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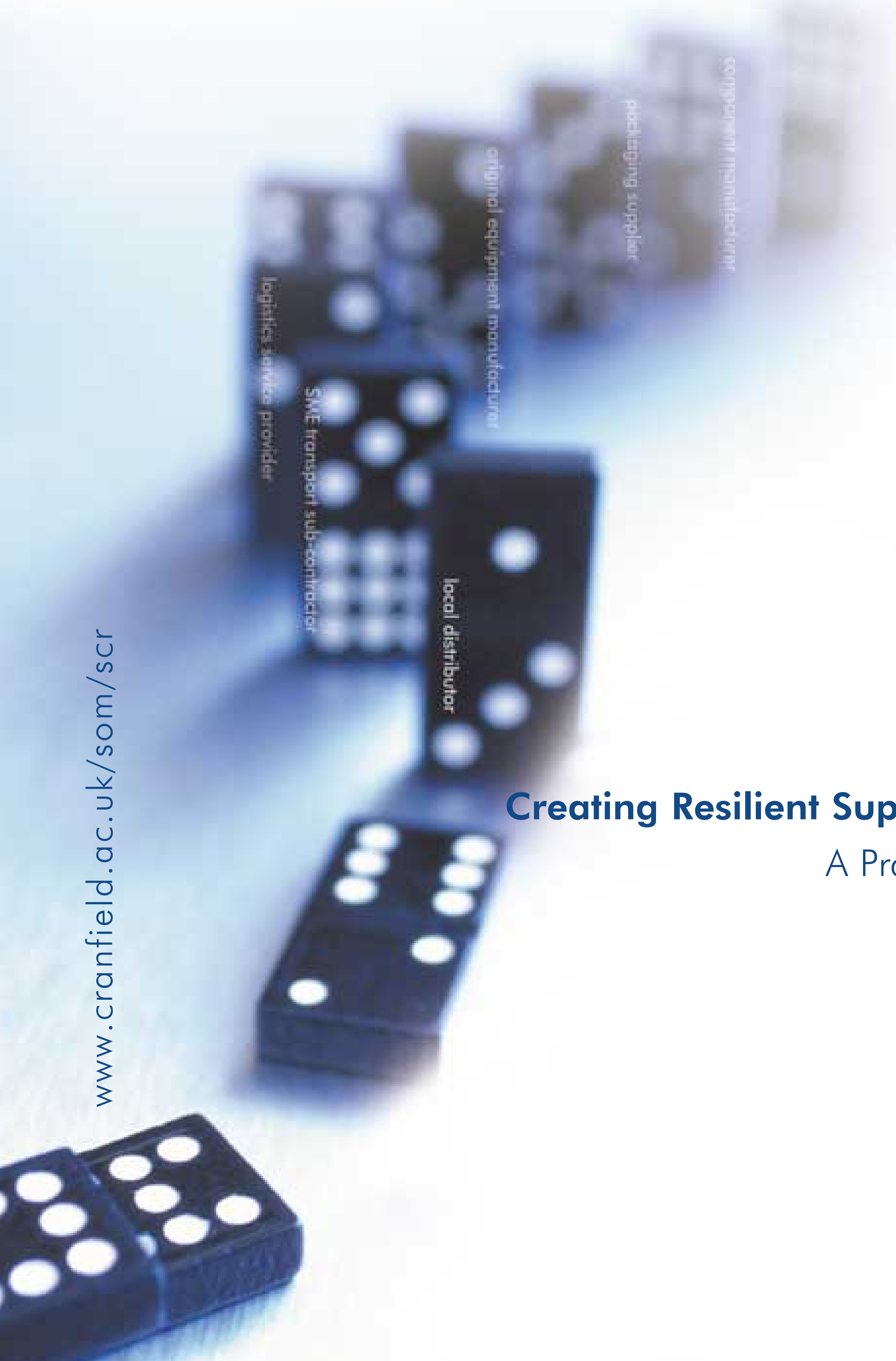

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Creating Resilient Supply Chains:
A Practical Guide

Creating Resilient Supply Chains: A Practical Guide

Report produced by the Centre for Logistics and Supply Chain Management,
Cranfield School of Management

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Foreword

The events of the last few years from the fuel crisis to foot and mouth disease to SARS, have highlighted the vulnerability of many supply chains. Quite apart from the external challenges to supply chain continuity are those possible sources of risk that are internal to the supply chain. A number of concurrent trends have contributed to the fragility that some observers believe now characterises many supply chains.

These trends include the rapid growth in global sourcing and offshore manufacturing; the continued move to reduce the supplier base; industry consolidation and the centralisation of distribution facilities to name just a few.

Following from the earlier report prepared for the DETR in 2002, *Supply Chain Vulnerability*, this report builds upon that work to identify the opportunities for the creation of more resilient supply chains.

As the research progressed, it became clear that there is still a lack of understanding of where an individual organisation might sit in the wider supply network. Few companies seemed to have real visibility beyond their first tier suppliers or downstream beyond their immediate customers.

This work, undertaken by the Cranfield Centre for Logistics and Supply Chain Management at Cranfield University and funded by the Department for Transport, is empirically based and draws on insights from a number of 'critical' industrial sectors including food retailing, oil and petrochemicals, pharmaceuticals, packaging, electronics, transport services and the distribution of automotive spares. It also includes input from private and public sector organisations involved in the provision of health care and in defence. In particular it focuses on the development of a managerial agenda for the identification and management of supply chain risk, with recommendations to improve the resilience of supply chains.

During the research we were concerned that the outputs, including this Executive Report, would address the needs of small and medium enterprises (SMEs) and provide relevant and practical tools to assist them to manage their supply chain risks.

Accompanying this Executive Report is *Understanding Supply Chain Risk: A Self-Assessment Workbook*, which provides a practical guide to assist companies both large and small to identify and plan for vulnerability and resilience in their supply chains.

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Executive Summary

This report commissioned by the Department for Transport and undertaken by Cranfield School of Management's Centre for Logistics and Supply Chain Management (CLSCM) aims to clarify the complex issues inherent in the identification and management of supply chain vulnerability.

Its objective is to increase awareness, understanding and thus the ability of UK industry to cope with disruptions to its supply chains. To that end it provides insight and practical tools, which will assist managers in improving the resilience of their organisation's supply chain networks.

To gauge awareness of supply chain vulnerability as a threat to business continuity a survey of senior supply chain professionals was undertaken together with an in-depth case study of one sector, military aircraft manufacturing. The findings of the case study were validated by interviews with managers from seven 'critical' sectors of industry.

Impact of business structures on continuity

Supply chains are increasingly at risk of disruption and it can be argued that the greatest risks to business continuity lie in the wider supply chain of key suppliers and customers (or more correctly supply/demand networks) rather than within the company itself. Yet for the vast majority of organisations, business continuity planning remains a one-firm focussed activity.

As supply chain networks increase in complexity, as a result of out-sourcing, globalisation and volatility in the trading environment, so too has the risk of disruption. The vulnerability of networks has increased as a result of longer, leaner supply lines between focused facilities within consolidating networks. Whilst many risks to the supply chain emanate from the external environment, e.g. war, epidemics, earthquakes, there is growing evidence that the structure of the supply chain is itself the source of significant risk. The same events that may once have caused minor local disruptions may now affect entire businesses, industries or economies.
Supply chain managers strive to achieve the ideals of fully integrated efficient and effective supply chains, capable of creating and sustaining competitive advantage. To this end they must balance downward cost pressures and the need for efficiency, with effective means to manage the demands of market-

For the vast majority of organisations, business continuity planning remains a one-firm focussed activity.

driven service requirements and the known risks of routine supply chain failures. Better management and control of internal processes together with more open information flows within and between organisations can do much to help.

However, in an age of lengthening supply chains serving globe-spanning operations, recent events around the world have provided frequent reminders that we live in an unpredictable and changing world. Natural disasters, industrial disputes and terrorism have all resulted in serious disruptions to supply chain activities. In these situations 'business as usual' is often not an option.

To assist managers in making their supply chains more resilient, the research has identified a number of practical tools which are briefly detailed in Appendix 1. Specific guidance for small and medium enterprises (SMEs) is also provided.

To complement this booklet a workbook, *Understanding Supply Chain Risk: A Self-Assessment Workbook* is available in down-loadable form at www.cranfield.ac.uk/som/scr.

The complete version of the Supply Chain Resilience Report is available from Tracy Stickells, Cranfield Centre for Logistics and Supply Chain Management, fax: 01234 752158, price £50.

An order form is also available on the above web site.

Section 1 - Introduction

This report outlines the findings of a programme of research commissioned by the Department for Transport and undertaken by Cranfield School of Management's Centre for Logistics and Supply Chain Management (CLSCM).

As a body of work it aims to move forward the understanding of the management of supply chain vulnerability. Its overarching objective being to increase the ability of UK industry to cope with supply chain related threats to business continuity. To that end it provides high-level insight and practical tools, which will assist managers in the task of improving the resilience of their organisations' supply chains.

Understanding supply chain risk: a network perspective

When working effectively and efficiently modern supply chains allow goods to be produced and delivered in the right quantities, to the right places at the right time in a cost effective manner. Until recently the term 'supply chain' was not widely used beyond the confines of academia, specialist sectors of industry and the professional management community. Latterly, in the wake of a number of far-reaching disruptions to economic activity it has crossed over into the everyday vocabulary of politicians, general managers and the wider public.

The term 'supply chain' is itself a relatively new addition to the lexicon of management, first used in the early 1980s when writers coined the phrase to describe an emerging management discipline. The new discipline was a response to changes in prevailing trends in business strategy, which in turn demanded that internal functional self-interests be put aside to achieve a greater good – a more efficient organisation, creating and delivering better value to customers and shareholders. It amounted to a redefinition and amalgamation of established business activities, notably 'logistics' (integrated transport, warehousing, and distribution) and manufacturing-based 'operations management'. The latter drew together elements of purchasing, order and inventory management, production planning and control, plus customer service.

In the 1990s - the efficiency driven age of 'business process reengineering' - supply chain management sought to speed the flow of goods and services by extending the integration of elements of logistics, operations management and marketing into

Modern supply chains allow goods to be produced and delivered in the right quantities, to the right places at the right time in a cost effective manner

The term 'supply chain' continues to imply different things to different people

cross-functional, inter-organisational, processes. Its avowed aim was to improve the efficiency of product flows from the production of raw materials all the way through to the marketplace where finished goods were delivered to the final consumer. The task was increasingly enabled by rapid developments in information technology, which in turn opened the way for further improvements in efficiency and greater awareness of a changing marketplace and emerging customer requirements.

In practice legacies of functional biases within organisations, together with varying perspectives of specialist firms means that the term 'supply chain' continues to imply different things to different people. It is still frequently used to describe either the management of integrated manufacturing and/or logistics activities within a single firm's manufacturing, transport, distribution or retail network. It is also regularly applied (particularly in the context of purchasing) to describe the management and performance monitoring of an organisation's supplier base, through quality improvement initiatives, involvement in new product introductions, promotions and overall cost reduction.

For the purpose of this report we adopt an all-encompassing, end-to-end perspective, defining a supply chain as: "the 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, 1998).

The notion of networks is particularly important and its relevance to this study will become apparent throughout this report. The key point is that modern supply chains are not simply linear chains or processes, they are complex networks. The products and information flows travel within and between nodes in a variety of networks which link organisations, industries and economies.

In defining other key terms we have aligned with appropriate common usage definitions. The term 'resilience' is used as it relates to supply chains as networks, so a dictionary-based definition that is rooted in the science of eco-systems has been adopted. Resilience is therefore "the ability of a system to return to its original [or desired] state after being disturbed". Implicit in this definition is the notion of network flexibility, and given that the desired state may be different from the original, 'adaptability' is also implied. Finally, the term 'risk' is used in the sense that it relates to supply chain 'vulnerability' as "at risk: vulnerable; likely to be lost or damaged".

Given the interdependencies between organisations and their supply chains, it may be the business that is at risk from its supply chain or the supply chain that is at risk from a business. The predicament of Land Rover, a subsidiary of Ford, in January 2002 illustrates this point. Land Rover's production was endangered by the collapse of its supplier UPF-Thompson – i.e. Land Rover's business was at risk from a problem within its supply chain. That supply chain was actually at risk because of the failure of UPF's business, not directly due to a problem between the supplier and its automotive industry customers, but as a result of losses suffered by UPF in an unrelated but ill-starred foreign venture.

Land Rover and UPF-Thompson

When chassis manufacturer UPF-Thompson became insolvent at the end of 2001, the impact upon its major customer, Land Rover, was sudden and severe. UPF Thompson was the sole supplier of chassis for the Land Rover Discovery, and receivers KPMG threatened to halt supply unless Land Rover made an immediate up-front payment of between £35 and £45m. KPMG justified its actions by pointing out that it was legally obliged to recover money on behalf of creditors and the sole supplier agreement represented a valuable asset. A recent court ruling had determined that receivers were legally entitled to exploit a customer's vulnerability for the benefit of creditors. Land Rover faced the possibility of having to suspend production of the Discovery, until a temporary injunction was secured granting the carmaker a short-term reprieve. The injunction averted the lay-off of 1400 workers at its Solihull plant, plus many more amongst Land Rover's network of suppliers.

The Land Rover/UPF-Thompson case highlights the risks associated with over dependence on a single supplier, but also illustrates that supply chain vulnerability should be viewed in its broadest sense as "exposure to serious disturbance, arising from risks within the supply chain as well as risks external to the supply chain".

The four levels of risk

However, improving supply chain resilience requires an appreciation that supply chain vulnerabilities may come in many guises, and the drivers of risk operate at several different levels. These are inextricably linked, but for the purpose of clarity are described here within four interlocking levels of analysis:

- Level 1 - Process/Value Stream
- Level 2 - Assets and Infrastructure Dependencies
- Level 3 - Organisations and Inter-organisational Networks
- Level 4 - The Environment

Level 1 approaches the supply chain from an idealised integrated end-to-end supply chain management perspective. Levels 2-4 progressively introduce sources of risk that can cause disruption, undermining the supply chain manager's efforts to optimise efficiency and effectiveness and ultimately threaten business continuity.

Supply chains are not simply linear chains or processes, they are complex networks

Level 1 examines supply chain vulnerability from the prevailing process engineering-based perspective, seeing the supply chain as a linear 'pipeline' flowing through and between organisations in the network (see Figure 1.1). The emphasis is firmly on the efficient, value-based, management of individual workflows and their accompanying information (usually by product or product class). Supply chains carry one or more of these 'Value Streams'. The availability of credible and reliable information is central to this view, and is in turn dependent on the willingness of the parties to share that information. This requires a high level of trust and cooperation between adjacent organisations. In short, it is an approach that aspires to a seamless flow of information and materials, facilitated by all supply chain partners thinking and acting as one. These process management ideals underpin the principles of both 'lean' manufacturing and agile approaches to supply chain management.

From a purely process-based perspective, supply chain risks are principally the financial or commercial risks arising from poor quality, sub-optimal supply chain performance, demand volatility and shifting marketplace requirements. The popular analogy of a supply chain as a seamless 'pipeline' is a useful metaphor, but in the context of supply chain vulnerability it can be a deceptively seductive one. It reinforces the notion of simplicity by promoting the vision of a stable, controllable, linear, self-transporting flow, hermetically sealed from disruptive environmental forces. In reality supply chains are rarely fixed, discrete, self-propelling or self-protecting. Moreover, the adoption of lean and agile practices (particularly JIT delivery) has made them increasingly reliant on the existence of a reliable, secure and efficient communication, transport and distribution infrastructure.

Level 2 of the framework represents supply chains in terms of these asset and infrastructure dependencies. At this level, the nodes in Figure 1.1 become fixed commercial sites or facilities (e.g. factories, distribution centres, retail outlets). The same facilities may house IT assets (hardware, processing, and communications/service centres), which are nodes in the internal and inter-organisational communications networks.
The individual sites are connected through the nodes and links of national and international communications infrastructure (e.g. cables, radio masts and satellites) and through the links and nodes of the transportation/ distribution infrastructures.
The links are pipelines, grids, roads, rail, waterways, shipping lanes and flight paths, and nodes rail termini/stations, ports and airports. The broken dotted lines in Figure 1.1 now can be viewed as assets (trucks, trains, boats and planes) that ply the links in transportation networks. None will function without the people who understand how to run and maintain them.

At Level 2 the resilience of the network should be assessed in terms of the implications of the loss (temporary or otherwise) of links, nodes and other essential operating

assets. Ensuring that they continue to operate is likely to fall within the remit of business continuity managers and/or logistics, operations, IT and human resource professionals and emergency planners.

Level 3 steps back further to view supply chains as inter-organisational networks. It moves supply chain vulnerability up to the level of business strategy and microeconomics. Here the nodes in Figure 1.1 revert back to being the organisations - commercial and public sector - that own or manage the assets and infrastructure, through which the products and information flow. The links become trading relationships, particularly the power dependencies between organisations. The principles of integrated approaches to supply chain management (as set out in Level 1) rely on the premise that strong organisations will not abuse their position of power vis-à-vis weaker ones. Additionally, that information and risk will be shared selflessly for the good of all, within an enduring network of complementary trading relationships. Whilst supply chain managers may work tirelessly to achieve this objective, other commercial interests, competitive pressures and divergent strategic goals can work against them. Discretionary reconfigurations (e.g. outsourcing) as well as business failures or mergers and acquisitions within the supply chain or industry can all herald network instability at this and lower levels. Where dominant organisations have the power, capabilities, and the will to manage their supply chains in an open and collaborative way, we have seen the emergence of 'extended enterprises'. However, establishing and monitoring close cooperative partnering relationships is resource-intensive. Consequently, large sophisticated customers have reduced the number of direct suppliers, often opting for single sourcing (usually by product line) as the lowest cost way to develop, manage and monitor their supplier base. The downside of this is that

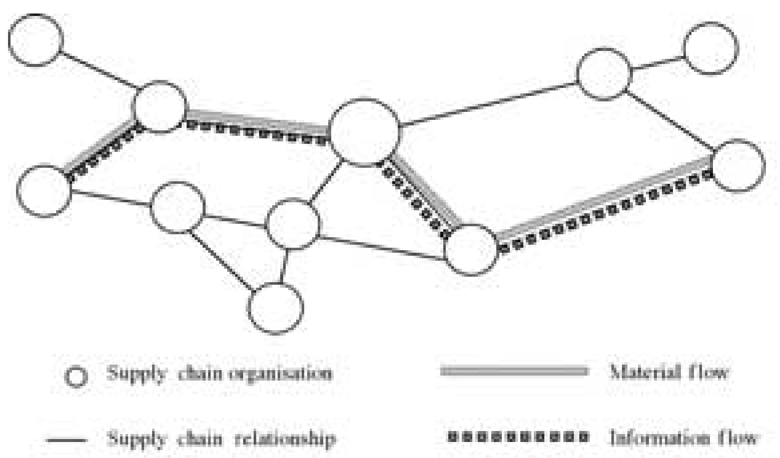


FIGURE 1.1: LEVEL 1 – PROCESS/VALUE STREAM

(Source: Peck, H. (2003), "Supply Chain Vulnerability: Levels in a Landscape", *Proceedings of Defence and Material Support Conference*, London.)

it has given rise to one of the most widely recognised sources of supply chain risk – disruptions caused by the failure of a single source supplier.

Level 4 – The fourth and final level in the framework is the wider macroeconomic and natural environment within which organisations do business, assets and infrastructure are positioned, supply chains pass and value streams flow. Factors for consideration are the political, economic, social, and technological elements of the operating and trading environment, as well as natural phenomenon – geological, meteorological and pathological. All can affect a supply chain at each of the first three levels of the framework. The sources of risks emanating at this level are likely to be beyond the direct control of supply chain managers, nevertheless the susceptibility of the networks can often be assessed in advance, thus enabling informed decisions to be made regarding the merits of risk avoidance or mitigation strategies.

Technological developments can affect demand for existing products, cause uncertainty with the launch of new ones, open up new channels and business models, and facilitate better supply chain cooperation and visibility. They can also create new or increased dependencies between supply chains, organisations and their supporting infrastructures.

Socio-political disruptions – e.g. protests, strikes or regulatory changes – rarely happen without warning, so routine scanning of the trading environment should be able to identify threats of this kind.

In terms of geo-politics, the consolidation of the European Union, the collapse of the former Soviet Union, together with the gradual emergence of China after years of isolationism, have had a profound effect on international trade, opening the way for truly global sourcing and supply. Businesses have redesigned their supply chains accordingly. However, the emergence of a post-communist new world order has brought many new uncertainties. Macroeconomic vacillations - whether due to terrorism, war worries, currency fluctuations or other cyclical downturns - have far reaching consequences for levels of demand, pricing, and purchasing policies.

Moving on to the forces of nature, there are numerous well-documented examples of how natural phenomena such as earthquakes, hurricanes, floods etc. have disrupted JIT supply chains. Meteorological and geological susceptibilities are identifiable, though exactly when and where disruptive events occur is less predictable.

