source an additional unit at a lower price.

7.2 Concentration risks exposed

However numerous shocks in the last three decades have insisted, to those listening, that efficiency is not the only driver of success. A famous example is the ten-minute fire at a Philips semiconductor plant in Albuquerque, New Mexico in 2000, a supply chain disruption to the production of both Ericsson's and Nokia's mobile phone production that resulted in Nokia appropriating Ericsson's market share . The Philips fire exemplified a concentration risk: Neither Ericsson nor Nokia had a ready alternative supply of microchips for their mobile handsets. Nokia's reaction time was faster, and their response more aggressive. Ericsson's passivity cost them over $400 million in the next 6 months. And yet this was a single fire in one factory.

7.3 Correlated crises

Broader risks have come to prominence as well. A series of natural catastrophes, political events, and external crises have demonstrated the potential for some events to cause systemic failures across transportation systems, disruption to large numbers of suppliers simultaneously, and to have consequential cascading effects on other networks and geographies. These events cause correlated crises to supply chains unexpectedly in several places and networks at the same time.

An example of correlated crisis and concentration risk was the 2011 Tohoku earthquake in Japan. Many companies suffered disruption to supply chains and some companies have struggled to recover market position as a result.

Many companies are learning and changing the way they manage their supply chains in response to these and other correlated crises.

7.4 The auto manufacturer example

A large auto manufacturer had one major supplier of microchip units (MCUs) that are used, by the dozen, in various control systems in automobiles. The supplier's production facilities were so badly damaged by the Tohoku event that MCU production ceased for four months. 80% of car production was lost in March 2011 and over 60% in April. What was the auto maker's response? To revisit its supply chain with key questions: How critical is a material or component to the manufacture of the final product? Are critical components available from multiple sources – if so, what investment is needed now to access these sources flexibly? If not, what mitigation should be applied, for example building inventory?

7.5 Balancing efficiency with resilience

It may seem contradictory to combine managed inventory, to mitigate the risk of supply interruption, with a just-in-time production system, for efficiency. This dual approach,

however, demonstrates maturation in logistics management and acknowledgement of the need to build efficient resiliency in international supply chains.

7.6 Dual sourcing

Another, increasingly common, strategy for trading off efficiency against risk is dual sourcing. For example a firm may have a local (to its retail market) supplier and an overseas supplier of the same service or component, where the former provides rapid response and a benchmark for quality and the latter, cost efficiency for high volume.

7.7 Implementing resiliency measures

In each case the underlying message is that tomorrow's success depends on identifying and implementing efficient resiliency today. Efficient resiliency is the art and science of being economically competitive while actively managing your exposure to operational risk.

More generally, building resilience is about building safety margins in both capacity of the systems of an organisation and in its human capital. Organisational support is critical for implementing approaches to longer term survival, instilling a risk management culture, and improving the overall 'risk intelligence' of an organization is a large part of the challenge of management in uncertain times.

7.8 Expecting crisis

Safety margins, either in organization, infrastructure or logistics, can be expensive. The benefits are in ensuring business protection against a future crisis that is uncertain, but can be expected at some point.

Many business managers ignore the likelihood of a major crisis impacting them, because of the uncertainties of their occurrence. Yet a systematic review of potential causes of macro threats identifies over 50 different categories of threat, each of which triggers some level of disturbance somewhere in the world every few months, and an extreme crisis – a "1-in-100" annual event from one of them – could be expected somewhere in the world every two years.

Managers of supply chains should expect to have to manage these types of crises routinely and putting measures into place to survive a crisis, and to weather a future storm, will pay dividends.

7.9 Assessing value of resilience

Judging which measures are worthwhile, and assessing the business case for resilience, requires a detailed assessment of a company's current risk and vulnerabilities. There is a

growing suite of business tools and analytical frameworks available to make these assessments with the best knowledge available.

7.10 Understanding risks and opportunities

It is difficult to forecast all the uncertainties, risks, crises that may occur, and opportunities that they represent, in the coming years of a business. But the future operations of any business and international supply chain can be expected to have its ups and downs, and to be tested by failures and crises. Improving management knowledge of the systems in place, the thinking that others are doing around implementing resilience, and the assessment of future outlooks, are important new developments in management science.

7.11 Embracing efficient resiliency

The modernisation and globalisation of commercial activity has exposed organisations and their supply chains to a significant increase in risk. New management philosophies, analytical tools, and information availability are now responding to that challenge. Best practice for a modern global business is embracing efficient resiliency.

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