Finally, pathological phenomenon are perhaps the most difficult to predict of all, and potentially the most disruptive, because they are mobile. Threats of this kind, whether Foot and Mouth Disease, SARS, or the man-made computer viruses that mimic them, highlight how efficient consolidated seamless distribution and information systems can become victims of their own success.

Events and network interactions

The multi-level framework outlined above breaks-down the problem of supply chain vulnerability into its constituent parts, nevertheless it should be born in mind that when an event occurs it may impact at several levels, as the celebrated example of Nokia and Ericsson illustrates (see below).

The Nokia/Ericsson example highlights the vulnerability of industries with capacity constrained production and also raises other important themes, such as the issue of common components and the consequential nature of supply chain risks. The latter is in turn linked to the fact that supply chains are linear processes within complex systems of interacting networks.

Nokia and Ericsson

In March 2000 worldwide demand for mobile telephones was booming. Two of the international market leaders were Finnish electronics company Nokia and its Swedish rival Ericsson. This is the tale of how an 'Act of God' half a world away would set off a train of events that would eventually precipitate a major competitive re-alignment.

The story starts on the evening of March 17th 2000, with a thunderstorm over central New Mexico. A lightening bolt hit a power line, which caused a fluctuation in the power supply, which resulted in a fire in a local semiconductor plant owned by Dutch firm Phillips Electronics NV. The fire was brought under control in minutes, but a batch of trays containing enough silicon wafers for thousands of mobile phones were destroyed in the furnace. The damage to the factory from smoke and water was much more extensive than the fire itself, contaminating the entire stock of millions of chips. The suppliers immediately prioritised customers, according to the value of their business. Between them, Nokia and Ericsson accounted for 40% of the plant's output of the vital radio frequency chips, so these companies were put at the top of the supplier's list.

On 20th March, in Finland Nokia's event management systems indicated that something was amiss. Orders were not coming through as expected, so a components purchasing manager phoned the supplier who informed him that there had been a fire in the plant, which would disrupt production for around a week. Nokia was not unduly alarmed, but dispatched engineers to New Mexico to investigate the situation. Philips were not encouraging visitors, so having been unable to investigate the problem further, Nokia increased monitoring of in-coming supplies from weekly to daily checks.

It became clear soon afterwards that the problem was so serious that supplies would be disrupted for months. Pressure was brought to bear at the highest levels between Nokia and its supplier to ensure that all other Philips plants were commissioned to use any additional capacity to meet Nokia's requirement. In addition, Nokia immediately sent representatives out to its other suppliers in the

US and Japan to secure priority status for all available supplies of chips, and persuaded them to ramp up production as quickly as possible. Because Nokia was such an important customer, they obliged with a lead-time of less than one week. Nokia also set about reconfiguring its products to take slightly different chips from other sources.

Ericsson had also found out about the fire soon after it occurred, but having been assured by the suppliers that the fire was unlikely to cause a major problem, had not acted further until early April.

By then Nokia had already moved to secure its supplies, and unlike the quick acting Finns, Ericsson had no alternative sources of supply. It had taken the decision some years earlier to single source key components in a bid to simplify its supply chains as a cost reduction measure. Ericsson lost an estimated $400m in new product sales as a result of the fire. An insurance claim would later offset some of Ericsson's direct losses, nevertheless it was forced to cease manufacturing mobile phones. In contrast, Nokia claimed it was able to maintain production levels throughout, enabling it to cement its position as market leader.

Nowadays companies often choose to buy-in goods and services they would have once provided in-house. They do so in order to concentrate on core competences, improve financial performance, and reduce the risk to their business of cost-related competitive disadvantage.

But this and other practices can open the door to hitherto unrecognised consequential risks, which may not be apparent to those who make the initial decisions. For example, manufacturers like Nokia, Ericsson and indeed car makers like Land Rover seek to reduce costs and improve efficiency through the use of common components across several product lines. This has distinct advantages for supply chain managers when looking at risk from a functional or internal supply chain perspective.

The use of common components allows planners to reduce forecasting and inventory holding risk, because aggregate forecasts are more reliable than those for a single product. Common components or ingredients (particularly single sourced) are also popular from a quality perspective because they offer consistency. From a purchasing perspective too, they are attractive because bigger order quantities means lower unit costs. The disadvantage of course is that should a disruption to supply occur, instead of affecting one product line, it may affect all.

Moreover, because the goods (or even services) are likely to be produced by a third party, they may well be used by competitors within the same industry and by users in other sectors. In times of shortage, the likelihood is that the biggest volume/value customer will receive priority treatment.

Section 2 - Managing Supply Chain Vulnerability - A case study

The turn of the new century saw the first real signs of interest in issues of supply chain vulnerability. Within industry fingers were pointing towards the combination of increased inter-organisational dependence, the globalisation of trade and the implementation of lean manufacturing strategies as sources of increased risk, but there was little more than anecdotal evidence to support these suspicions.

Consequently, a single in-depth exploratory case study of one industry sector was undertaken to identify drivers of supply chain risk and ascertain the adequacy of currently available managerial tools.

Companies engaged in the manufacture of high-performance military aircraft were chosen as the subject of the case study. The industry operates in an extreme risk environment, characterised by high levels of commercial, technological and political risk, as well as inherent product safety issues. The case provides the basis for subsequent cross-sector comparisons and the development of a generally applicable toolkit, to assist managers in the identification and management of vulnerabilities within their own supply chain networks.

Data Collection

Interviews were conducted with 47 managers, drawn from five levels of the supply chain and several different aircraft programmes. They represented the customer (buyers for the armed forces), the prime contractor (aircraft assembler), its first and second tier suppliers, plus industry bodies representing SMEs active in the higher reaches of the supply chains.

The managers' responsibilities included sales and marketing, supplier management/development/audit, customer management, operations management and supply chain design.

Each manager was asked to reveal what they considered to be the vulnerabilities within their supply chains, the sources of risk and the tools or techniques currently used to mitigate those risks. Interviewees were also invited to comment on alternative techniques and suggest others that might be considered appropriate. Finally they were canvassed for suggestions as to how implementation of existing approaches might be improved along the whole supply chain. Earlier work had shown that supply chain risk and vulnerability are highly sensitive issues, so interviews were conducted on a one-to-one basis with assurances given that the anonymity of all respondents, departments and organisations would be protected.

Sources of Risk

The practitioners readily identified the 'sources' of risk as they saw and understood them, not in terms of a specific location within the network, or the risks from fire, flood, protests or terrorism. The managers focussed instead on the risks to their own areas of responsibility.
More often than not, these were the consequential risks to supply chain performance arising from other well-intentioned initiatives and industry trends. Several managers related the problems back in terms of the commonly used critical success factors (CSFs):

- Cost focussed decisions
- Quality/performance requirements
- Delivery schedule adherence
- Customer-supplier relationships

The CSFs represent the industries own interpretation of Better, Faster, Cheaper and Closer - the almost universally accepted goals of contemporary supply chain management.

In short, the problem seemed to be that efforts made to raise performance against one dimension tended to compromise one or more of the others.The actions themselves were often the result of decisions taken elsewhere in their own companies or the wider network.

Available tools and techniques

A wide variety of supply chain management tools, techniques and higher-level principles were being utilised within the networks to identify, manage and mitigate the effects of risk within the supply chains. The tools were well known managerial devices, appropriate for one or more of three categories of supply chain management activity:

- Supply Chain Planning
- Supply Chain (Operations) Management
- Supply Chain Change Management.

The first two, Supply Chain Planning and Supply Chain (Operations) Management share the basic assumptions and respective time-horizons of long-term 'strategic' and everyday 'operational' supply chain management respectively. The third corresponds with medium-term 'tactical' refinements and incorporates elements of the previous two. Taken together the three categories describe a spectrum of supply chain management activity.

Figure 2.1 illustrates how the three categories relate to one another, overlap and combine.

FIGURE 2.1: THE SPECTRUM OF SUPPLY CHAIN MANAGEMENT ACTIVITY

(Source: Haywood, M. (2002) *An investigation into supply chain vulnerability management within UK aerospace manufacturing supply chains*, MSc Thesis, Cranfield CLSCM).

- **Supply chain planning**. The extreme left of the spectrum is occupied by pure supply chain planning, which in an 'ideal world' would be unencumbered by the legacy commitments of existing production facilities or supplier contracts.
- **Supply chain operations management.** To the right are pure supply chain operations management activities. This portion represents the day-to-day activities undertaken in the management of a mature established supply chain. It is the stage where volumes have gone from developmental prototypes, through the step change to full-scale production, where demand patterns are expected to follow a more predictable pattern. The well-managed supply chain is supposedly operating in a stable 'steady state' with supply and demand perfectly balanced. In this steady state processes are not impacted by the sources of risk from planned process changes or new product introductions.
- **Supply chain change management.** The centre of the spectrum is occupied by supply chain change management activities. It represents the times when planned modifications to existing supply chain processes are implemented.

Vulnerability during periods of change

Many of the managers felt that supply chains were most vulnerable during periods of change, as the risk profiles affecting their supply chains were also changing. Technology upgrades, total quality management (TQM) and other process improvement initiatives, together with pressure to reduce costs and outsource non-core activities mean that change is almost constant. In practice, the managers felt that the supply chains never reached that mature, stable 'steady state' in their industry. As a result they reported that the majority of their time was actually occupied with supply chain change management related activity, hence the relative importance indicated in Figure 2.1.

Scope and limitations of existing tools and techniques

The principles, tools and mitigation strategies identified by the practitioners to manage risk were arranged according to class of activity, and in relation to the CSF-defined sources of risk into the 12-cell matrix shown in Figure 2.2. It is important to recognise that Figure 2.2 represents only a summary of what is or could be in use somewhere in the network. Each cell contains a set of one or more tools, techniques or principles. Collectively they offered the basis for a cohesive process risk management tool kit. Some monitoring devices e.g. Current Supplier Database (detailing costs, qualified component characteristics, capabilities and performance), though not currently in use emerged as being useful to organisations in this industry in times of change, to mitigate the effects of all manner of risks, regardless of the source or driver. However, other tools and mitigation techniques again suggest contradictory requirements. For example; to mitigate cost-related risks, lean manufacturing techniques were being used (Set 5), while elsewhere someone is using inventory, capacity and capability

Supply chains were most vulnerable during periods of change

buffers on a regular or temporary basis to mitigate delivery or schedule adherence problems (Set 7 and 11). This highlights the tensions between the market-driven demands of the CSFs and the impact of industry constraints, resulting in conflicting operational imperatives. There were also some risks that the supply chain managers were unable to manage or mitigate. These often emerged as a result of strategic business decisions taken at a more senior level elsewhere in their own organisations or in those of customers or suppliers.

There was no common understanding of the scope or extent of supply chain risk management

Barriers to effective implementation of risk management

Three key issues were identified as barriers to effective implementation of the tools and techniques:

- Staff training- there was quite a widespread recognition that existing tools could be much more effective if implemented correctly.
- Terminology - interviewees interpreted the term 'supply chain' in a number of different ways.
- Supply chain visibility – the general view was that upstream and downstream visibility was poor.

The research revealed that there was no common understanding of the scope or extent of supply chain risk management, much of the problem related to a confusing and contradictory array of interpretations of ‘supply chain’. Once a common definition was established, using the diagram in Figure 2.3 as a basis for comparison, all interviewees agreed that end-to-end management of an organisation's complex and unstable supply chain network, (particularly up-stream into the supplier base), would be an improbable if not impossible task.

The challenge faced by supply chain managers was likened to navigating across a featureless terrain in a “confusing fog” of sometimes useful and sometimes useless, misleading, contradictory or partial information. Interviewees representing every tier in the supplier chain indicated that they chose to look for risks only as far as their respective Tier 1 suppliers. A small proportion of interviewees believed they could see sources of risk as far as their Tier 2 suppliers. In further discussions, it became clear that this was not the case. They based their response on the expectation that their Tier 1 suppliers would be feeding through relevant information from Tier 2. The assumption was that if Tier 2 identified a risk or event that it could not deal with, it would issue an alert message to its customer.

When invited to consider whether the limited upstream and downstream reach of their risk management techniques was sufficient, the managers responded unanimously that it was. Having proclaimed themselves to be satisfied with the reach of their existing supply chain management tools, the practitioners initially refused to accept the need to improve the reach of their risk management techniques.

Supply Chain Management Activities

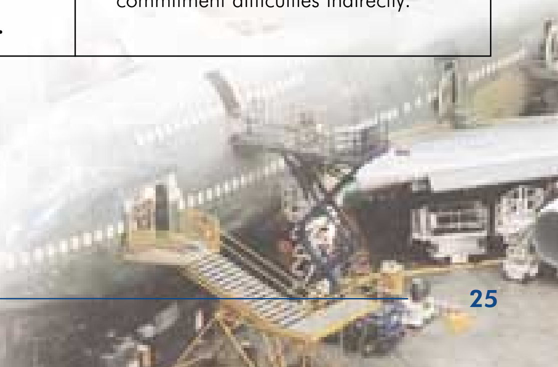
Supply Chain Risks

	Supply Chain Planning	Supply Chain Change Management	Supply Chain Operations Management
Cost	**SET 1** • Trade-Off Analysis to achieve lowest total process cost. • Supply Chain Mapping/Situational awareness - to understand quality and delivery cost pressures on direct/indirect customers/suppliers • Design supply chain for maximum simplicity. • Design product components for maximum simplicity.	**SET 5** • Lessons learned feedback and corporate knowledge database. • Process innovation. • Supplier Development Programme within collaborative customer-supplier relationships. • Lean manufacturing techniques, to benefit from higher resources utilisation and lower inventories. • *Current supplier database - costs, qualified components' characteristics, capabilities and performance*.	**SET 9** • Open-book accounting. • Contingency funds for impact of risks. • e-commerce techniques to improve demand data transmission and reduce costs. • Utilise Frozen Horizons. • *Standardised quality requirements*.
Quality	**SET 2** • Supplier Quality Audits.	**SET 6** • Lessons learned feedback and corporate knowledge database. • Supplier Development Programme within collaborative customer-supplier relationships. • Net Good Assets register. • *Current supplier database - costs, qualified components' characteristics, capabilities and performance*.	**SET 10** • Supplier managed quality adherence. • Supplier quality review.
Delivery	**SET 3** • Analysis of past performance. • Supplier's Risk Management Audits. • Supplier capability assessment – effectiveness and efficiency. • Supply Chain Mapping – inventory, process capacities/capabilities, lead-times (intra/inter-process/ organisation) and lead-time flexibility.	**SET 7** • Lessons learned feedback process and corporate knowledge database. • Process innovation. • Supplier Development within collaborative customer-supplier relationships. • Lean manufacturing techniques, to benefit from improved process integration and proactive mitigation of process risks. • De-conflict with critical path. • Temporary inventory, capacity and capability process buffers to create management space. • *Current supplier database - costs, qualified components' characteristics, capabilities and performance.*	**SET 11** • Inventory, capacity and capability process buffers. • Project plan, including milestones. • Critical Path Analysis. • Risk Register informed by supplier KPIs and reviews. • Root Cause Analysis. • Utilise Frozen Horizons. • Process innovation. • Formal project risk processes. • *Shared supply chain management data* • *Continuous staff training to maintain effectiveness of current tools.*
Relationships	**SET 4** • Supply Chain Mapping – relationships and influences • **Process relationship analysis**.	**SET 8** • Lessons learned feedback and corporate knowledge bank. • Collaborative customer-supplier relationships. • *Current supplier database - costs, qualified components' characteristics, capabilities and performance.* • **Process relationship analysis.**	**SET 12** • Categorise suppliers using Pareto Analysis and manage differently. • Collaborative customer-supplier relationships. • Use knowledge from network relationship mapping to resolve supplier commitment difficulties indirectly.

FIGURE 2.2: SUMMARY OF TOOLS AND TECHNIQUES

(Source: Haywood, M. (2002) *An investigation into supply chain vulnerability management within UK aerospace manufacturing supply chains*, MSc Thesis, Cranfield CLSCM).

Key: Techniques currently in use. *Techniques recognised as desirable but not yet in use.*
Modifications/additional techniques identified during the validation process



They reconsidered only when presented with a definition of supply chain risk management as

'the identification and management of risks within the supply chain and risks external to it through a co-ordinated approach amongst supply chain members to reduce supply chain vulnerability as a whole',

which emphasised the need to consider risk management from a total supply chain view. Some of the additional risk management tools/techniques, identified by interviewees as desirable but not known to be in use – see Figure 2.2 (italic text) - reflect a requirement for tools/techniques to be applied with a wider, multiple-organisation supply chain perspective in mind.

Options for improved implementation

Three possible approaches designed to improve visibility, and thereby risk management within the supply chains, were put forward to the interviewees and later subjected to review by groups of other managers from within the industry. All three options were inspired by literature reviews and by earlier interviewee responses.

The first method, a 'go it alone' option was motivated by the possibility of achieving competitive advantage over rival organisations through exclusive or advanced identification of sources of risk. For example, if the consequences of an anticipated event were expected to disrupt others in the same industry sector, an organisation might gain advantage by simply improving its tolerance relative to its competitors. Alternatively, if the risk was a perennial concern or one that extended beyond the firm's immediate sector, the organisation could market the skills it acquired to deal with the risk, potentially developing a new revenue stream. In the context of aerospace manufacturing this option was deemed to be impractical. The complexity of the networks as well as issues of power and influence limited the viability of such an approach. Moreover, the managers stressed the problem of selection - which of their many thousands of supply chains should they interrogate, when, how far into it and which supply chain branches to follow?

The second method tabled was a more limited audit encompassing the focal firm, its immediate customers and suppliers, Figure 2.4. The method involves organisations acting collaboratively, in interlocking risk management relationships to produce overlapping information flows all along the supply chains. Such an approach would allow organisations to identify relevant sources of risk within their control or immediate supply chain vicinity

FIGURE 2.3 – SIMPLIFIED SUPPLY CHAIN MODEL

and enjoy the confidence that others were doing the same. The approach represented a formalisation of what was supposed by some to be already occurring. It was supported in principle, but practitioners believed that it would require industry-wide acceptance to be effective in practice. Aerospace is already a heavily regulated sector and a number of interviewees identified currently accepted quality standards, such as ISO 9001, the Total Quality Management process standard, or its European equivalent, EFQM, as cost-effective vehicles for confidence-building risk management measures. The Society of British Aerospace Companies' (SBAC) 'Supply Chain Relationships In Action' (SCRIA) code of conduct already promotes the benefits of accepting more widely recognised and trusted manufacturing quality standards amongst its member organisations.

The third approach was an extension of the second, based on interviewees' suggestions that the effectiveness of their current management tools would be improved by the introduction of a shared data environment. It was felt that this would significantly reduce the commercial risks attached to sub-optimal supply chain performance. The majority of interviewees considered this method to be sound in principle. It reflected the frequently expressed view that improved sharing of data would lead to consequential improvements in profitability and facilitate continuous improvement practices that contribute to longer term supply chain health. Furthermore, a successful precedent had already been created in the defence sector. The establishment of a shared data environment for organisations involved with a single shipbuilding project had achieved significant benefits. Whilst there was clearly support for the method in terms of its proven potential for reducing demand-related and process performance risk, there were equally clear indications that organisations would be unwilling to share data relating to other forms of risk. In short, they expected good risk

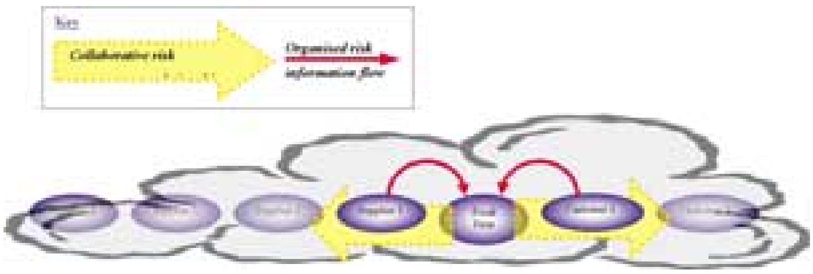


FIGURE 2.4: ORGANISATIONS CHOOSE TO LOOK ONLY AS FAR AS THEIR TIER 1 SUPPLIERS

(Source: Haywood 2002 op cit)

There was no commonly accepted definition of the term supply chain and thus 'supply chain' risk or vulnerability within the industry

management practices to be retained in an organisation as a source of competitive advantage. News of bad risk management would also be retained within the organisation for fear of competitive disadvantage.

Conclusions from the case study

The managers interviewed for this study identified the sources of risk as they saw and understood them. Interestingly, their principal concerns were not with the direct risks that characterise the preoccupations of insurers, crisis managers and businesses continuity planners (e.g. impacts of fire, flood, protests or terrorism on facilities or other assets). References to these 'external' forces were few. The managers focussed instead on the risks to their own areas of responsibility, in this instance on the consequential risks to supply chain performance arising from other managerial decisions and industry trends. In particular they emphasised those trends that were believed to be undermining efforts to optimise supply chain processes. The risks they identified and the 'in context' examples provided highlighted tensions between:

- Individual process performance measures
- The impact of strategic business decisions
- Constraints imposed by the complex safety-critical nature of the products and by
- Industry or supply chain structures.

Complexity

Counteracting complexity was a recurrent theme. The demands of the marketplace, constant changes in product specifications, together with other continuous improvement initiatives within the organisations and the wider industry as a whole meant that the supply chains never actually reached a stable 'steady state'. Furthermore, product and supply chain complexity meant that although interviewees were implicitly or explicitly adopting a process-based view of risk in their supply chains, this was certainly not an 'end-to-end' supply chain perspective. Though it was clear that extant managerial practices reinforced a much-truncated view of the supply chain. None of the organisations concerned routinely monitored beyond their immediate customers or suppliers.

Risk management tools

The audit of risk management tools and techniques currently in use within the supply chain/networks revealed a host of well known process reengineering and control tools. They further underlined the prevailing process management-based view of supply chain risk, and one that was largely single organisation, internally-focused. Concerns expressed by some that the available tools and techniques were not being applied in a consistent and coherent manner across the networks also proved to be well founded.

Collaboration v competition

Competitive commercial interests were likely to deter organisations and individuals from sharing risk management data

A truncated (but as yet undetermined) interlocking and commonly accepted approach to supply chain risk management, supported by a common data environment, emerged as the managers' favoured way forward. The evidence from this study suggests that inter-organisational cooperation to reduce demand related forecasting and inventory management risk would be significantly improved by more wide-spread collaboration, allowing mitigating action to be taken to deal with supply-side disruptions. However it was very clear that competitive commercial interests were likely to deter organisations and individuals from sharing other forms of risk management data. In addition this would not overcome problems arising from a disconnection between supply chain management objectives and changes in business strategy.

Section 3 - Managing Supply Chain Risk – Industry Comparisons

The findings and conclusions of the base case study have been validated through cross-sector comparisons and discussions with managers from leading organisations representing the following 'critical sectors':

Managers were conscious that supply chain vulnerability and indeed resilience were important issues

- Food & drink (manufacturing & retailing)
- Electrical/electronics (manufacturing)
- Oil/petrochemicals (extraction & refining)
- Healthcare/pharmaceuticals (manufacturing, private sector; distribution, public sector)
- Automotive spares/construction (manufacturer and distributor)
- Logistics/transport (private & public sector)
- Packaging (manufacturer)

The organisations selected are all household names, significant players in the UK with international interests and supply chains that span the world. Their core businesses cover at least one of the critical sectors, but some have interests in others. For example, the food retailer also has significant petrol sales, and the food processing company is also a leading producer of household cleaning and personal care products (soap, shampoo etc). Similarly one of the two private sector logistics and transport companies we spoke to was also a manufacturer and distributor of automotive spare parts.

The managers we interviewed were asked to consider:

- Whether the sources of risk identified in the aerospace case study where recognisable and relevant to their industries
- The vulnerability of supply chains during different stages of the product life cycles and the balance of managerial effort and activities
- The reach of supply chain risk management measures used by their own organisations
- The usefulness of tools and techniques identified in the original case to improve the resilience for their supply chains
- Which tools and techniques were in use in the supply chains they managed
- The feasibility of the proposals for how inter-organisational supply chain risk management might be improved or extended.

The managers interviewed found no difficulty in answering questions relating to the drivers of risk, the balance of managerial effort through a range of supply chain management activities, and the appropriateness of the methods we put forward to improve implementation up and down the supply chain. But when it came to the other questions there was often hesitation. Managers were conscious that supply chain vulnerability and indeed resilience were important issues, but not ones that they were explicitly required to address.

Sources of risk

All of the organisations we consulted were attempting to manage longer, leaner global supply chains. The problems encountered by the aerospace

managers were also familiar to the practitioners from other sectors, and were resulting in challenging complications for those concerned. In the ensuing discussions, the themes of quality, delivery, relationships were clearly detectable, but cost was the overriding issue. In the words of one practitioner with extensive experience covering several 'critical sectors':

"There is no common language other than cost".

Leaner supply chains and the move towards JIT delivery

All of the manufacturing or processing organisations consulted had 'leaned' down in recent years and were actively pursuing further opportunities to reduce overheads and inventory holdings. Nevertheless several managers were concerned that whilst leaner operations were accepted as a commercial necessity, overzealous application of lean principles would restrict opportunities for growth. For example, the oil company noted that in some of the markets it served there was not enough capacity to meet short-term upswings in demand.

Managers from the grocery retail business also expressed a belief that there was a danger that leanness could limit future opportunities to expand the business and not just in terms of organic growth. Their primary concerns related to the dynamics of the industry and strategic change.

Similarly, the packaging manufacturer and a public sector healthcare organisation were keen to take significant costs out of their business by reducing inventory holdings. In an uncertain and dynamic environment the dilemma they faced was just how deep those cuts should be.

Managing obsolescence, an issue raised by the aerospace managers, was highlighted by the packaging company and automotive spare suppliers. They identified the conflicting requirements of lean supply chains and the need to manage obsolescence. For the packaging company, it was the management of inventory holdings of capital equipment spares that posed the biggest questions. The automotive industry spares supplier accepted that it had to buffer with 'all-time buys' as a way to deal with issues of obsolescence in order to protect service commitments in the future.

One interviewee, himself a purchasing specialist, suggested that the root of many problems with managing obsolescence was that the purchasing managers who originally sourced the parts based their decisions on price at time of order and did not have to deal with any of the consequential problems. He suggested that the 'part not current' problem was a particularly common with US suppliers.

Globalisation of supply chains

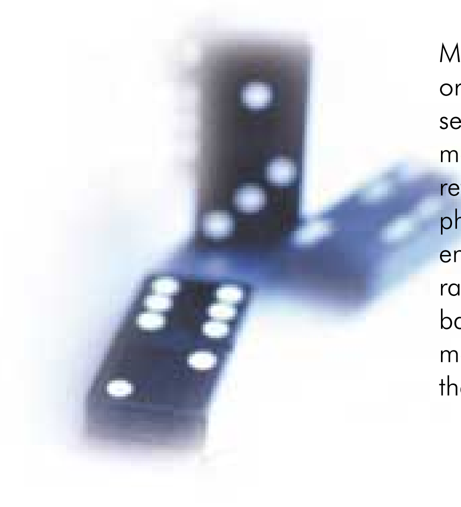
The interviews undertaken for this research supported earlier assertions that the globalisation of business has amplified the tensions between price-focussed purchasing and the

The globalisation of business has amplified the tensions between price-focussed purchasing and the management of supply chain risk

Reduced supply chain resilience as a result of the smaller supplier base and longer supply chains

management of supply chain risk. A manager from the automotive spares company noted that material brought in from the Far East at a lower unit cost resulted in "bigger order quantities, higher inventory and higher storage costs, but the purchaser doesn't have to pay them". The same manager also reiterated another theme from the aerospace findings – the risk associated with the migration of a parts supplier from one location to another. These relocations rarely went smoothly, not least because experienced staff were lost at the time. The companies had to buffer stock against these moves.
For the transport and logistics providers to these companies, globalisation was changing the risk profile at an operational and strategic business level. The managing director of one of the third party logistics providers (3PL) explained that his company found that although developing markets offered many opportunities, the risks associated with operational control increased dramatically. He cited a lower level and breadth of managerial skills in the indigenous populations, as well as the risks associated with political instability, lawlessness etc as root causes.

Consolidation of production and distribution



Most of the manufacturing organisations we consulted were seeking to consolidate manufacturing sites to maximise return on assets. The pharmaceutical manufacturer was engaged in a post-merger rationalisation of its manufacturing base, but like the aerospace managers we interviewed previously, the company reported that it did not have an entirely free hand in the matter. In at least two instances its efforts to optimise the efficiency of its manufacturing operations were restricted by contractual obligations to certain governments. The US Food and Drugs Administration (FDA) imposed a further limitation, by refusing to accept product manufactured in some countries.

The oil company, food manufacturer and retailer were planning further consolidation of their distribution networks. For the oil company this meant fewer larger terminals. Its supply chain planners were aware that they were potentially increasing the risk from any unforeseen disruptions, but margins were under pressure and shareholders had to be satisfied. Hydrocarbon margins were already so low that shareholders were urging the company to be less not more risk averse.

Managers representing the food manufacturer and the 3PLs also raised concerns about reduced supply chain resilience as a result of the smaller supplier base and longer supply chains. In particular they recognised the susceptibility of consolidated networks to the effects of natural disasters.
The retailer we interviewed was principally a UK operation, though its in-bound supply chains extended to the furthest corners of the globe. In the UK, cost-driven decisions were also driving consolidation of its domestic distribution network. Fewer larger service centres were planned and the company was looking at the risks associated with the network redesign and were aware that the consolidated network has fewer nodes and therefore greater vulnerability. Supply chain

and business continuity managers were very conscious of the fact that the leaner supply chains and greater reliance on JIT deliveries, coupled with higher dependence on technology, may pose greater risk to the new network than the old one. The technological risks were not just IT dependencies, they also related to increased automation of picking and sorting activities.

Reduction of the supplier base

Rationalisation of the supplier base was another common theme, some of the organisations had tackled the issue long ago, others were currently in the process of doing so. The pharmaceutical company was moving towards greater reliance on single sourcing, again as part of its post-merger optimisation programme. It was acknowledged that a reduced supplier base could increase supply-side vulnerability, but this was traded off against reduced inventory and demand-related risk from better quality control and the benefits arising from the subsequent introduction of consensus forecasting.

The packaging manufacturer was also rationalising its supply base from over 7000 suppliers to a much lower and more manageable figure, allowing it to introduce a supplier development programme with first tier suppliers. The motives, risks and anticipated rewards were the same as those outlined by the pharmaceutical company. From a production perspective, using a single source of supply was better because it resulted in less variable inputs which in turn meant fewer production problems. The company was aware of alternative sources of supply by family of product, but switching would not necessarily be straight forward as customers were not always willing to accept product changes.

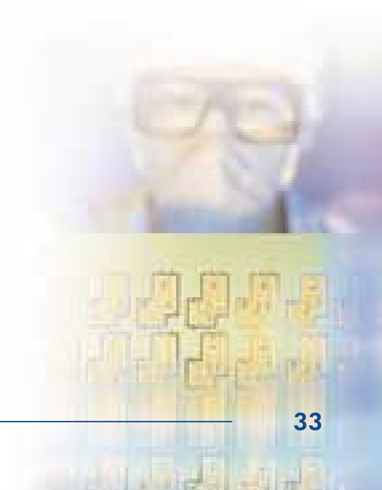
The trend to outsourcing

Views on the issue of outsourcing were more varied than for any of the previous themes. It was seen as an irrelevance by some of the managers we interviewed and a simple fact of life by others. To most it was mixed blessing. It was least relevant to the oil and petrochemicals production company managers. Theirs was a vertically integrated process-based manufacturing business with no direct responsibility for secondary distribution beyond post-refinery regional distribution centres (RDC).

The supermarket managers we interviewed felt that the outsourcing of some activities - including transport - had definite advantages when it came to mitigating certain types of risk. For example, the retailer outsourced some but not all of its transport. The mixed strategy allowed it to retain some control and guard against the risks of industrial action by an in-house provider.

A manager from the pharmaceutical company explained that his company tries to look at the internal impact of outsourcing decisions both “horizontally and vertically” i.e. from a functional cost effectiveness position and in terms of the efficiency of internal processes. Nevertheless, occasionally outsourcing decisions still turned sour. For example, when the manufacture of one active ingredient was outsourced with disappointing results, efforts to bring

The outsourcing of some activities - including transport - had definite advantages when it came to mitigating certain types of risk



The balance of supply chain management is changing, placing greater emphasis on design and the management of change

the activity back in house then failed because key staff had been lost and with them the knowledge needed to manage the process. A similar problem had occurred when IT was outsourced and there too, the company come to realise too late that it had lost the vested knowledge needed to understand how the new systems should relate to specific issues within the business.

The most heavily outsourced business we consulted was the electronics equipment manufacturer who reported that over 85% of what used to be internal process activity had now been outsourced. Such extensive outsourcing has forced greater interest in supply chain change and redesign as a brand protection measure. Most operational processes were not 'brand critical' though service levels did require care and attention. The resulting changes in the supply chain manager's role meant that contract management skills had become a much more important aspect of supply chain design.

Supply chain management activities: the balance of managerial effort

For this part of the cross-sector validation we asked the managers interviewed to assess the balance of managerial effort in relation to the three types of supply chain management activity:

- Supply Chain Planning
- Supply Chain Operations Management
- Supply Chain Change Management

and to assess when they believed their supply chains were most vulnerable and why.

The majority of managers agreed that the balance of supply chain management is changing, placing greater emphasis on design and the management of change.

The food/personal care company manager and his colleagues estimated that in terms of its supply chain management strategy, the balance for their organisation was 80% cost reduction and 20% innovation. Most of the innovation was linked to change management. At the operational level, the managers believed that there was a significant increase in managerial effort going into managing change in the supply chain. They highlighted how marketing moves relating to brand management and product churn were creating real difficulties for supply chain managers. It was a view echoed by the supermarket managers who confirmed that volumes and ranges change all the time. Like the aerospace managers in the case study they too denied that their supply chains ever reached the established 'steady state'. Managers in packaging, automotive components and in the 3PL organisations agreed.

The supply chain specialist from the electronics equipment company agreed that the balance of supply chain management is changing, but was less dismissive of the notion of a steady state. There was a danger that established 'steady state' processes were likely to be very susceptible to external events, again because most people would be trying to optimise and to reduce the control limits to reduce variability of the process. Tighter controls would reduce risk, but only non-conformance risk, which was fine as long as the process requirement remained unchanged

and the supply chain continued to operate within a predetermined set of scenarios.

The oil company managers had in effect highlighted the same issue for their refining activities, identifying changes in marketplace requirements or surges in demand as their main sources of supply chain risk.

Managers from automotive parts manufacturing and pharmaceuticals stressed that supply chain managers should be more involved in, and pay more attention to, supply chain design in the run up to new product launches.

There is a need within an organisation and its associated suppliers to improve R&D, logistics and manufacturing coordination at the supply chain design stage. The automotive industry manager also emphasised inter-organisation cooperation at an earlier stage to overcome the inherent risk in new models and supercessions.

A slightly different perspective was given by a 3PL. By the very nature of their business, 3PLs do not design inter-organisational supply chains, only logistics networks, with most managers' energies spent working on operational issues. One manager estimated that roughly 60% of managerial energy was directed there, with only about 10% going into supply chain change management and about 30% into design. He felt this would increase, as the 3PL moved to become a provider of 'solutions' instead of 'requirements'.

The same manager was eager to stress that the three classes of supply chain management activity should not just be viewed only in terms of single product supply chains and their lifecycles. The issues of supply chain maturity were often poorly understood and that risk was not restricted to the issue of ramping up product volumes. There was also a need for channel volumes to be considered from a life-cycle perspective. Furthermore he believed that the learning curve issues were often underestimated by those planning channel and network reconfigurations. His experience suggested that the supply chains his company supported rarely got the opportunity to mature properly into a mid-life cycle 'steady state'. He observed that every time the grocery retail industry looked as if it was approaching a 'steady state' the major players changed the structure of the industry, catapulting everyone back to the uncertainty and inherent inefficiencies of the early part of the life cycle.

Finally, the major supply chain trends that we have identified, e.g. globalisation, centralisation and rationalisation were widely recognised. However, it was felt by some of those interviewed that the change management implications of these trends, particularly their combined effects, were not fully appreciated by senior management.

Supply chain risk management: processes and tools

The research revealed that companies representing all sectors were engaging in general corporate risk management and in supply chain management, though inter-

There was uncertainty about what supply chain vulnerability and indeed resilience entailed

organisational supply chain resilience was not the motivation. Furthermore when asked to assess the risk management tools and techniques available to manage supply chain resilience, the managers sometimes struggled to answer the question. There was uncertainty about what supply chain vulnerability and indeed resilience entailed. The knock-on effect of that was a degree of uncertainty about the relevance of managerial tools currently employed for other purposes. With further explanation, most interviewees could readily relate to at least some of the tools identified in the aerospace case study, occasionally suggesting others that they had found to be useful for their particular circumstances. A summary of the risk assessment tools and techniques used in the 'critical sector' companies are detailed below:

Pharmaceutical company - had one of the most comprehensive and well-developed risk management processes in place to cover its own manufacturing and distribution network (see inset box).

Risk management within a pharmaceutical company supply chain

The firm uses a three tier *Audit Pyramid* to guide risk management activities. One side of the pyramid covered FDA requirements and those of other drug regulatory authorities. Side two drew on international or global quality assurance schemes such as the Baldridge Awards and ISO 9000. The third dealt with matters of corporate governance. Each of the three dimensions is addressed at corporate and at business unit level and as self-assessment at the departmental level. The process involves looking internally within the company itself and then externally for threats in the business environment and increasingly for risks within the network of first tier suppliers. Over the last two years the company had moved to ensure that third party suppliers were audited for product quality, recently it had also started to work on the inclusion of other risk factors.

Supply chain management as a global function is represented just below board level in this company and although risk audits and assessments are conducted at this level, there are efforts within the business to encourage *structured self-assessment* that is relevant at the local or business unit level. To that end, the company had recently developed and implemented a checklist-based self-assessment tool to standardise risk management processes across the business units. The technological investment required to produce this was negligible. The intranet-based tool took one of the company's IT specialists only four weeks to prepare and uses simple 'bolt together' spreadsheets. It required no additional investment in software or technology. More significant effort was required for the preparation of the statement-based checklists and accompanying help texts, which had to be business specific. This part of the project took considerably longer to develop, test and refine. Nevertheless, the system now provides visibility on supply chain management critical issues (e.g. capacity) across the network.

Inevitably, things still go awry from time to time, so a formal structured *'issues' management process* is also in place for when things are out of kilter, which has to be implemented within four days of detection. Its aim is to resolve (internal) problems at the lowest possible level. If the problem is an internal one it can be up to three months' away from the market and lead times with primary suppliers are up to a year. The implications of far reaching externally driven events, such as war, are considered by each manufacturing or marketing unit, which inform the regional supply chain planning, manufacturing or therapy directors who review these on a monthly or bi-monthly basis. The company is also trying to pull together teams from across its own network, involving suppliers if appropriate, with a view to a more community-based approach to the resolution of problems.

In addition the company is using other functionally-based approaches, reporting excellent results from the application of the *Six Sigma* methodology to its internal manufacturing processes. It has found that the methodology helps greatly in assisting the factories to meet the 'pull of the customer' while maintaining reduced levels of finished inventory. The implementation of Six Sigma began as a functionally driven facilitator of lean supply chain management philosophies. The company has since come to recognise that many reported stock outs were not really stock-outs. Stocks of finished goods existed, but were previously not always visible to those who needed them. Consideration is being given to extending Six Sigma usage into purchasing activities.

The company also uses *scenario planning* to support the structured formal annual risk analysis of suppliers and uses supply chain mapping as a diagnostic approach when problems arise. For example, when a supplier was unable to meet demand, supply chain mapping revealed capacity constraints in the system. As a result the company now holds one year's supply of the active ingredient to ensure continuity of supply. The buffer stock covers the time needed to ramp up volumes of supply if necessary. The manager we interviewed believed that it was possible for his company to map value-adding processes more or less end-to-end, because pharmaceuticals is, to a large extent, a process driven industry. Scenario planning is also used to support the internal risk management assessments on the possible impact of major strategic moves such as the introduction of new enterprise planning software following the rationalisation of the network.

Oil company - had a form of *self-assessment risk control* and crisis management or business continuity procedures in place, to cover buildings, people, communications and IT in the event of terrorist attacks or other potentially serious disruptions like those expected with Y2K. It reported that process control was important in refining, because quality problems reduced margins. *Alerts and event management* principles were well understood within the business, though automated systems to manage these were not yet operational. As a continuous process business, it could not track

"individual molecules" as they passed through its logistics pipelines, but mapping the structure of the network was relatively simple up until the point where the finished product entered the secondary distribution network. Beyond the exceptional external events and everyday process control risks, the managers felt that the risks to its business were chiefly political, or socio-political in nature.

The petrochemicals industry is very tightly regulated. Product quality and even the disposal of waste and old equipment are subject to the most rigid controls. Consequently, the company monitored UK and EU quality legislation very closely. Managers also advocated *media monitoring*, using international news agencies such as Reuters and CNN to keep them abreast of developments, whether it was price volatility as a result of changes in the level of the US government's strategic reserves, or more localised events that could impact them and/or their competitors. The company used *force majeure* in commercial contracts and *hedging* was also used quite extensively as a risk mitigation strategy. Moreover, the company was itself actively involved in market trading, so there was a chance that the company could actually profit from changes in oil prices.

Automotive parts supplier - favoured *media scanning*, together with the use of *'PEST' (Political Economic Social and Technological)* analysis as effective tools to monitor the environment for many forms of external risk. It advocated *'situational awareness'* (i.e. going to have a look). Issues such as loss of a facility, security, environmental health and safety were all handled by the relevant functions within the business where well-established procedures were in place. The company had the usual risk assessment for the corporate plan, plus higher-level business continuity/disaster recovery plans for IT and catastrophic accidents or disasters. For most other eventualities they relied on the knowledge of people within the organisation to manage day-to-day uncertainties. For example, the organisation's distribution centre managers had well versed procedures in place for managing commercial risk associated with new contracts or new clients. They performed risk assessments at bid stage, before contracts were signed and again on the eve of implementation.

Electronic equipment manufacturer – the business had formalised risk assessment and contingency planning processes in place, but as with most of the other companies it was largely one-firm focussed. In terms of risk identification within the supply network, the manager concerned suggested that it was important to identify the network structure and then drill down to individual supply chains to do diagnostic mapping etc as required. The need to improve contract management skills was recognised as the organisation became more dependent on outsourced supply chain management services. In addition, the use of *trade-off analysis* was recommended to prioritise action items.

Food processing company - used some modelling tools, but stressed that these are static not dynamic. Recognising that the interpretations of risk were likely to be hugely

subjective, the managers were seeking to improve their risk assessment, modelling and trade-off analysis methods. In particular they were keen to find better ways to quantify costs vs risk trade offs. They had identified a requirement for dual-purpose tools to assess supply chain risk and performance. Internally they believed that each node of their own network was risk assessed, though the process was not entirely formalised. The feasibility of end-to-end supply chain mapping was limited as the company was no longer a vertically integrated concern. Supplies of raw ingredients were no longer as closely controlled as in the past.

Packaging manufacturer - believed that it was technically possible for them to establish an end-to-end view of their supply chains from raw materials to consumer. It uses some commodity raw materials as inputs to its manufacturing processes and, like the oil company, it uses hedging mechanisms when purchasing aluminium – its most expensive commodity. Otherwise it minimises its own inventory holding risks by receiving all other materials (non-metallic) from suppliers on a consignment basis. Importantly, however, the packaging manufacturer's team stressed that although they could end-to-end map value-adding processes, they could not map the supply chains of the vital capital equipment manufacturers (CEMs) whose machines they relied upon.

As with several of the other organisations we consulted, the packaging company was working hard to integrate supply chain management efforts within its own business units. The company had established *net good assets registers* for the costly production equipment parts (some of which represented multi-million pound purchases), but it was still striving to get the different European plants to work effectively together. Some of the problems experienced were believed to relate to tensions between the plants (individual profit centres) and the centralised inventory management function. For other supply chain management risks, managers recommended *FMEA (Failure Mode Effect Analysis)* as an effective and versatile tool that had been used at many levels during the project management and commissioning of a new plant in southern Europe. They also supported the use of open book accounting when dealing with tier one suppliers, including logistics and transport service providers.

Third party logistics providers - risk management for clients' businesses was not yet a formally articulated consideration. At least one of the companies used modelling tools to estimate the impact of the loss of a link or node within their clients' networks, but stressed that they did not attempt to calculate the probability of such an occurrence. Furthermore, while they were aware of the risks to day-to-day operations and from transportation links, their principal task was to optimise the efficiency of their clients' logistics networks.

Food retailer – as in the pharmaceutical company, the retailer used a range of well-developed tools to assess supply chain risk. It used modelling tools to calculate the effect of the loss of nodes within their own networks.

Supply chain and business continuity managers recommended *brainstorming* for scenario generation. Given the nature of their business, which tended to have to trade-off conflicting requirements of several interest groups - e.g. farmers, customers and governments – they used *stakeholder analysis* to estimate the likelihood of problems occurring (e.g. the blockade of a distribution centre by protestors) as a result of a given course of action.

Recently managers had been doing more varied scenario planning and monitoring at local, regional and international levels. Their trading division monitored international affairs and high-level political risks factors such as war and terrorist threats. As one of the nation's largest distributors of food and petrol it has a more active interest in emergency planning procedures than any of the other commercial organisations we contacted.
The company has well-developed business continuity processes in place, centring around a high level cross-functional group of managers who can convene within one to two hours of notification of an emergent threat to business continuity. The team is authorised to assume complete control of the business in times of crisis, and to take whatever actions are necessary to limit the effects of major incidents.

The business continuity planning procedures were originally developed to deal with IT-related failures, but the organisation has steadily built on this to provide contingency planning for other specific threats. These procedures were used to good effect during the 2000 fuel protest and the 2001 foot and mouth outbreaks. An assessment of external risks, such as flooding, to each of its nationwide network of stores has been undertaken and a business continuity plan has recently been presented to the company's supply chain director (a main board member). Implementation would also require the involvement of its leading logistics service providers.

All the retailer's business continuity measures implemented up until this point had been within the retailer's direct control. Managers conceded that although it seemed relatively simple to impose business continuity requirements on suppliers, enforcement presented many difficulties. Managers confirmed that the priorities of functional business units were not always entirely in tune with higher-level corporate strategic vision. As a result, business continuity planning was a requirement for some, but not all suppliers of outsourced activities. The managers had however identified 20 out of the company's top 100 suppliers with which to start the dialogue. This would move forward with a handful of the largest suppliers rolling out to the others as resources allowed.

The retailer has the advantage that if one of its product suppliers failed it was such an important customer to most that another supplier could be prevailed upon to step into the breach. However, there have been incidents such as the problems experienced in 2002 with pesticide contaminated Chinese honey, that have resulted in the simultaneous withdrawal of all suppliers' products. That incident left the shelves devoid of honey until suppliers had completed ingredient checks on their own supply chains. As a result a supply chain specialist has been invited to join the 'Serious Incident Committee', prompting moves for closer working between the retailer's supply chain managers and business continuity teams.

Extending the reach

Most managers interviewed agreed that it was possible to extend the widely applied internal audit processes upstream and downstream as far as the most immediate adjacent organisations, but that trust and relationship issues still posed a problem. Commercial sensitivities could be a limiting factor. One logistics service provider noted the tendency to share data vertically but for the purposes of his business, it should be a horizontally shared environment at first tier. The sheer volume of work and the resource requirement needed to impose business continuity procedures throughout a company's supply chain supported the view of the aerospace industry that end-to-end monitoring of every conceivable risk to the supply chain was impractical. A majority of the managers interviewed agreed that more widely applied internal audit processes extending upstream and downstream to the immediate adjacent organisations was the way forward.

Conclusions

- Sources of risk – the findings demonstrated similarities between all sectors
- Cost reduction remained a constant theme, emerging as the principle driver behind the universal moves towards longer, leaner, more consolidated, but potentially less resilient networks
- When and where supply chains (as the managers interviewed understood the term) were most vulnerable were usually known, but not always recognised elsewhere in the organisation or supply chain
- The volatility of operating environments was highlighted. Few managers believed that their internal networks or those of the wider industry were stable enough to reach a mature balanced state. Changes in product specifications, continuous improvement initiatives, outsourcing, internal network redesigns, changes in IT support systems and process technology, supply base and industry consolidations all contributed to the volatility of their operating environment.
- The management of change coupled with regulatory and geopolitical changes and the practicalities of managing across different legal, cultural and environmental settings made supply chain management a far more complex set of activities than was perhaps widely recognised. The balance of effort seemed to be changing too, with a growing emphasis on planning and change management activities.
- The managers interviewed found the identification of suitable risk management tools initially problematic. Nevertheless, they supported the general principle of a limited reach approach to supply chain risk management, encompassing the focal firm, its immediate customers and suppliers, where possible within a shared data environment.

It was possible to extend the widely applied internal audit processes upstream and downstream

Section 4 - Creating the Resilient Supply Chain: Recommendations for business

Emerging from the research are a number of key points which impact supply chain resilience and business continuity:

Biggest risk to business continuity may well come from the wider supply chain

- There is a disconnect in organisations between the determination of business strategy and the recognition of the impact of these strategic decisions upon supply chain vulnerability

- The globalisation of business and the pressure for cost reduction have in turn created supply chain risks

Current understanding of supply chain risk is underdeveloped

- Managers with supply chain responsibilities focus, in general, on internal operational risks. They are not explicitly required to address supply chain vulnerability or resilience

- Business continuity planning tends to focus on the internal network yet the message that needs to be understood and acted upon is that the biggest risk to business continuity may well come from the wider supply chain rather than from within the business

Why businesses should act

Supply chains, we have suggested, are in fact networks connecting businesses, industries and economies. Consequently, the diverse range of effects triggered by even a modest incident can fail to lead to underlying weaknesses being diagnosed if they are considered in isolation and not as part of the wider, overarching system. In effect, current understanding of supply chain risk is underdeveloped and only capable of looking at pieces of the supply chain vulnerability jigsaw, without the ability to connect these pieces and see the wider picture.

Business continuity and risk management, particularly with regard to IT appears to be fairly well understood and applied in most companies. The same is not true of risk management in supply chains. Where awareness exists, major impediments are the lack of:

- An integrated programme of action incorporating the supply chain function
- Access to an appropriate 'toolkit'

Dealing with supply chain vulnerability requires a change management approach. Such an approach recognises that the 'right' philosophy for tackling supply chain vulnerability depends on culture, structure and business drivers dominant in an industry sector. Against these criteria we have identified four issues that foster success in supply chain continuity management:

- Risk awareness among top managers
- Risk awareness as an integrated part of supply chain management
- Understanding by each employee of their role in risk awareness
- Understanding that changes in business strategy change supply chain risk profiles.

Scanning the landscape – a managerial framework

Given the inter-organisation, international and inter-industry nature of contemporary supply chain networks, a managerial tool-kit for the identification and management of supply chain risk and vulnerability represents something of a 'bottom-up' approach to dealing with the problem.

At the beginning of this report we suggested that supply chain risk can stem from sources within the supply chain and/or sources external to it. However, the application of a managerial tool-kit necessarily advances from the perspective of a manager in an organisation or business unit – i.e. a single node in one or more of the inter-organisational networks described in the earlier framework.
We have also established that organisations rarely have knowledge of the working of their customers or suppliers beyond those immediately adjacent to them. Consequently, we have provided a structured analytical framework, using this truncated supply chain perspective as a starting point, Figure 4.1. The framework leads management to consider how, where, when and why supply chains may be vulnerable at each of the four levels of the landscape (i.e. value-stream, asset/infrastructure, organisations, environment).

The managerial framework categorises the sources of risk according to perceived location of a potential risk or manifestation of an event, i.e. into three stages:

•Internal to the focal firm
o Process
o Control

•External to the focal firm but internal to the supply chain network
o Demand
o Supply

•External to the network
o Environment

The first two 'internal' categories of the framework relate to elements which are within the control of the focal firm, more often than not this will be within the bounds of the firm as a legally defined unit.

Processes are the sequences of value-adding and managerial activities undertaken by the firm. The execution of these processes is likely to be immediately dependent on internally owned or managed assets and on a functioning infrastructure. Therefore, internally owned or managed assets and the reliability of supporting transport, communication and infrastructure should be carefully considered. Process risk relates to disruptions to these processes.

Controls are the assumptions, rules, systems and procedures that govern how an organisation exerts control over the processes. In terms of the supply chain they may be order quantities, batch sizes, safety stock policies etc. plus the policies and procedures that govern asset and transportation management. Control risk is therefore the risks arising from the application or misapplication of these rules.

Changes in business strategy change supply chain risk profiles

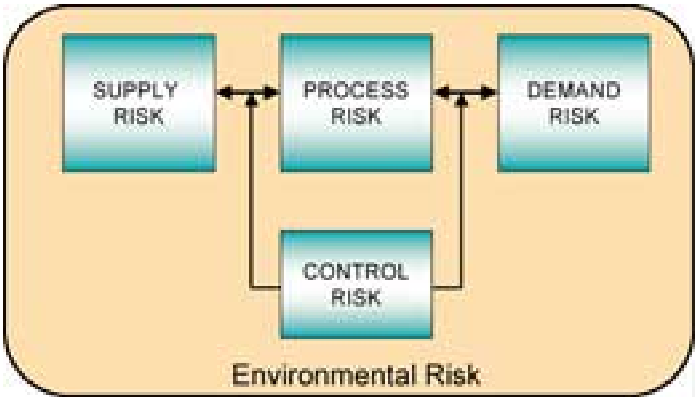


FIGURE 4.1: A MANAGERIAL APPROACH – SOURCES OF RISK IN THE SUPPLY CHAIN

(Source: Adapted from Mason-Jones, R. and Towill, D.R. (1998) "Shrinking the Supply Chain Uncertainty Cycle", *Control*, September, pp17-22).

Processes and control mechanisms should be aligned to support corporate and supply chain strategies. The next two categories are external to the focal firm, but remain internal to the inter- organisational networks through which materials, products and information flow. Ideally the focal firm should have an awareness of potential or actual disturbances to the anticipated flow of product and information from within and between every node or link in the supply chain networks through which its own value-streams flow. In practical terms this may not be possible, but the focal firm should at least strive to familiarise itself with those that are known or likely to affect adjacent organisations. It is unlikely that the focal firm will ever have intimate knowledge of all potential risks, though appropriate monitoring should increase the likelihood and provide early warning of actual events.

Demand risk relates to potential or actual disturbances to flow of product, information, and in this instance cash emanating from within the network, between the focal firm and the market. In particular, it relates to the processes, controls, asset and infrastructure dependencies of the organisations downstream and adjacent of the focal firm.

Supply risk is the upstream equivalent of the above, it relates to potential or actual disturbances to the flow of product or information emanating within the network, upstream of the focal firm.

The fifth and final category relates to disruptions that are external to the network of organisations through which the value-streams/product supply chains flow.

Environment - These events may of course directly impact upon the focal firm or on those upstream or downstream, or indeed on the marketplace itself. They may affect a particular value stream (e.g. product contamination) or any node or link through which the supply chain passes (e.g. as the result of an accident, direct action, extreme weather or natural

disasters). They may be the result of socio-political, economic or technological events many miles or organisations removed from the focal firm's own supply chains, but may have knock-on effects through linkages to other industry networks. The type or timing of these events may be predictable (e.g. those arising from regulatory changes), but many will not be, though the impact of these types of events may be assessed.

Principles underpinning resilience

Determining the appropriate practices to manage supply chain vulnerability appears to be context specific, dependent amongst other things on the supply chain's response to the need for operational excellence. Recognising this situation it was possible to identify four general principles:

- Risk considerations should influence the supply chain design and structure (i.e. supply chain (re) engineering)
- Risk management should be based on a high level of supply chain visibility, process alignment and understanding/cooperation amongst all supply chain partners
- Supply chain resilience implies agility, i.e. being able to react quickly to unpredictable events
- The creation of a risk management culture in the organisation based on clear performance requirements and lines of communication between all supply chain organisations will enhance, indeed make possible, supply chain resilience.

At a tactical level a set of activities should be carried out to prepare for and handle disruptions. These activities are the processes:

- Risk identification process, e.g. product, supplier, supply chain related
- Risk assessment process, e.g. likelihood v impact v cost
- Supply chain continuity management and co-ordination processes
- Processes to ensure learning from experiences.

Supply chain resilience implies agility

Supply chain (re) engineering

Conventionally supply chains have often been designed to optimise for cost and/or customer service, rarely was resilience an 'objective function' for the optimisation process. Given the risks to which modern supply chains are exposed this may need to change. A number of recommendations are suggested to provide the basis for the design of supply chains with risk reduction in mind.

Mapping tools can help in the identification of 'pinch points' and 'critical paths'

i) Supply chain understanding

A fundamental pre-requisite for improved supply chain resilience is an understanding of the network that connects the business to its suppliers and their suppliers and to its downstream customers. Mapping tools can help in the identification of 'pinch points' and 'critical paths'.

Pinch points will often be characterised as bottlenecks where there is a limit of capacity and where alternative options may not be available e.g. ports capable of taking large container vessels or central distribution facilities which

Single sourcing maybe advantageous from a cost and quality management perspective, but is dangerous in terms of resilience

The strategic disposition of additional capacity and/or inventory can be extremely beneficial

if they were to become inoperable would place a heavy strain on the rest of the system.

A critical path in the supply chain/network may have one or more of the following characteristics:

- Long lead-times e.g. the time taken to replenish components from order to delivery
- A single source of supply with no short-term alternative
- Linkages where 'visibility' is poor, i.e. little or no shared information between nodes
- High levels of identifiable risk (i.e. supply, demand, process, control and environmental risk).

Following from this risk assessment exercise should be the creation of a supply chain risk register where the vulnerabilities of critical nodes and links in the network are noted and procedures for their monitoring and subsequent mitigation and management are defined.

ii) Supplier base strategy

Whilst there has been a move towards the reduction of the supplier base in many companies, there may be limits to which the process should be pursued. Single sourcing, where one supplier is responsible for the supply of a specific item or service, maybe advantageous from a cost and quality management perspective, but is dangerous in terms of resilience.

Whilst it may be desirable to have a lead supplier, wherever possible alternative sources should be available. Where a firm has multiple sites it may be possible to have a single source for an item or service into each site thus gaining some of the advantages of single sourcing without the downside risk. Similarly if a manufacturing firm makes a range of products it may be possible to single source by product thus keeping an alternative source of supply available.

It is strongly advocated that one of the key criteria for the selection of suppliers should be the risk awareness of the supplier. For example have they audited their own supply chain risk profile? Do they have procedures in place for the monitoring and mitigation of risk? It may be appropriate for the company to adopt a pro-active strategy of supplier development to work closely with key suppliers to help them improve their supply chain risk management practices.

iii) Design principles for supply chain resilience

A number of principles have emerged which should be considered when (re) engineering supply chains to improve resilience:

- Choose supply chain strategies that keep several options open. This may not be the lowest cost course of action but may be the lowest risk. There is an analogy here with 'Real Options Theory' in investment planning. Thus a strategy that is based around centralisation of distribution facilities may be the lowest cost option but it could also shut down other options and hence increase vulnerability.

- Re-examine the 'efficiency vs. redundancy' trade off. Conventionally surplus capacity and inventory have been seen as undesirable. However, the strategic disposition of additional capacity and/or inventory can be extremely beneficial in the creation of resilience within the supply chain. Capacity is a form of inventory but is often more flexible in that inventory may already be committed to its final form or destination. Both capacity and inventory can provide 'slack' in a supply chain to enable surge effects to be coped with. Inventory, carried in a generic or semi-configured form, can enable the creation of a 'de-coupling point' that, together with additional capacity (e.g. production, transport, people), can enable demand uncertainty to be more effectively managed.

Supply chain collaboration

A high level of collaborative working across supply chains can help significantly to mitigate risk. The challenge is to create the conditions in which collaborative working becomes possible. Traditionally supply chains have been characterised by arms-length, even adversarial, relationships between the different players. There has not been a history of sharing information either with suppliers or customers. More recently however there have been encouraging signs that a greater willingness to work in partnership is emerging in many supply chains. In the fast moving consumer goods (fmcg) industry there is now significant collaboration between manufacturers and retailers in the form of Collaborative Planning, Forecasting and Replenishment (CPFR) initiatives.

The underlying principle of collaboration in the supply chain is that the exchange of information and application of shared knowledge can reduce uncertainty. Thus a key priority for supply chain risk reduction has to be the creation of a supply chain community to enable the exchange of information between members of that community. The aim is to create a high level of 'supply chain intelligence' whereby there is a greater visibility of upstream and downstream risk profiles (and changes in those profiles), ie at each node and link in the supply chain and at each level of analysis, i.e. environment, network, asset/infrastructure and process.

Supply chain knowledge can be categorized as Strategic, Tactical and Operational, Figure 4.2.

Strategic knowledge is an awareness of trends and emerging issues that may have an impact on supply chain continuity at some point in the future. This type of knowledge can be generated through formal 'P.E.S.T.' type analysis (Political, Economic, Social and Technological). Such analyses are intended to enable a formalised appraisal of the context within which networks and supply chains operate.

At the *tactical* level the knowledge required is specific to the assessment of risk to current operations, primarily in the areas of:

- Demand, e.g. market volatility; product life cycle

Traditionally supply chains have been characterised by arms-length, even adversarial relationships

Many organisations are at risk because their response times to demand changes or supply disruption are too long

- Supply, e.g. lead-times; supplier consolidation
- Process, e.g. bottlenecks; variability
- Control, e.g. lack of visibility; poor data integrity

The *operational* level pertains to the day-to-day management of the business. The emerging field of supply chain event management is potentially of great value in managing operational disruptions.

Agility – responding to change

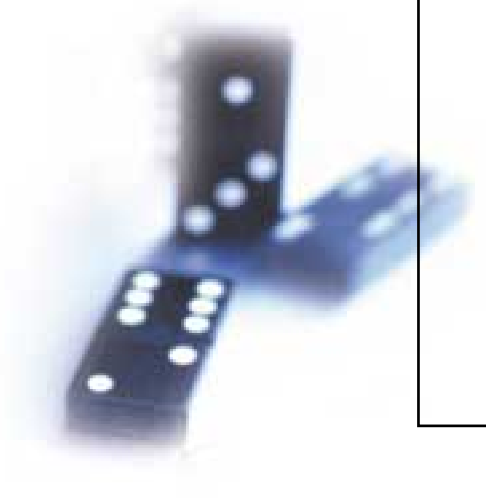
Supply chain agility can be defined as the ability to respond rapidly to unpredictable changes in demand or supply. Many organisations are at risk because their response times to demand changes or supply disruption are too long. Agility has many dimensions and it relates as much to networks as it does to individual companies. Indeed, a key to agile response is the presence of agile partners upstream and downstream of the focal firm.

Two key ingredients of agility are:
•Visibility and
•Velocity.

Supply chain visibility

Supply chain visibility is the ability of all members of the supply chain to see from one end of the pipeline to the other. Visibility, for example, implies a clear view of upstream and downstream inventories, demand and supply conditions, and production and purchasing schedules with clear lines of communications and agreement on 'one set of numbers'.

Lack of visibility forces supply chain managers to rely on forecasts and build intervening inventories (i.e. buffers), which do not correspond to actual demand thus worsening the situation. These intervening inventories are usually created independently of each other as a result of members of the supply chain not having detailed knowledge of what is happening in the rest of the network, e.g. information on finished goods inventory, materials inventory, work in progress demand, capacity, order status and so on. Visibility will be further distorted by the presence of the bullwhip effect that can magnify small changes in marketplace demand as it moves back up the supply chain.



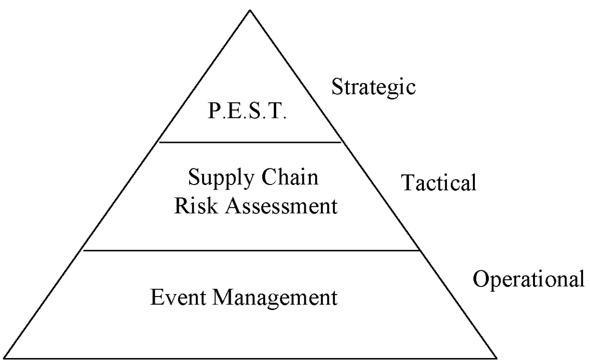


FIGURE 4.2: SUPPLY CHAIN KNOWLEDGE

The achievement of supply chain visibility is based upon close collaboration with customers and suppliers as well as internal integration within the business.

Collaborative planning with customers is important firstly to enable visibility of their demand to be gained but also for information to be shared on market trends and perceptions of risk. Equally, upstream visibility also requires high levels of collaborative planning with suppliers and the use of 'event management' logic to enable alerts of potential supply disruptions to be signalled.

A significant barrier to visibility is often encountered within the focal firm's internal organisation structure. The presence of 'functional silos' inhibits the free flow of information leading to 'second guessing' and a general lack of communication. This situation is often exacerbated when the company has internal suppliers or customers with limited integration between them. The challenge here is to break down these silos to create multi-disciplinary, cross-functional process teams.

Supply chain velocity

The second ingredient of supply chain agility is velocity. Velocity is defined as distance over time. To increase velocity time must be reduced. Here we are referring to 'end-to-end' pipeline time i.e. the total time it takes to move product and materials from one end of the supply chain to the other. End-to-end pipeline time – as it relates to agility – can be measured as the elapsed time from when the focal firm places orders on its Tier 1 suppliers to when it delivers finished product to the customer. It is not just velocity that matters in the creation of agile supply chains it is acceleration. In other words how rapidly can the supply chain react to changes in demand, upwards or downwards?

There are three basic foundations for improved supply chain velocity and acceleration:

- Streamlined processes,
- Reduced in-bound lead-times
- Non-value added time reduction.

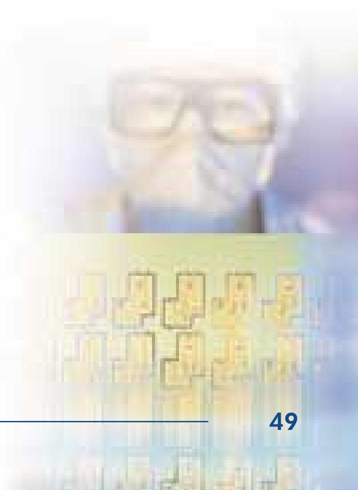
***Streamlined processes* -** have been engineered to reduce the number of stages or activities involved, they are designed to perform these activities in parallel rather than in series and they are e-based rather than paper-based. At the same time they are designed around minimal batch sizes – be they order quantities, production batch sizes or shipping quantities. The emphasis is on flexibility rather than economies of scale.

***Reduced in-bound lead-times* -** one of the criteria for the choice of supplier and the source of supply should be their ability to respond rapidly in terms of delivery and to be able to cope with short-term changes in volume and mix requirements. Synchronisation of schedules based on shared information enables suppliers to become more agile without necessarily having to rely on inventory as a buffer with all its consequential problems.

***Non-value adding time reduction* -** most time spent in a supply chain is not value adding from a customer perspective.

Supply chain visibility is based upon close collaboration with customers and suppliers

It is not just velocity that matters in the creation of agile supply chains it is acceleration



Nothing is possible without leadership from the top of the organisation

More often than not it is idle time i.e. inventory which is itself generated as a result of cumbersome processes – every day of process time requires at least a day of inventory to cover during that lead-time.

Creating a supply chain risk management culture

In the same way that many organisations recognised that the only way to make total quality management (TQM) a reality was to engender a culture that made quality the concern of everyone, so too today is there a requirement to create a risk management culture within the business. We would argue that this culture of risk management should extend beyond the current boundaries of business continuity management to become 'supply chain continuity management'.

As in every case of culture change at an organisational level, nothing is possible without leadership from the top of the organisation. One of the key conclusions of our research is that supply chain risks present the most serious threat to business continuity and yet, paradoxically, not every company has supply chain management represented in its own right in the Boardroom. If the supply chain has a voice at all at that level it is often represented through IS/IT directors. Whilst this can work it is often the case that in such instances the understanding of what constitutes supply chain risk is limited to an information systems based perspective.

It can also be argued that supply chain risk assessment should be a formal part of the decision making process at every level, for example when new products are at the design stage, issues of supply chain vulnerability such as component availability and lead times should be considered. Similarly when changes in business strategy are contemplated such as a move to off-shore sourcing from domestic sourcing, then the resulting supply chain risk profile should be assessed.

A supply chain risk management team should be created within the business and charged with regularly updating the supply chain risk register and to report to the main Board through the supply chain director on at least a quarterly basis. The team will need to be cross functional and to be able to audit risk using the tools detailed in Appendix 1 in this report.

Figure 4.3 summarises the constituent elements of our proposed route map to resilience.

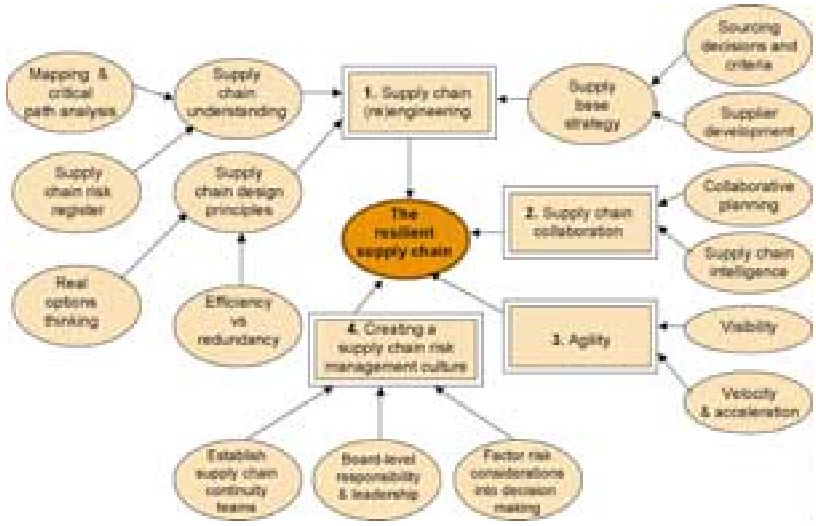


FIGURE 4.3 : CREATING THE RESILIENT SUPPLY CHAIN

Appendix 1- A Toolkit for Supply Chain Process Risk Management

A number of tools have been identified that can be used by managers to identify and manage supply chain risk at the business process level.

Understanding and managing the processes that comprise supply chains is critical to the reduction of risk

Supply chain processes

A supply chain is a set of processes that are linked together to enable the movement of products, materials and information from source to use. These processes exist not only within the individual firms that comprise any given supply chain but also between those firms. We can describe supply chains as networks of nodes and links. The nodes are the individual organisations, business units or entities that are connected through links such as transportation systems and information transfers.

Process variability and supply chain risk

Understanding and managing the processes that comprise supply chains is critical to the reduction of risk. The reason for this is simple: if the process is under control then the risk of non-conformance (i.e. deviation from the plan) is significantly reduced. This idea has long been recognised in manufacturing where process control is seen as the key to maintaining product quality on a consistent basis. It can be argued that the concept and techniques of process control and quality management can be applied to any process, not just manufacturing. In fact every process within a supply chain can benefit from the application of these ideas. The underpinning idea behind process management is the reduction in variability. It should also be recognised that in a supply chain variation increases as a result of the combined impact of variability at each stage in the chain, for example if there are 20 stages in a supply chain and each achieves 99% success against planned performance, the likelihood of the final outcome being as planned is actually $(0.99)^{20}$ i.e. 81.8%.

It is therefore important to understand how performance variability of one process in the supply chain can impact on the performance of consecutive processes. In effect process variability accumulates as we move along a supply chain.

Methodology for process risk management

The process of risk management within the supply chain should be approached in a systematic and holistic manner. A step-by-step approach similar in many ways to the approach taken in quality improvement programmes would seem appropriate. Figure A1.1 shows the key elements considered essential in any process for supply chain process risk management.

A number of tools and techniques have emerged over the years to help in the identification and reduction of variability in business processes. Recently many of these ideas have been brought together under the umbrella of 'Six Sigma' – a philosophy and a methodology for process improvement that is data based and reliant on statistical tools and techniques.

Six Sigma

The term Six Sigma is largely symbolic and it refers to the chance of defect or failure; sigma (or the standard deviation) being the statistical measure of variation in a distribution. Six Sigma implies that the chance of failure is only 3.4 in a million opportunities. Whilst Six Sigma performance may be unattainable in many cases, it is used as a target – sometimes Six Sigma is referred to as "a journey not a destination". Many of the tools of Six Sigma have come from the total quality management (TQM) toolbox. Six Sigma is a continuous improvement methodology, which seeks to make existing processes more robust. This may be too limiting a goal for supply chain risk management, merely making a process robust rather than changing it to make it more resilient. However, reducing process variability creates capacity; capacity that can either be removed if the aim is to become leaner or maintained if the aim is a more resilient (or perhaps agile) supply chain. Whether the goal is robustness or resilience, the Six Sigma methodology can bring dramatic results.

The Six Sigma methodology follows a five-stage sequence:

- Define
- Measure
- Analyse
- Improve
- Control

Define:	What is it we are seeking to improve? What Key Performance Indicator (KPI) do we want to improve?
Measure:	What is the current capability of the process? What averages, what variability is evident?
Analyse:	Map the process, use cause and effect analysis (e.g. Pareto Analysis and Fishbone Diagrams)
Improve:	Re-engineer the process, simplify
Control:	Improve visibility and transparency of the process. Use statistical process control

A modified Six Sigma model for supply chain process risk management

The modified Six Sigma model for supply chain risk management, illustrated in Figure A1.2 provides a robust and systematic methodology that can be applied to supply chain processes. The methodology is fashioned on the Six Sigma model of *Define-Measure-Analyse-Improve-Control*, more commonly referred to as the DMAIC Improvement Process that is used widely by manufacturers for process and product quality improvement. The proposed Process Risk Model, Figure A1.2 adapted for supply chain risk management comprises two cycles:

- Tactical cycle
- Operational cycle.

Notably the tactical cycle includes a risk prioritisation step, 'Prioritise', and we replace 'Define' with 'Identify'. The 'Improve' step is given the more appropriate title of 'Reduce', thus transforming the DMAIC Process for Improvement

into the IMP & ARC Processes for Risk Reduction.

Tactical cycle

The main objectives for the tactical cycle are to Identify, Measure & Prioritise (IMP) risks inherent in the organisation's supply chain processes. Collectively this is referred to as Risk Chain Analysis (RCA) because the aim is to identify those process risks inherent within the supply chain that are critical to the business and to prioritise them so that ultimately the organisation can maximise the reduction in the total cumulative supply chain process risk. It is recommended that risk managers adopt FMEA (Failure Mode and Effect Analysis) as a framework for execution of the IMP cycle. The main objectives of RCA are defined as follows:

- **Risk identification:** Identify critical path processes that represent significant sources of risk to the output of the organisation's supply chain.

- **Risk measurement:** Measure the impact of each risk on the business and extended enterprise.

During this step of the process all identified risks are measured in terms of their effect on the supply chain and impact on the business. Using the FMEA approach and a suite of appropriate tools and techniques, risks can be measured using three criteria:

- The probability or expected frequency of risk occurrence
- The severity of the impact of the risk on the business in both cost and customer service terms
- The probability of early detection and impact avoidance.

- **Risk prioritisation:** Prioritise risks so that attention can be focused on those with the greatest potential to cause damage and those that represent the greatest opportunity for risk reduction. The process of prioritisation should consider the cost of risk reduction in cost-benefit terms, i.e. the organisation should focus on those risks where the expected degree of risk reduction achievable per unit cost invested is the greatest.

Operational cycle

The main objectives for the operational cycle are to Analyse, Reduce and Control (ARC) high priority risks through individual risk management projects; these are defined as follows:

- **Risk analysis:** Analyse in detail the root causes of each risk and translate the findings into risk reduction projects.

It is the effect of the risk and the potential damage that the effect can cause the business that is of importance when considering risk reduction strategies and tactics.

Although some analysis is required in order to carry out 'Risk Measurement' and 'Risk Prioritisation' during the tactical cycle, this analysis step involves a more in-depth investigation in order to quantify the effects of each risk.

- **Risk reduction:** Implement risk reduction strategies to reduce or mitigate those high priority risks for which cost effective solutions

FIGURE A1.1: KEY ELEMENTS OF SUPPLY CHAIN PROCESS RISK MANAGEMENT

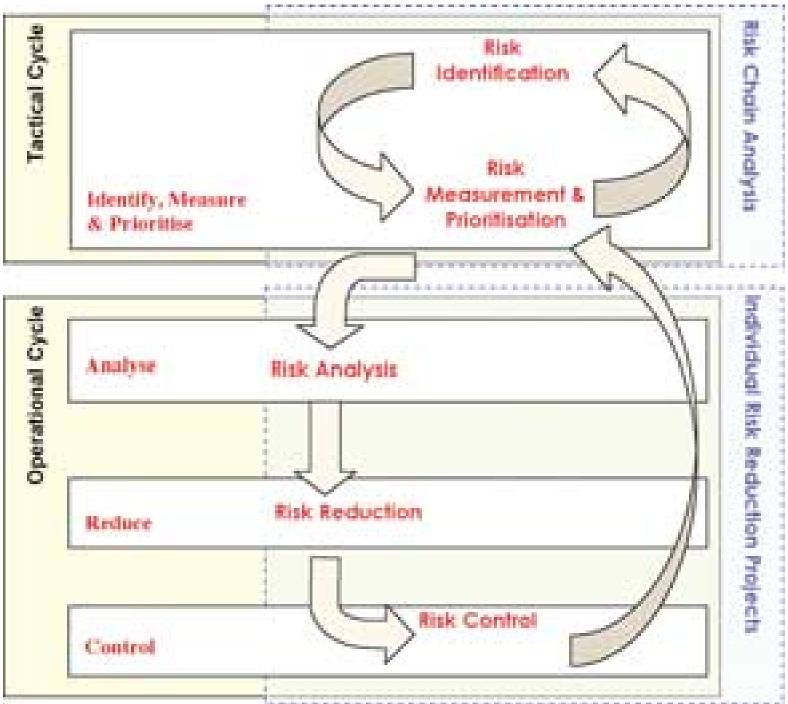


FIGURE A1.2: THE PROCESS RISK MODEL FOR SUPPLY CHAIN PROCESS RISK MANAGEMENT

Source: Adapted from Knowles, G. (2003) *Supply Chain Improvement Model,* Warwick Manufacturing Group, University of Warwick.

Six Sigma Methodology (DMAIC)	Supply Chain Process Risk Management (IMPARC)	Tools and Techniques	Scenario Planning	Delphi Forecasting	Brainstorming	Failure Modes and Effect Analysis (FMEA)	Flowcharting	Supply Chain Mapping	Critical Path Analysis	Bottleneck Identification	Statistical Process Control	Process Capability Analysis	Simulation Modelling	Root Cause Analysis	Fishbone Diagram	Pareto Analysis	Process Decision Programme Chart	Benchmarking	Business Process Re-engineering	Time-based Process Mapping
Define & Measure	Identify, Measure & Prioritise		x	x	x	x	x	x	x	x	x	x	x	x	x	x				
Analyse	Analyse										x	x	x	x	x			x		x
Improve	Reduce				x								x			x	x	x	x	x
Control	Control										x	x								

FIGURE A1.3: THE TOOLKIT

can be found. The ultimate aim should be to follow a risk management programme that maximises the reduction in the total cumulative supply chain risk. The aim of risk reduction is to find and implement a solution that will provide the greatest reduction in the combined effect of the three key risk criteria:

- probability of occurrence
- severity of impact
- ability to detect.

- **Risk control:** To continually monitor the magnitude of the reduced risk over time, maintain control of the process and feedback into the tactical cycle.

The Toolkit for resilient supply chain processes

Figure A1.3 lists the tools identified as being of practical help in supply chain process risk management. A brief description of each is provided. A more detailed guide to the tools and their application is provided in the complete version of this report. For details see page 12.

Further reading

George, M. L., (2002), *Lean Six Sigma*. McGraw-Hill.

Scenario Planning - What is it?

Scenario planning is the process of constructing plausible futures against which alternative strategic business decisions can be evaluated. Scenario-planning focuses on how the future can evolve; scenarios focus on the sources of uncertainty without attempting to convert them into probabilities.

It implicitly accepts that managers are not able to assess the probability of unique future events; it assumes that at best they can identify critical future uncertainties and based on these construct a set of plausible futures. During the process of scenario planning the relationships between critical uncertainties, important predetermined trends and the behaviour of stakeholders in a particular future are investigated such that the resultant scenarios are considered to be plausible (but not necessarily very likely). Using it, businesses can:

- Develop scenarios that can be used to assess the risks associated with alternative supply chain strategies
- Develop alternative scenarios that consider the key uncertainties associated with each of the identified sources of supply chain risk, i.e. supply, demand, process, control and environmental risks
- Test the resilience of the current or proposed supply chain strategy against a set of plausible futures
- Prepare for the future and get a better understanding of the uncertainties that lie ahead
- Take the opportunity to ‘rehearse’ responses to possible futures.

Step by step outline

1. Establish a team of 2-3 managers with appropriate knowledge/experience to facilitate the construction of a set of scenarios
2. The team then sets the objectives to define boundaries and focus, e.g. time horizon for scenarios, constraints on future plans, products etc
3. Objectives are then agreed with key stakeholders, individually or in groups
4. Brainstorming session/s held with stakeholders to establish a set of scenarios
5. Strategic options are evaluated against the future represented in the set of scenarios, i.e. use the scenario as a basis for comparison in the strategic decision making process.

Further reading

- Goodwin, P. and Wright, G. (1998) *Decision Analysis for Management Judgment*. 2nd Ed. Wiley, England.

Delphi Forecasting - What is it?

The Delphi method of futures forecasting has sometimes been described as 'an anonymous debate by questionnaire'. The idea behind Delphi Forecasting is to utilise the insights and knowledge of experts (e.g. managers, customers, suppliers with knowledge of the supply chain) to create a view of how likely various future scenarios are and, usually, to place some timescale on when those future events might happen.

One of the key underpinning aspects of Delphi Forecasting is that it seeks to avoid the problems of group pressure and/or dominant opinions that might arise if those experts were brought together to debate the same issues. Instead individual views are sought by questionnaire, the results are pooled anonymously and then circulated back to the respondents who may, if they wish, then modify or justify their earlier responses.

The first applications of the Delphi method in the 1950's and 1960's were primarily focused on technological forecasting. Soon, the technique was applied to predicting social and demographic change and then to business and market scenario development.

Using Delphi methods in the context of supply chain risk management businesses can

- Utilise expert opinions to identify emerging trends
- Understand the likelihood of future events and their timescale
- Develop alternative scenarios against which contingency plans can be developed.

Step by step outline:

1. Identify possible events that could impact the supply chain. Brainstorming the five risk sources – demand, supply, control, process and environment is a good start point
2. From step 1 formulate the Delphi questionnaire. Questions must be phrased in terms of probabilities and/or timescales, e.g. "by which year will 'x' happen" or "what percentage of supply chain operations will be contracted out by 2010?"
3. Form a panel of 20-30 people with knowledge and experience of the supply chain under review. This can include customers, suppliers and competitors
4. Collate panel's responses to questionnaire, calculating upper, lower and medium quartiles and comments received
5. Repeat the process; the second round questionnaire with the aggregated response is circulated. The panel reconsiders original judgments and complete and return the questionnaire with comments where appropriate
6. Repeat the process to enable debate and an agreement to emerge.

Further reading

- Wright, G. and Goodwin, P. (1998) *Forecasting with Judgment*. John Wiley and Sons Ltd.

Brainstorming - What is it?

Brainstorming is a technique used to generate ideas and solve problems. It is a group-based approach utilising the collective ideas and insights of individuals and to use those ideas and insights to generate others.

An essential principle of the brainstorming process is that it is judgment-free. In order to stimulate original thinking any idea, no matter how wild it may seem at first, is encouraged. Only at a later stage should there be evaluation.

Using brainstorming in the context of supply chain risk management businesses can:

- Identify both internal and external sources of supply chain risk
- Identify opportunities for risk reduction and/or mitigation
- Build greater awareness of supply chain vulnerability as a business issue.

Step by step outline:

1. Group of 8-10 managers, reflecting the organisation's supply chain, and external partners, e.g. suppliers, customers and third party providers, are brought together for a half-day session
2. Provide the group with a brief prior to meeting
3. Appoint a facilitator and note taker
4. At the start of the first session participants will write down the three biggest risks to the supply chain. These are recorded and can be used as the basis for the session
5. Post session, ideas generated are summarised and circulated to the group
6. The process should be repeated one or two weeks later to develop the ideas from the first session.

Further reading

- Rawlinson, J. (1986) *Creative Thinking and Brainstorming*. Gower.

Failure Mode and Effect Analysis (FMEA) - What is it?

Failure Mode and Effect Analysis (FMEA) is a tool that makes it possible to determine a system's possible modes of failure, and then to establish the effects of those failures on the overall performance of the system.

FMEA is widely used as a quality improvement tool that can be applied equally to physical systems (vehicles, aircraft, electronic devices and so forth) and non-physical systems such as supply chain processes. The purpose of FMEA is to prevent process and product problems during the design phase. However, conducting an FMEA on existing processes is also hugely beneficial; unlike products, processes can be re-engineered more easily.

An extension of the approach involves ranking possible failures in order of the seriousness, in order to prioritise remedial actions. This is formally known as Failure Mode, Effect and Criticality Analysis (FMECA). In practice, Failure Mode and Effect Analysis is often used as a generic term embracing both concepts.

Using FMEA (or FMECA), businesses can:

- Exhaustively identify and catalogue the various ways in which links and nodes in the supply chain may fail
- Determine the effects of those failures
- Rank failures according to their likelihood of occurrence, their disruptive effect and the likelihood that imminent failure can be detected in time to put in place remedial action.

Combined, this then gives an estimate of criticality, in order to guide preventative action.

Step by step outline

1. Break down the supply chain (or the selected part) into its component parts
2. Brainstorm each individual operation, activity or process
3. Establish the effects of each failure. Rank failure modes on a scale of one to 10 to indicate the failure in terms of its effect (one equals low severity; 10 equals high severity) and to establish priority for remedial action (one equals easy; 10 equals difficult)
4. Calculate the product of the ranking to establish the criticality or Risk Priority Number (RPN) of the failure:
   Failure probability x severity x detection probability = criticality or RPN.

FIGURE A1.4: A FRAMEWORK FOR PROCESS RISK ANALYSIS USING FMEA

1	Map and review supply chain processes
2	Brainstorm failure modes and carry out cause and effect analysis to determine the cause/s of each failure
3	List the potential effects of each failure
4	Assign a Severity rating (1 to 10) to each failure effect - what is the extent of the impact of the failure effect on the organisation and the extended enterprise.
5	Assign an Occurrence rating (1 to 10) – what is the probability of occurrence
6	Assign a Detection rating (1 to 10) – how easily is the failure detected - consider current control mechanisms
7	Calculate the Risk Priority Number (RPN) for each failure effect: Severity x Occurrence x Detection. Maximum score = 1000.
8	Prioritise risks and calculate total process risk (sum of all RPNs)
9	Assess the cost of risk reduction for each risk identified and estimate the expected RPN
10	Calculate the expected cost-benefit i.e. (current RPN – expected RPN)/cost, and prioritise for action.

Further readings

- McDermott, R. E., Mikaluk, R. J. and Beauregard, M. R. (1996) *The Basics of FMEA*. Productivity Inc. USA

Flowcharting - What is it?

Although borrowed from computer science, flowcharting is not a complex technique. It is based upon the fact that to understand the characteristics and problems in a process, it is first necessary to understand the process itself - and that the easiest way to understand a process is often to draw a picture of it.

By employing pre-defined and standardised ways in which to depict the major elements of a supply chain or process—such as tasks and operations, flows of materials, multiple customers or suppliers, decision points, storage areas or queues—it is possible to not only produce a very rich pictorial representation, but also one that aids analysis and improvement activities, Figure A1.5.

Flowcharting can help businesses to:

- Define and understand the individual processes, decision points, transport flows and inventory holding points within their supply chains
- Determine the decision points at which alternative sources of supply, transport, storage location or process would be most appropriate, supplementing these where necessary
- Identify—as a side-benefit—opportunities for supply chain improvements by process simplification or eliminating non value-adding operations.

Step by step outline:

1. Understand and define the process, e.g. order fulfilment, in the supply chain, see Figure A1.5. Include inter-change decision points where alternatives exist, e.g. choice of suppliers or transport mode
2. Prepare chart; collect data, e.g. process time, distance travelled
3. Connect the various symbols to indicate the progress from one activity to the next. Analyse the process flow looking for actions, decision points or alternatives.

Date: 30 – 04 – 03 **Location: Factory A**
Analyst: ANY **Process: Sub-assembly**

Step	Operation / Transport / Inspect / Delay / Storage	Description of Process	Time (min)	Distance (metres)
1	○ ⇨ □ D ▽	Unload pallets from truck	20	
2	○ ⇨ □ D ▽	Move to goods in		125
3	○ ⇨ □ D ▽	Check, inspect	30	
4	○ ⇨ □ D ▽	Move to warehouse		75
5	○ ⇨ □ D ▽	Store until needed	360	
6	○ ⇨ □ D ▽	Move to production		35
7	○ ⇨ □ D ▽	Sub-assembly	25	
8	○ ⇨ □ D ▽	Work in progress store	240	
9	○ ⇨ □ D ▽	Place on conveyor	5	
1	○ ⇨ □ D ▽	Move to final assembly		25
%		Total:	680	260

FIGURE A1.5: PROCESS FLOWCHART

Further reading

- Damelio, R. (1996) *Basics of Process Mapping*. Quality Resources

Supply Chain Mapping - What is it?

Supply chain mapping is a conceptually simple and very powerful technique. It provides a time-based representation of the processes involved as the materials or products move through the supply chain from, for example, the raw materials supplier to the end user.

The map will also show the time that is taken at various points along the chain including time when the materials or products are waiting, i.e. as work in progress or finished goods.

Using it, businesses can determine:

- The inter-connecting "pipeline" of suppliers through which products, components and materials must travel to reach the end-user
- The transport links by which products, components and materials are passed from one node to another in the chain
- The amount of work-in-progress and inventory stockpiled at each stage in the pipeline
- The time it would take to source replenishment from various points in the pipeline in the event of disruption.

The resulting information can assist businesses to identify areas of risk and take appropriate actions, including:

- Determining alternative sources of supply
- Decisions to hold additional "just in case" inventory
- Contingency plans regarding alternate transport arrangements in the event of disruption
- Decisions to hold inventory in a form in which it is most flexible, e.g. undyed cloth, rather than dyed.

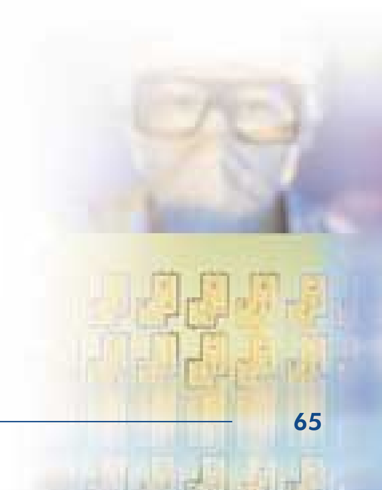
Step by step outline:

1. Plot the different processes through the supply chain from raw material to end user, through production and all other processes on to the horizontal axis of the map.
2. Horizontal time is when something is happening, e.g. the days taken to ship a product from point A to B. This is measured in number of days.
3. Vertical time is when nothing is happening; the inventory is standing still. This can be because it is being held as part of the production process, e.g. curing or machining, or it is held in buffer against demand.

4. Inventory holding points are positioned as vertical lines rising upward from the horizontal line and are again measured in days. The resulting outputs from the technique are: a) pipeline length, i.e. the sum of the horizontal intervals. This is often described as the time taken to pull a product through the supply chain; b) pipeline volume, i.e. sum of the horizontal and vertical lines. This is the time that the supply chain can operate without further replenishment of supplies.

Further reading

- Christopher, M. (1998) *Logistics and Supply Chain Management: Strategies for Reducing Cost and Improving Service*. 2nd edition. Financial Times Prentice-Hall.



Critical Path Analysis - What is it?

Critical Path Analysis is the most commonly used form of network analysis. Typically, it is employed for one off or infrequent tasks, and is the conceptual backbone behind most project planning.

The term 'critical path' comes from the technique's ability to determine which sequence of activities within a project or process will tolerate the least amount of slippage, in time or resources, before the project or process is jeopardised.

Using Critical Path Analysis, businesses can:

- Define and understand the dependencies and relationships between activities, i.e. which activities cannot be begun or completed until other activities have first been completed
- Determine which activities in the upstream or downstream supply chains lie on the critical path and are therefore possible points of disruption but could also control the rate at which post-disruption recovery can occur
- Identify—as a side-benefit—opportunities for inventory reductions and other savings by relating non-critical operations, and the resources they consume, to the timings that are dictated by the critical path.

Step by step outline:

1. The decision to carry out a Critical Path Analysis on a supply chain, or part of it, will generally result from another technique such as Bottleneck Identification or Supply Chain Mapping identifying a need
2. An activity, such as order fulfilment, can rarely be represented as a single line sequence of events. For example, the simple task of inserting a post into a hole displays this tendency for parallel tracking and activity ordering – the post cannot be inserted before a location is decided on and a hole dug; the hole cannot be dug before a spade has been acquired and brought to the location, and so on. A critical path is a pictorial representation of the activity or process showing 'events' running in parallel which come together at 'nodes' before again fragmenting into parallel paths. Projects are made up of 'activities, i.e. a task which must be carried out, and ' events',

i.e. the start and/or finish of an activity or group of activities.

Diagrammatically, in a network diagram, an activity is represented by an arrow and an 'event' by a node or circle, e.g. Figure A1.6. Bar charts can also visually represent a critical path. Alternatively, the information required, i.e. activity duration, order of precedence and resource consumption can be calculated arithmetically.

3. Project or process time is the shortest time in which the project or process can be completed and this is determined by the sequence of activities known as the critical path, i.e. the sequence of events where the least slippage can be tolerated before the overall sequence of 'events' (i.e. project or process) is jeopardised.

Further reading

- Baker, S. and Baker, K. (2000) *The Complete Idiot's Guide to Project Management*. Alpha Books, Macmillan, USA

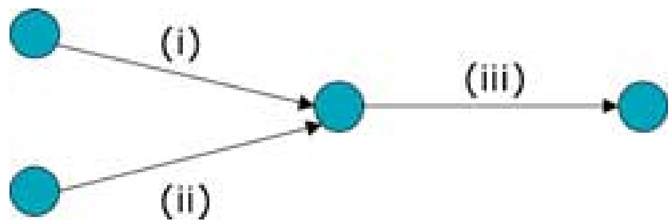


FIGURE A1.6: A SIMPLE NETWORK DIAGRAM

(activity (iii) depends on activities (i) and (ii))

Bottleneck Identification - What is it?

Bottleneck management is a concept associated with the work of Dr Eliyahu Goldratt. The core principles now form the basis of the "Theory of Constraints".

A bottleneck in a supply chain can be simply defined as an operation that has the lowest effective capacity compared with other operations and thus limits the supply chains outputs, i.e. the supply chain can only produce as fast as the slowest operation. A number of software tools are available to help identify and schedule bottlenecks in a manufacturing environment but their application to supply chains is still in its infancy. Simple analytical exercises can identify bottlenecks that can range from physical operations, such as machining or configuring a pallet, to transportation and even administrative processes, such as inspection or customs procedures.

Using the principles of bottleneck management within their supply chains, companies can:

- Identify where disruption is most probable
- Understand where in the supply chain they can most effectively concentrate preventative actions aimed at avoiding disruption
- Put in place reporting points to track the progress of goods and materials through critical points
- Understand the likely constraints on production and supply in a post-disruption recovery scenario.

Step by step outline:

1. Identify bottlenecks either by analytical exercises or the use of specialist software tools. The latter, however, tend to be manufacturing related and are not always appropriate in a supply chain context
2. Focus on avoiding disruption at the bottleneck and improvement programmes to maximise capacity and flexibility at the bottleneck. Spare capacity at critical bottlenecks may be advisable.

Further reading

- Goldratt, E. M., Ptak, C. A. and Shragenheim, E. (2000) *Necessary But Not Sufficient: A Theory of Constraints Business Novel. North River Press.*

Statistical Process Control - What is it?

Statistical Process Control (SPC) is a technique that has long been used to great effect within manufacturing industry.

Supply chain applications are undeniably something of a novelty but the technique is well suited to detecting or preventing potential supply chain disruption particularly where time is involved, e.g. "How long does a warehouse process take"? or "How long is the queuing duration"? As the name implies, it imposes statistically derived limits of acceptability on repetitive processes, helping to determine at a particular point in time whether a given process is – in statistical terms – in control, or out of control.

Using SPC, businesses can:

- Understand the normal range of variability for any given parameter of particular supply chain resource or process
- Impose "warning" and "action" limits to these parameters beyond which appropriate actions should be taken
- Detect and prevent potential out of control situations before they have occurred, thus reducing scrap, downtime, lost output and disruption.

Step by step outline:

1. Identify processes or operations within a supply chain or manufacturing plant that tend to exhibit variances around an average
2. A Capability study (see Process Capability Analysis) would determine the average and how the variance was distributed about the average when the process was in a stable condition
3. A standard error applied to that average produces a tolerance band either side of the average into which the process should fall. Outside of this range provides a warning that the process may be coming unstable or should be stopped for corrective action
4. Samples are taken at regular intervals; the results are plotted on graph paper on which the relevant warning and action limits have been drawn
5. If a sample indicates that the activity is outside the warning limit a second sample would be taken immediately to establish if the activity/operation is within normal variance or if it has started to become unstable
6. If necessary remedial action should be taken.

Further reading

- Amsden, T. T. Butler, H. E. and Amsden, D. M. (1998) *SPC Simplified: Practical Steps to Quality*. Productivity Inc.

Process Capability Analysis - What is it?

Process Capability Analysis is a technique for determining, on a statistical basis, if a given process is performing to specification.

A process that is performing to specification is described as being in control; a process that is not performing to specification is described as being out of control. Desktop software tools are available to facilitate the statistical analysis and plotting required by the technique. Alternatively, conventional graph paper or even spreadsheets could be used.

Using Process Capability Analysis, a business can:

- Establish which processes within its inbound and outbound supply chains are in control or out of control
- Prioritise those processes that are in need of remedial action by ranking the extent to which they are out of control
- Identify, as a side-benefit, any opportunities for cost, efficiency or specification improvements thrown up by either varying the specification limits or permitting greater process spread.

Step by step outline:

1. Determine the upper and lower specification limits for the process in question. In the case of a shipment time, for example, these might be that journey lengths are no less than 48 hours, and no more than 96 hours
2. Take a number of samples, where the actual process performance is logged
3. Plot these on the appropriate Normal distribution (the technique relies on the fact that processes can be expected to follow the Normal probability distribution, i.e. the bell-shaped curve) and compare with the previously determined upper and lower specification limits
4. Where the spread of process observations are well within or more or less match the specification tolerances the process is described, respectively, as Highly Capable or Barely Capable and is considered to be in *control*. Where the spread of observations is wider than the specification it is described as Not Capable, i.e. *out of control*.

Further reading

- George, M. L. (2002) *Lean Six Sigma.Combining Six Sigma Quality with Lean Speed*. McGraw-Hill.

Simulation Modelling - What is it?

A simulation model imitates the operation of a real-world process or system over time. The development of a computer-based simulation model allows the user to study the behaviour of a system or process.

There are a number of high-level simulation programming languages that are specially designed to facilitate model building. Once developed and validated a simulation model can be used to investigate a wide range of 'what if' questions. The attention to detail and resource available to undertake the simulation project will determine its success.

Using simulation modelling, businesses can:

- Explore the impact of new policies, operating procedures, information flows, etc., without disrupting the real system and thus reduce the risk associated with implementation by being prepared for what may happen
- Assess the risks inherent within current processes when subjected to input fluctuations, e.g. a surge in demand, an increase in supplier lead-time, a reduction in component quality, etc
- Investigate the causes of bottlenecks within the organisation where work in process, information, materials, and so on are being delayed
- Evaluate the impact of demand, supply, process, control and environmental risks on the performance of the organisation
- Verify and test the limitations of solutions obtained using analytic optimisation tools.

Step by step outline:

1. Define the problem, set the objectives and overall project plan
2. Establish a project team with experts in real time system processing and the supply chain
3. Select an appropriate software package
4. Create the model. The simulation model must capture the essential features of the process
5. Data collection – this should be carried out as the model evolves
6. Translate the model into computer format using simulation software or a suitable software language
7. Verify the model, i.e. is it running properly
8. Validate the model against the actual system, i.e. it should be an acceptable representation of the system
9. Undertake simulation runs, analyse the results. Determine the alternatives to be simulated
10. Maintain documentation and reports of the model, its architecture and assumptions and a history of the simulation runs including decisions made.

Further reading

- Evans, J.R. and Olson, D. (2002) *Introduction to Simulation and Risk Analysis*. Pearson Education Inc., New Jersey, USA

Root Cause Analysis - What is it?

Root Cause Analysis, sometimes known as Fault Tree Analysis, is a technique that aims to discover the first - or "root" - cause of a failure or problem.

The emphasis is on thorough investigation of real problems to determine real causes. It is also sometimes known as the "Five Whys?" technique; a reference to its reliance upon the repeated asking of "Why?" until the real reason that a problem occurred is pinned down, Figure A1.7.

Using it, businesses can:

- Identify the underlying causes of disruption in the supply chain
- Understand the linkages that can cause quite innocent actions to inadvertently cause disruption
- Prioritise these into a hierarchy for action.

1. **Why** did the freezer unit fail, spoiling the shipment?
   Because a circuit breaker tripped.

2. **Why** did the circuit breaker trip?
   Because the coolant pump had seized.

3. **Why** did the coolant pump seize?
   Because its bearings had not been lubricated.

4. **Why** were the bearings not lubricated?
   Because a lubricant filter was blocked.

5. **Why** was the lubricant filter blocked?
   Because periodic filter replacement had been omitted from the preventative maintenance schedule.

FIGURE A1.7: AN EXAMPLE OF THE '5 WHYS?'

(Source: adapted from Taiichi Ohno (1988) *Toyota Production System*. Productivity Press).

Conceptually related to Fishbone Diagrams, the technique is a powerful tool for distinguishing symptoms from causes, and for understanding the relationships between a problem and its causes.

Step by step outline:

1. Identify a frequently occurring problem. Place it at the bottom of a schematic termed a 'fault tree'. Starting from a single point a tree-like series of branches represent the linkages between problems and causes
2. Investigate the contributing cause/s and map onto the fault tree

3. Establish by asking 'why' five times what created the contributory causes and map onto the fault tree
4. Repeat the process until the initial problem's root cause is identified. Take action to eliminate the problem
5. Secondary factors and circumstances which exacerbated the problem will also be identified
6. Use a matrix diagram to plot problem characteristics against possible causes to identify if the same cause keeps reoccurring.

Further reading

- Andersen, B., (Editor) (1999) Root Cause Analysis: *Simplified Tools and Techniques.* American Society of Quality.

The "Fishbone" diagram - What is it?

Fishbone diagrams are a well-known tool in the worlds of quality management and continuous improvement.

They are a simple visual way of tracking a problem or risk back to a number of (sometimes widely dispersed) root causes. In turn, these may have other contributory factors.

Diagrammatically, the main problem is represented as the fish's 'head' with the major categories of potential causes as structural 'bones' leading off the central spine. A number of 'ribs', each representing a specific cause, are depicted as branches off the bones. These ribs may in turn have other smaller ribs where each smaller rib represents a contributory factor to a root cause.

Despite its apparent simplicity the Fishbone diagram, see Figure A1.8, is a powerful way of:

- Identifying the causes and contributory factors which may bring about disruption in the supply chain
- Understanding the links and dependencies between the different causes and contributory factors
- Prioritising these into a hierarchy for action aimed at eliminating or ameliorating them.

Step by step outline:

1. First use a tool best suited to risk identification, such as Critical Path Analysis, Flowcharting or Pareto Analysis, to identify, order and rank the problem to be tackled
2. Brainstorming or other group activities can be used to highlight the contributory factors
3. Conduct experiments to test hypothesis, e.g. "does this cause that?" or undertake analysis of data to establish the effect of individual causes on the problem
4. The fishbone diagram is developed through the iterative process of brainstorming, testing and analysis.
5. Prioritise preventive steps.

Further reading

- Ishikawa, K et al (1988) *What is Total Quality Control?: The Japanese Way*. Prentice Hall.

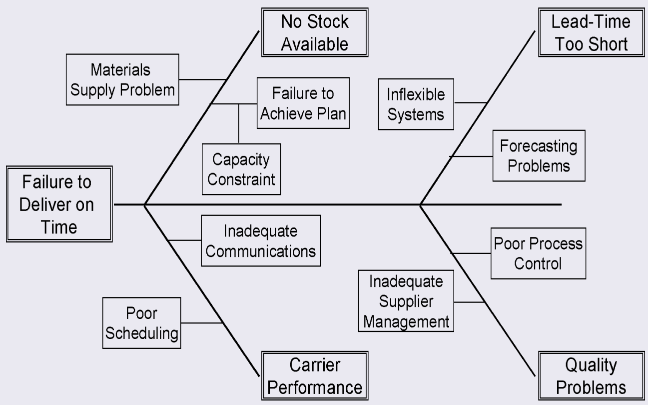


FIGURE A1.8: AN EXAMPLE OF A FISHBONE DIAGRAM

Pareto Analysis - What is it?

Pareto Analysis, sometimes referred to as ABC Analysis, is a decision support tool that aids in prioritising problems and issues to be tackled.

Pareto Analysis is aptly described as the '80:20' rule, i.e. a business might find that 20% of the customers account for 80% of the sales, or that 80% of the profits came from just 20% of the products. Rather than scatter scarce resource across a wide range of problems and issues, Pareto Analysis can guide their deployment to where they will have greatest effect. Pareto analysis is probably most effective when combined with the outputs of other tools such as Benchmarking, Fishbone Diagrams, Statistical Process Control, Supply Chain Mapping.

Applying Pareto Analysis to the analysis of supply chain resilience, businesses can:

- Rank the various risks and potential dislocation points in their upstream and downstream supply chains according to their severity of impact, probability of occurrence, or cost of remedial action
- Allocate either remedial resources or time spent on further analysis to those areas and issues where they will have greatest effect in improving overall supply chain resilience.

Step by step outline:

1. Sort and rank raw data, e.g. a list of problem areas and the cost of rectification or problem areas and the likely cost of disruption
2. Sort list into ascending or descending order, i.e. to identify the 20% with the greatest contributory effect
3. The list is summed, item by item, with each row now showing, for example, the accumulated value or the accumulated cost of rectification or disruption. Each accumulated figure is transformed into a percentage of the total accumulated figure. Very quickly the 80:20 ratio will emerge, producing the typical Pareto Curve, Figure A1.9.

Further reading

- Reynard, S. and Mann, D. (1995) *Pareto Charts: Plain and Simple.* Inc. Staff Joiner Assocs. Oriel Inc.

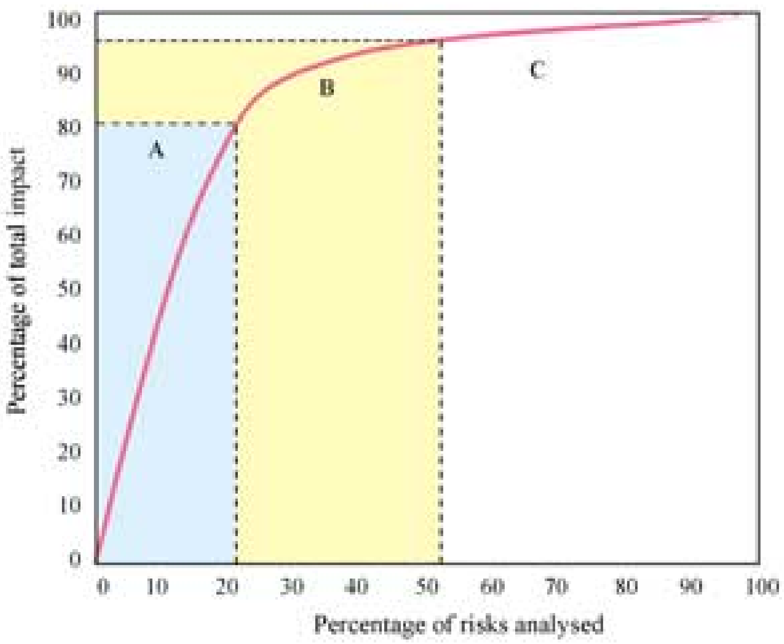


FIGURE A1.9: A PARETO CURVE ILLUSTRATING THE 80/20 RULE

Process Decision Programme Chart - What is it?

A Process Decision Programme Chart is a tool for use in contingency planning.

Essentially, the Process Decision Programme Chart diagrammatically depicts what might go wrong at particular points in a process or chain of events, and presents alternative countermeasures showing how those disruptions might best be countered.

While conceptually and operationally both very simple and straightforward, the technique yields a wealth of resilience-promoting information. The technique is essentially brainstorming based and resource intensive.

Using Process Decision Programme Charts, businesses can:

- Identify the causes and contributory factors which may bring about disruption in the supply chain
- Prioritise these into a hierarchy for action aimed at eliminating or ameliorating them
- Determine the decision points at which alternative sources of supply, transport, storage location or process would be most appropriate, supplementing these where necessary
- Identify - as a side-benefit - opportunities for supply chain improvements by process simplification or eliminating non value-adding operations
- Determine the sequence of operations or events that represents the conceptual "path" that minimises risk throughout the supply chain
- Determine in advance of any disruption those actions that can once more restore normal operations as quickly as possible.

Step by step outline:

1. Taking a supply chain or part of a supply chain ask the question, "what could go wrong and where?"
2. Brainstorm the counter measures; potentially viable solutions will emerge
3. Test the practicality of each solution; a 'first choice' solution will be identified
4. The process continues with the next 'failure' scenario being brainstormed for possible solutions
5. Each failure point and its solutions are entered onto the Process Decision Programme Chart. An example layout is shown in Figure A1.10.

Further reading

- Gillett, J. (2000) *The Process Manager*. Process Management International Ltd.

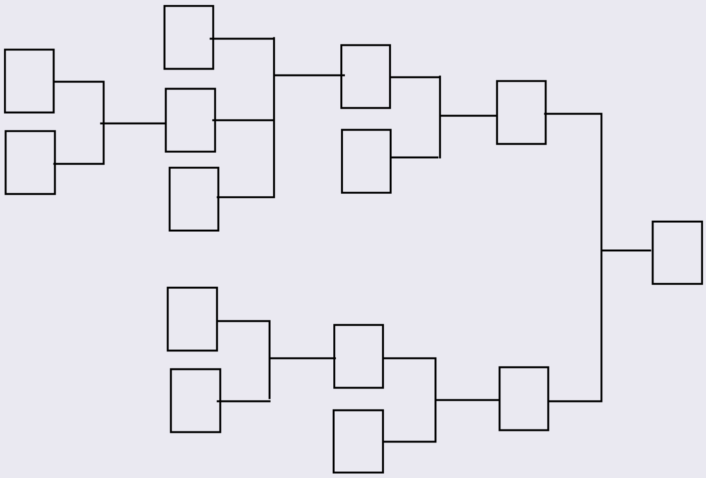


FIGURE A1.10: A PROCESS DECISION PROGRAMME CHART

Benchmarking (incorporating SCOR) - What is it?

Benchmarking was popularised in the late 1980s and early 1990s by companies such as Motorola, Xerox and Hewlett-Packard.

These pioneer companies recognised that it was possible to achieve significant improvements in their operations by undertaking detailed comparisons with those of others, seeking out—and then emulating—best practice. Conventionally used as a way of identifying cost and efficiency improvements, benchmarking readily lends itself to developing greater supply chain resilience. A more recent approach is the SCOR model. This comparison methodology was developed by the Supply Chain Council in the USA, and adopted globally. Its strength is that it formally codifies supply chain management into a series of rigorously defined processes, thus imposing a degree of standardisation of meaning. Under SCOR definitions, the metrics used to describe the operation of the supply chain will be far more readily comparable than would otherwise be the case, as like will be being compared with like.

Using benchmarking, businesses can:

- Measure, at a detailed level, how the potential for disruption within their own supply chains compares to the potential for disruption in other supply chains belonging to suppliers, customers, industry-peers and other businesses
- Determine, at a detailed level, how the preventative measures and recovery plans in these supply chains compare to their own measures and plans
- Identify - as a side-benefit - any opportunities for cost and efficiency improvements thrown up by this process of comparison.

Step by step outline:

1. Select a broad group of organisations against which to benchmark. This group can include companies from other industry sectors and of different sizes
2. Agree with benchmarking partners the metrics and points of comparison (to ensure that like for like is being compared)
3. Each company details its own capabilities
4. Data collection, followed by analysis of agreed metrics, operations or characteristics will show a spread of results, with leaders and laggards emerging. Anonymity can be maintained to this point
5. For best practice to emerge anonymity is discarded, information is shared between benchmarking partners, visits may take place and actions leading to particular improvements exchanged.

Further reading

- Codling, S. (1998) *Benchmarking*. Gower.

Creating Resilient Supply Chains

Business Process Re-engineering - What is it?

Business Process Re-engineering (BPR) is a management technique that came to the fore in the early 1990s.

The main driver behind the BPR philosophy has been the search for more time-effective ways of doing things and a reduction in non-value-adding activities. Business Process Re-engineering, ignoring previous custom and practice, re-designs processes 'from the ground up'. The result is a greater level of performance. The re-engineering process is deceptively simple.

Businesses can use Business Process Re-engineering within their supply chains to:

- Define and understand the individual processes within the supply chain which underpin its operation
- Map onto these processes the sources of externally identified potential disruption
- Re-design supply chain processes, wherever they take place within the supply chain, so as to eliminate these sources of disruption
- Identify - as a side-benefit - opportunities for inventory reductions and other cost savings by eliminating non-essential processes
- Further identify—as a side-benefit—the potential to re-tune the supply chain to enable it to focus more effectively on its core mission of customer satisfaction.

Step by step outline:

1. Step 1 take a process-centric view of the business, e.g. order processing, design, production, warehousing, and understand how these processes fit 'across' the business
2. Step 2 is the 'As Is' phase – look at things as they are, e.g. the vulnerability to disruption of various processes within the supply chain. This process is aided by diagrammatically representing the supply chain using techniques such Flowcharting and Critical Path Analysis. Tools such as Fishbone Diagrams and Failure Mode and Effect Analysis can be used to understand susceptibility to disruption
3. Step 3 is to build a vision of the future – the 'To Be' phase, i.e. what could be achieved by re-designing the supply chain processes to eliminate the sources of vulnerability
4. Turn the vision into reality. The 'directed team' approach, lead by a senior team of executive strategists, has been found to deliver consistent results. Implementation has been found to be the most difficult part of the project.

Further readings

- Hammer, M and Champy, J. (2001) *Re-engineering the Corporation: A Manifesto for Business Revolution*, Nicholas Brealey Pub. Ltd.

Time-Based Process Mapping - What is it?

Time-Based Process Mapping is a technique for identifying and examining the durations of time involved in the steps of manufacture from supply to delivery, with a view to eliminating unnecessary delays.

It remains a relatively unused tool within most supply chains. While most executives subscribe to the importance and principles of time compression within supply chains, they tend to adopt time compression initiatives on a piecemeal basis, operation by operation. In contrast, a strategy of viewing the supply chain as whole from the perspective of risk elimination can be expected to generate a disproportionate return on the resources invested.

It is most helpfully regarded as an extension of other tools and techniques, such as Critical Path Analysis, Supply Chain Mapping and Flowcharting, but with the added dimension of time.

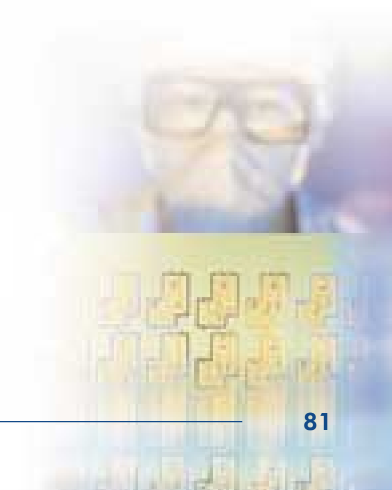
Using metrics to analyse where time is consumed, and how fast inventory is moving at various points in the supply chain, improvements in throughput time can be achieved. This in turn reduces the time during which inventory remains at risk of disruption.

Linked to the outputs from other relevant tools and techniques, such as Critical Path Analysis, Supply Chain Mapping and Flowcharting, businesses can use Time-Based Process Mapping within their supply chains to:

- Determine the extent to which individual processes within the supply chain make up the overall time taken to move goods through the supply chain
- Identify through the application of time-based metrics those processes and operations within the supply chain where the velocity of inventory flow can be improved
- Re-design supply chain processes, wherever they take place within the supply chain, so as to eliminate non-value adding activities that nevertheless consume time
- Configure - as a side-benefit - the supply chain so that the overall velocity of inventory is faster, thus reducing working capital, increasing responsiveness and improving customer service.

Step by step outline:

1. Using outputs from other tools that have documented the supply chain, plot operations and processes on a two-axis ‘map’. The x-axis represents time; the y-axis is divided into rows or blocks with each representing a process or operation ‘owner’
2. Calculate the metrics that measure the flow of inventory through the system, e.g.



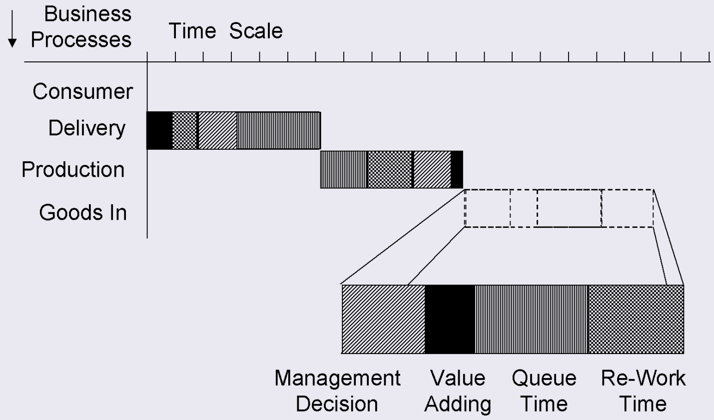


FIGURE A1.11: TIME BASED PROCESS MAPPING

(Source: Wilding, R. (1999) "The Role of Time Compression and Emotional Intelligence in Agile Supply Chains" *Supply Chain Practice,* Vol. 1, No.4, pp14-25)

throughput rate = 1/cycle time

3. By ranking and comparing metrics and additional data gathering, e.g. set-up time (the time for resources to be set-up to enable the process to run), run time and queue time, it is possible to determine those points at which the throughput rate is lowest and where changes could yield the greatest improvement.
4. The resulting Time Based Process Map shows the different processes, their component activities and times, Figure A1.11

Further reading

- Gregory, I.C. and Rawlings, S.B. (1997) *Profit from Time: Speed up Business Improvement by Implementing Time Compression*. Palgrave.

Supply Chain Event Management

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. Ideally SCEM will also enable a proactive, even automatic, response to deviations from the plan.

The Internet can provide the means whereby SCEM reporting systems can link together even widely dispersed partners in global supply chains. The use of XML communications across the web means that even organisations with different information systems can be linked together.
The key requirement though is not technological; it is the willingness of the different entities in a supply chain to work in a collaborative mode and to agree to share information.

Supply chain event management 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 A1.12. It is particularly appropriate for companies with a large supplier base working on extended lead-times and long distances for complex products, e.g. aerospace and high technology products.

Event management is rooted in the concept of workflow and milestones.

An event is a conversion of material at a node in the chain or a movement of material between nodes in the chain. Events should only happen as a result of an instruction (control). Therefore on the time horizon over which instructions are issued, events are capable of being monitored for the timeliness and completeness with which they are executed against the original instruction.

Event management provides the 'visibility' that is crucial in managing risk and vulnerability in the supply chain.

Further reading

- Styles, P. (2002) *Determining Supply Chain Event Management*, in 'Achieving Supply Chain Excellence through Technology'. Montgomery Research, San Francisco.

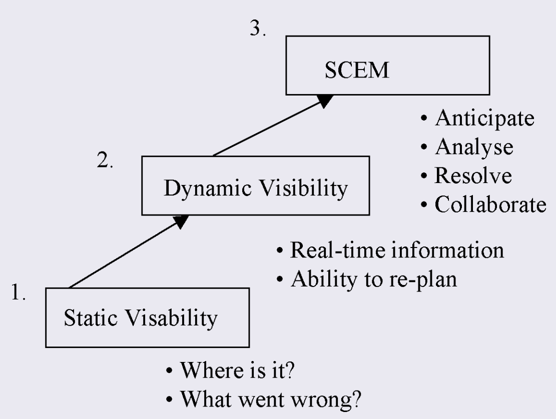


FIGURE A1.12: AN ACTIVE APPROACH TO SUPPLY CHAIN RISK

Appendix 2 - Part 1: A Risk Management Approach for Small and Medium Enterprises

The general observation of supply chain vulnerability management in the Small and Medium Enterprise (SME) sector is that many SMEs currently do not address the supply chain disruptions that could affect their business, and ultimately their customers.

The relationships established with suppliers and customers are recognised as key tools in reducing supply chain vulnerability

Our research identified that some organisations have generated an informal 'list' of identified risk-sensitive areas in the business and there was an observed correlation between quality assessment/ control qualifications such as the ISO 9000 series, and the ability of SMEs to understand and proactively 'see' possible areas of vulnerability and supply disruption in their network. For example, ISO qualifying requirements often include visits to suppliers to assess the extent of their quality and process compatibility.

To improve the resilience of their supply chains, SMEs need to take charge of their individual competitive and supply chain situations. Tracking of disruptions that do occur helps to better tailor future risk management strategies to high risk areas within the organisations and its supply chain. The chosen tools need to be relatively easy to use, and easily accessible and flexible. Internet based product and order status traceability is no longer out of the reach of SMEs and could provide a level of supply chain visibility for example. The relationships established with suppliers and customers are recognised as key tools in reducing supply chain vulnerability.

The research concluded that SMEs have found it difficult to determine sources of supply chain defects and problems without investing in expensive tools and systems. Hence, the availability of an affordable tool to better address this issue is essential.

Basic tools that can support risk management

The cost and complexity of software can be very high and beyond the financial and technical capacity of many small and medium sized firms and their trading partners. The key requirements for software tools that can be applied by SMEs are:

- Affordability for companies with a modest budget
- Ease of application in organisations that will likely be constrained for both skills and resources
- Ability to start to connect with both customers and suppliers to gain visibility, albeit at a simple and low cost level
- Ability to quantify basic risk issues at a simple level – mainly in the dimensions of demand and supply

The criteria for software tools that are both in widespread use and could assist in the management of supply chain risk for SMEs are:

- The cost should be no more than £20,000 or be charged on a 'pay for use' basis, and
- The software can be implemented and applied without very high level IT skills, extensive training or major data integration.

Risk and Event Management Software Tools for SMEs

	Long term	Medium / short term	Operational
Design	Spreadsheets	Spreadsheets	n/a
Plan	Spreadsheets	Demand planning & inventory management	n/a
Schedule	n/a	Demand planning / inventory and MRP	Consignment tracking
Execute	n/a	MRP & Consignment tracking	MRP & Consignment tracking
Recover	n/a	Consignment tracking	Consignment tracking

Key:
Risk Management
Event Management

FIGURE A2.1: RISK MANAGEMENT TOOLS FOR SMES

There are four blocks of software functionality that could be applied by SMEs that meet the basic criteria, Figure A2.1. The role, application and limitations of the solutions are summarised below.

i) Spreadsheets

The spreadsheet is almost ubiquitous in the world of business. It can be used for a wide range of tasks and can be user configurable or apply industry/application templates. It is important to note that quite large companies do much of their planning based on spreadsheets, which have evolved to the company's way of thinking and expression of their activities. It is extremely low cost and is now present on most personal computers at the time of commissioning. Microsoft Excel and Lotus 123 are dominant in this area and few users look beyond these choices unless they have particular requirements.

In the area of risk and vulnerability, spreadsheets can be applied by SMEs to develop a solution to understand issues of vulnerability in relation to:

- Investment in capacity and the risks associated with different demand forecasts on a long term horizon
- Long/medium/short term time-phased models of supply and demand to illustrate the sensitivity of the business to different outcomes of both demand and supply.

The challenge for the user, as with all spreadsheets, is to maintain data accuracy and quality and to design the spreadsheet without error to accurately reflect the issues that the company faces. An example of supply chain modelling using spreadsheets is provided at the end of this section.

ii) Demand forecasting and inventory management

There are a variety of low cost tools that can support the short to medium term task of demand management planning and inventory deployment. PC based software packages generally range from around £10,000 to £20,000 although some can be less costly. The advantage of these systems over spreadsheets is that they have logical data architecture and hold the data for the firm in a database that is likely to have greater integrity and be less user-dependent than a spreadsheet. The solutions also provide a degree of parameterisation which can ensure the integrity of the calculations. Solutions in this domain will offer abilities to support a level of risk management in the demand and control dimensions for both planning and scheduling based on functionality around:

- Creating demand forecasts
- Analysing and recommending inventory policy
- Netting inventory against actual demand and forecasts to create a demand schedule using the inventory policy.

The resolution of risk lies in the ability of these solutions to express uncertainty around demand forecasts and inventory policy. An issue for SMEs is their ability to manage their investment in inventory and customer service; failure to do this well represents risk for them. These solutions are ideal for smaller firms in this regard since they offer an entry level approach with which a suitably trained individual can start to make an impact.

Data will either be input manually or imported to the workstation and the outputs will typically be in the form of tables, reports and graphs. On occasion it may be appropriate for data to be output to another system such as MRP.

iii) Manufacturing planning and material control

In figure A2.1 the medium / short term box is populated by both demand planning and MRP. MRP also occupies the medium /short term and the operational 'execute' boxes. In the planning space, MRP systems may have the functionality described above for forecasting and netting inventory, though they may not offer inventory policy recommendations. This means that they can support the demand side risk dimension to some extent, i.e. offering abilities to:

- Create demand forecasts
- Nett inventory against actual demand and forecasts to create a demand schedule using the inventory policy
- Build manufacturing schedules and nett materials requirements using the Bill of Materials
- Create purchase order recommendations for components based on the actual demand and forecasts and the parts inventory on hand.

MRP supports the supply side risk area since the core of MRP is the creation of purchase requirements to align manufacturing plans and the inventory of parts on hand. Hence the scheduling of material acquisition against requirements recognising lead-times is a crucial role for an SME to identify its needs and ensure that materials are on hand.

In common with demand planning, the risk resolution capabilities of MRP and material control give a level of visibility of requirements and the ability to place orders with confidence in known lead times. It is clear from the research that this will be a useful first step for those firms that do not have that capability.

iv) Consignment tracking

The facility for SMEs to take advantage of basic event management using the consignment tracking capabilities of their logistics service or transport providers should be considered depending on the nature of their inbound and outbound freight.

SME's with short lead times for inbound supply based on buying locally will have no need for this facility as lead times are typically short, but those trading internationally could find this exceptionally useful.

Similarly on the outbound leg to customers, outsourcing to a transport partner that can provide the visibility to both the company and its customers is valuable for long shipping lead times.
The cost of this capability is normally included in the cost of the transport service so the choice may be one between that of a low cost transport company where the controls and processes are missing and a 3PL who can offer this facility. This level of consignment tracking is essentially a 'pay on use' facility. Companies that offer track and trace allow password protected Internet access to the service and this means that visibility is available on demand. However the track and trace capability is not the same as an event management solution.

Part 2: Using spreadsheets for supply chain design and risk assessment – an example

Spreadsheets are frequently used to undertake modelling studies because the software is readily available, data acquisition is straightforward and the approach is flexible in the level of detail that is employed.

A summary of the strengths and weaknesses of this approach to supply chain modelling is shown in Figure A2.2.

Supply chain models can be used to test the performance, resilience and vulnerability of supply chains.

Designing a supply chain

The complete process of designing a supply chain and assessing the risk is shown in Figure A2.3. This process has much in common with that which has been used for supply chain design for some years. However, a critical addition is the inclusion of risk assessment as part of the design. In this example risk is examined in the context of the impact on total cost and service levels of a supply chain disruption, e.g. what if a facility is destroyed by fire?

Key strengths:

- Quickly developed
- Limited specialist knowledge required
- Can be straightforward to use
- Flexible
- Inexpensive software.

Key weaknesses:

- Allows consideration of only the simplest constraints
- Requires building and can be difficult to change the overall model structure once built
- No graphical user interface (text based)
- Does not contain links to any standardised databases (e.g. freight rates, etc)
- Contains no gco -coding, mapping of results usually requires additional software and expertise
- Typically, knowledge resides with the tool builder.

Applicability:

- Small, low complexity networks (e.g. two DCs;single echelon)
- No complex constraints (e.g. supplying each customer from only one DC; open/close decisions for plants or DC; etc)
- Useful when a quick/approximate answer is required
- Useful when budget is very limited or resources with specialist skills are unavailable.

FIGURE: A2.2: SPREADSHEET APPROACH TO SUPPLY CHAIN MODELLING

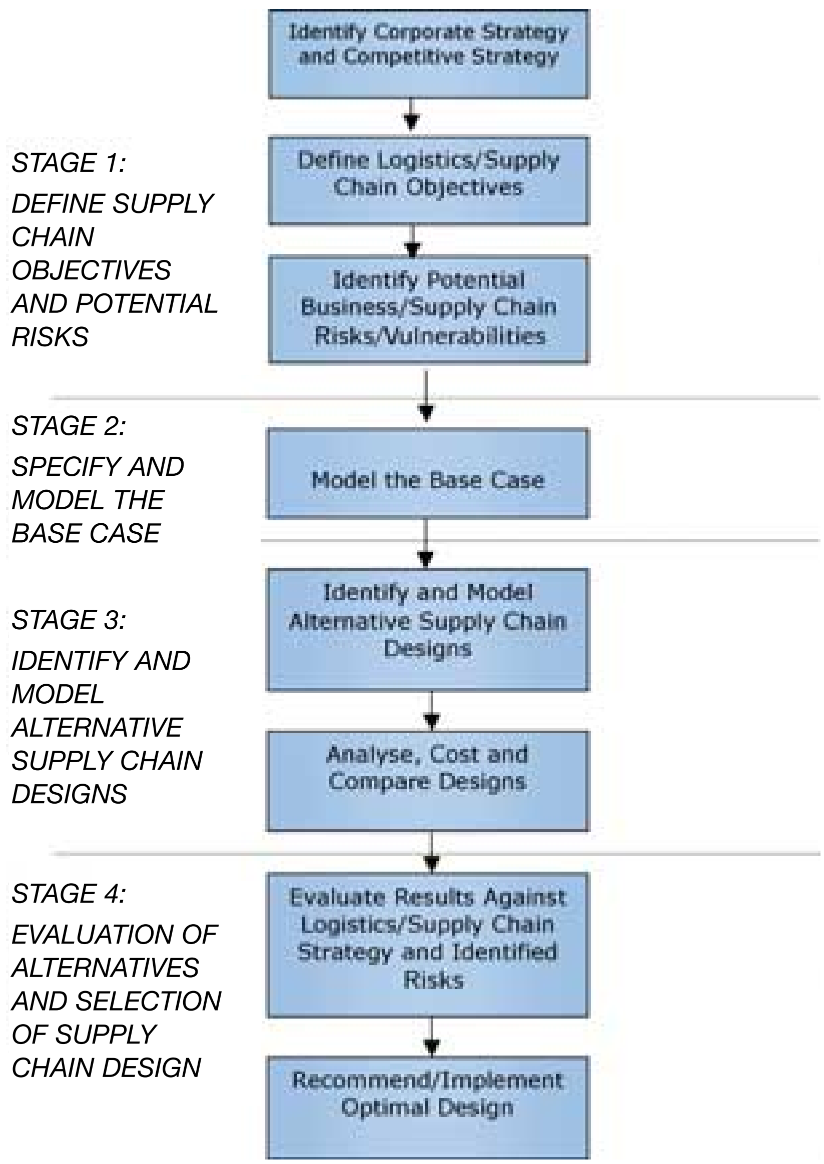


FIGURE A2.3: OVERVIEW OF THE DESIGN PROCESS

It is important that before changes in business strategy are implemented a supply chain risk analysis be conducted

Stage 1 Defining supply chain objectives and potential risk

All business strategies will have a level of risk attached to them and this is well understood. However, what is not always recognised is that these strategies will also have supply chain risk consequences. Thus, a decision to move manufacturing off-shore in order to take advantage of lower labour costs might adversely affect the supply chain risk profile in terms of increased variability in lead-times.

It is important therefore that before changes in business strategy are implemented a supply chain risk analysis be conducted.

Stage 2 Specification and modelling the base case

The base case is a model of the current situation. Data is collected and assembled into a model that represents the important aspects of the supply chain. The components of base case modelling are:

- **Site identification and customer location.**
  All sites must be identified and located including first and second tier suppliers, manufacturing sites, warehouses and distribution centres. To model the location of customers it is usually necessary to group (cluster) them according to a generalised location - grid - square, country or department.

- **Product categorisation.**
  Establishing the product groups; too many and the model will be too complex; too few and the model will not represent the behaviour of the supply chain in sufficient detail. A product group is likely to consist of similar products, with raw materials from the same suppliers being sold to similar customers.

- **Product flow.**
  Using agreed product groups and sites/locations the flow of raw materials from suppliers, through manufacturing and distribution is determined. A to/from matrix can be used to represent the flow of a product; each worksheet representing a different product group.

- **Product costs.**
  In order to represent the total picture of the supply chain base case, for each flow there is a corresponding cost. These costs of flows can be summed along the supply chain to represent the total delivered cost of each product group to each final customer. Transport (trunking and local delivery), inventory holding and facilities are the key costs.

- **Inventory.**
  The flow of product does not represent the total supply chain situation. At each site, for each product group the level of inventory needs to be measured.

- **Service.**
  The final aspect of the base case picture is the service level, which is provided to end-users and intermediate customers. A variety of metrics can be used to measure customer service: usually these reflect availability and order-fill. In some situations

detailed metrics are not available and approximate measures have to be used – for example, delivery frequency.

The Model

With the six major data sets available, the base case model can be constructed - flows are represented by matrices, total costs can be calculated by multiplying a flow matrix by a unit cost matrix. To flow costs must be added the costs associated with sites - warehouses, factories and depots.

Having constructed the base case model, the results must be compared with the real situation. This process is called validation. Only when the model reproduces the performance of the real system with a reasonable level of agreement can the base-case model be accepted. The usual key comparators are costs, service and inventory. The demands and flows are the independent variables in the model.

Stage 3 – Identify and model alternative supply chain designs

Examination of the base case, in order to identify alternative designs leads to a number of questions being asked, for example:

- Which existing facilities should be left open or expanded?
- Which existing facilities should be closed down?
- Which new facilities should be opened and with how much throughput capacity?
- What if warehouse 'x' was destroyed by fire?
- What if supplier 'y' moved to Eastern Europe?
- What modes of transport should be used?

Answering these questions is made easier with an understanding of the key cost trade-offs associated with the decisions.

Key supply chain cost trade offs

Changing the design of the supply chain has different impacts on different related costs.

- **Facility costs -** can be described in terms of a fixed cost for the capital investment involved, and also in terms of a variable cost, which equates to the cost of managing activity levels. This variable cost relates to the level of throughput at a given facility.

- **Transport costs -** are made up of two components:

    - o Trunking costs which represent the bulk transport of products, for example from a source factory or port to a warehouse.
    - o Local delivery costs, i.e. relate to the cost of transporting products to customers/markets.

- **Inventory holding costs -** increase with lead times. Therefore, if transport cost savings are achieved through the use of cheaper, but slower transport modes, this can increase the costs associated with inventory holding.

The costs described above are depicted on Figure A2.4. This shows that as the number of facilities increases, there is a complicated trade-off between increasing trunking and inventory, and facility costs, and a reduction in local delivery costs.

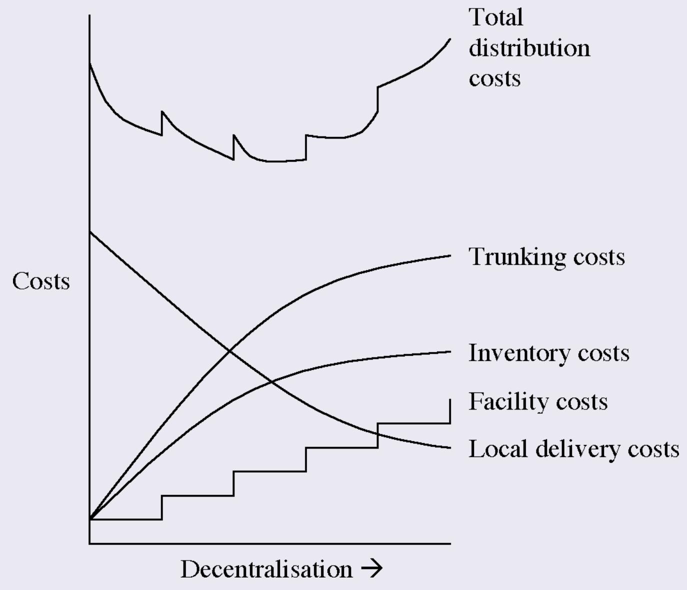


FIGURE A2.4: THE TOTAL COST OF A DISTRIBUTION
(Adapted from Christopher, M. (1998)
***Logistics and Supply Chain Management: Strategies for Reducing Costs and Improving Service*, Financial Times (Prentice Hall)**

Modelling Alternative Supply Chain Designs

Two main spreadsheet methods are available to identify alternative supply chain designs:

i) What-if analysis

With an understanding of the supply chain cost trade-offs and through examination of the base case it is possible to model potential supply chain designs. This analysis would include:

- Examination of demand densities and comparison with facility locations using maps
- Comparison of average local delivery distances associated with each facility
- Examination of the allocation of demand points to each facility
- Identification of alternative transport modes along established and proposed routes

This analysis is not meant to be an exact science, but more a common sense approach to supply chain design. It will not produce the optimal solution for the supply chain design. However, alternative supply chain designs that are generated from the analysis can be modelled in the same way as the base case, and total cost comparisons made.

ii) Optimisation techniques

Where the location of demand points are represented within a spreadsheet using map co-ordinates, it is possible to develop simple optimisation models. Built-in spreadsheet optimisers, or extra add-ons to spreadsheets are available to enable supply chain models to be developed that allow total supply chain costs to be minimised, subject to the location of facilities, and specified constraints.

This approach to supply chain design can allow the modeller to approach an optimal theoretical solution for the location of a given number of facilities. Within the confines of a simple spreadsheet the user would still engage in an iterative process of model testing, where the impact of alternative numbers of facilities for example, could be compared against total supply chain costs.

Stage 4 Evaluation of alternatives and selection of supply chain design

Alternative supply chain designs can be tested against risks identified during phase one of the design process. This can be achieved through the examination of the impact on total costs of various changes to the model inputs. For example this allows the modeller to ask questions such as:

- What if increases in fuel costs increase transport costs?
- What if the lead-time for rail transport is higher than was first estimated?
- What if one of the facilities was destroyed by fire, and throughput had to be redirected through an alternative facility?
- What if one of my transport routes was disrupted?
- What if there was a port strike affecting the transport of product by ship?

The relative vulnerability of different supply chains can be identified through changes to total supply chain costs. These cost changes can be identified through alteration of the spreadsheet models either by simply changing a model parameter such as transport unit costs, or through the manual manipulation of the spreadsheet (for example reallocating throughput).

The relative vulnerability of the alternative designs, the probability of different identified risks occurring, and the total costs of the supply chain at equilibrium need to be carefully examined to determine which supply chain design should be selected and implemented.

Appendix 3 - Glossary of Terms

The following terms are used in this report:

Agility - is the ability of the supply chain to respond rapidly to unpredictable changes in demand.

Bullwhip effect - the magnification of demand as orders move up the supply chain away from the original point of order. Small changes in demand can result in large variations in orders placed upstream. The bullwhip effect can result in increased cost and reduced service.

Business continuity - a proactive process, which identifies the key functions of an organisation and the likely threats to those functions, from this information plans and procedures can be developed which ensure key functions can continue whatever the circumstances.

Business continuity planning - the advance planning and preparations which are necessary to identify the impact of potential losses; to formulate and implement viable recovery strategies; to develop recovery plan(s) which ensure continuity of organisational services in the event of an emergency or disaster; and to administer a comprehensive training, testing and maintenance programme (Associated terms: disaster recovery plan).

Business process re-engineering (BPR) - a management philosophy that focuses on the simplification and reduction of non value-adding activities. In supply chain terms BPR aims to improve the efficiency of product flows from raw material through to the marketplace and delivery to the final customer.

Collaborative planning, forecasting and replenishment (CPFR) - an initiative that enables companies along a supply chain to work together, to develop a single, more accurate demand forecast and to create a plan for delivering product to meet that demand (Source: *Supply Chain Package Solutions Handbook* (2003) DCE Consultants, Oxford)

De-coupling point - the point of commitment, i.e. the moment where inventory held in a generic form, is committed to a particular finished form or to specific customers or markets (Source: Christopher, M and Peck, H (2003) *Marketing Logistics*, 2nd edition, Butterworth Heinemann)

Disaster recovery plan or recovery plan - a plan to resume, or recover a specific essential operation, function or process of an enterprise (Associated term: business continuity planning)

Just in Time (JIT) - a demand driven inventory control philosophy which views production as a system in which all operations, including the delivery of materials needed for production, occur just at the time they are needed. Thus stocks of materials are virtually eliminated. Related term - Just in time distribution includes delivery, just in time, to the retail store and the production line. (Associated term: lean)

Lean (or lean thinking) - i) the elimination of unnecessary waste in business (Womack, J.P and Jones, D (1996) *Lean Thinking: Use Lean Thinking to Banish Waste and*

Create Wealth in your Corporation, Touchstone) ii) by clearly defining 'value' for a specific service or product from the perspective of the end customer all non-value activities, or waste, can be removed step by step (Source: Lean Enterprise Centre, Cardiff Business School)

Links - are the transport and communication infrastructures (e.g. roads, railways, shipping lanes), which link together the nodes (i.e. the fixed assets such as factories, distribution centres, retail stores) in a supply chain.

Logistics - i) the time related positioning of resources (Institute of Logistics and Transport)
ii) strategic management of the procurement, movement and storage of materials, parts and finished product inventory and the related information flows, through the organisation and its marketing channels in such a way that the current and future profitability are maximised through the cost-effective fulfilment of orders (Source: Christopher, M (1998) *Logistics and Supply Chain Management: Strategies for reducing cost and improving service*, 2nd edition, London, Financial Times Prentice Hall)

Networks - see Supply chain

Nodes - are points in the supply chain where value is added through processes taking place, e.g. a factory where products are configured, distribution centre where orders are assembled. The focal company, its suppliers and customers are all nodes

Recovery management team - a team of people, assembled in an emergency, who are charged with recovering an aspect of the enterprise, or obtaining the resources required for the recovery.

Resilience - the ability of a system to return to its original (or desired) state after being disturbed.

Risk assessment and management - identification and evaluation of operational risks that particularly affect the enterprise's ability to function and addressing the consequences.

Risk reduction and mitigation - implementation of the preventive measures which risk assessment has identified.

Robust - strong or sturdy in physique or construction *(Collins English Dictionary)*.
In IT terminology robustness is the ability of a computer system to cope with errors during execution.
A robust process may be desirable but it does not equate to a 'resilient' supply chain

Strategic knowledge - an awareness of trends and emerging issues that may have an impact on supply chain continuity at a point in the future (Associated term: Supply chain intelligence)

Supply chain - the total sequence of business processes, within a network of organisations that enable customer demand for a product or service to be fulfilled. The notion of **networks** is particularly important. Modern

supply chains are not simply linear chains or processes. They are complex networks. The products and information flows travel within and between nodes in a variety of networks that **link** organisations, industries and economies.

Supply chain events management (SCEM) -
the process of monitoring the planned sequence of activities along a supply chain and the subsequent reporting of any divergence from that plan.

Supply chain intelligence -
is the process of using knowledge generated and shared by partners in the supply chain

Supply chain management -
the management of upstream and downstream relationships with suppliers and customers to deliver superior customer value at less cost to the supply chain as a whole.

Supply chain resilience -
see resilience

Supply chain risk management -
the identification and management of risks within the supply chain and risks external to it through a co-ordinated approach amongst supply chain members to reduce supply chain vulnerability.

Supply chain visibility - is the ability to see from one end of the pipeline to the other. Visibility implies a clear view of upstream and downstream inventories, demand and supply conditions, and production and purchasing schedules for example.

Supply chain vulnerability -
an exposure to severe disturbance, arising from risks within the supply chain as well as risks external to the supply chain.

Visibility -
see supply chain visibility

Vulnerability -
see supply chain vulnerability

Appendix 4 - Further reading

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Christopher, M. (1998) *Logistics and Supply Chain Management: Strategies for Reducing Costs and Improving Service*, Financial Times Prentice Hall.

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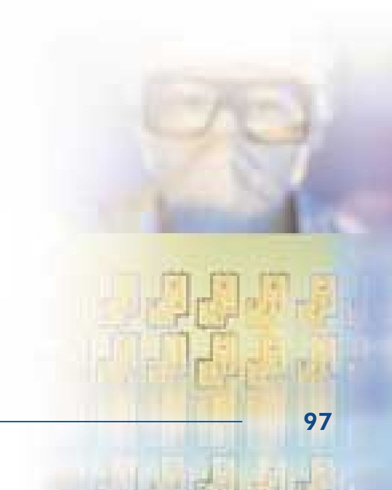

Notes

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