CRANFIELD UNIVERSITY

Delia Richardson

Disruptive Risk Management: What makes supply chains resilient to low probability/ high impact disruptions to the inbound and outbound aspects of the supply chain?
A Systematic Literature Review

School of Management

MRes Dissertation

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Disruptive Risk Management: What makes supply chains resilient to low probability/ high impact disruptions to the inbound and outbound aspects of the supply chain?
A Systematic Literature Review

Supervisor: Professor Richard Wilding

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EXECUTIVE SUMMARY

The business community has found itself in the predicament of first understanding and then knowing how to deal with the risk and disruptions to which it is exposed. Risk management is a well informed field in other disciplines. Supply chain risk management however, still needs to be understood and adequately practised, but seemingly, of even more urgency is disruption risk management, which as a new hot topic, is still evolving in both the academic and the practical fields. To compound the problem is the fact that not all practitioners believe that this risk actually exists and that they need to plan for it. If they believe that it exists, they still are unsure as to how to prepare for it and many still need to be convinced that money needs to be put aside to plan for and to mitigate against disruptive events. Disruptive events such as acts of nature, accidents, terrorist and non-terrorist activities can cause a breakdown in the supply chain and thus very quickly cripple the supply chain, possibly causing disruptions to the transportation, communication and information technology systems. This is indeed a critical situation given the fact that many companies have chosen efficiency over effectiveness by employing such strategies of JIT, outsourcing and single sourcing strategies (Norrman, Jansson, 2004; CLSCM 2003, Christopher 2005, Tang 2006). In effect what they have done is exposed their supply chains making them very vulnerable to disruptive events.

This report then, seeks to answer what makes a resilient supply chain. To this end the author has used the systematic review process in an attempt to use evidence-based methods of scientific research (Tranfield *et al.,* 2003) to identify, select and critically appraise relevant research. The process is so designed that the information, once discovered and developed can then be discussed and synthesized. The broad fields of literature will include Supply Chain Risk, Vulnerability, Resilience, Risk Management and Disruption Risk Management.

Findings thus far indicate that resilient supply chains have seemed to evolve from business continuity planning and supply chain risk management. Additionally, they are hinged on creating a flexible and agile supply chain, having enhanced communication within the network and establishing the right company culture. Firstly, the report seeks to situate the research in the current body of knowledge. It then describes in detail the methodology employed for the research and analysis of the information. The descriptive and thematic findings are presented, followed by their synthesis, discussion and conclusion. One of the main purposes and benefits of the systematic review is that it sets the stage to allow an issue to evolve, which can then be used to frame a PhD question. To this end, the conclusion includes PhD questions that the author has found of interest and considers as good, sound and feasible for further research and analysis.

ACKNOWLEDGEMENTS

Firstly, I acknowledge my Mum who has been my guiding light throughout this process. Without her encouragement and unwavering support and belief I most certainly would not have been here today. Then I acknowledge the rest of my family, i.e. my Father and two brothers, sister (and family) and relatives for their constant support and encouragement.

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Finally, I say thank you to my special friends and class mates who journeyed through this programme with me. The company and support was invaluable.

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DEFINITIONS

Agility means using market knowledge and a virtual corporation to exploit opportunities in a volatile market place. (Naylor *et al* 1999)

Business continuity is the development of strategies, plans and actions which provide protection or alternative modes of operation for those activities or business processes which, if they were to be interrupted, might otherwise bring about a seriously damaging or potentially fatal loss to the enterprise. BCP includes crisis management, disaster recovery, business recovery and contingency planning (Norrman & Jansson 2004)

Business Continuity Management is described as a holistic management process that identifies potential impacts that threaten an organisation and provides a framework for building resilience and the capability for an effective response that safeguards the interests of its key stakeholders, reputation, brand and value creating activities (Foster & Dye 2005).

Contingency tactics are those in which a firm takes an action only in the event a disruption occurs (Tomlin 2006)

The de-coupling point is the point at which the market 'pull' meets the upstream 'push' (Christopher & Towill 2000)

Demand Management is the ability to shift customer demand to alternative products, particularly in the face of a disruption to the supply chain (Tomlin 2006)

Enterprise Resilience is the ability and capacity to withstand systemic discontinuities and adapt to network environments (Starr *et al* 2003)

Globalisation is the process by which many companies have become interconnected for business purposes. This may have been through the consolidation of the supplier base, through mergers and acquisitions or through the move to increased offshore sourcing, manufacturing and assembly. Though the motivation of out sourcing has been to decrease cost there is the increased risk associated with having longer pipelines and increased lead times. (Christopher 2005).

Just in time (JIT) is an integrated, problem solving approach aimed at improving quality and facilitating timeliness in supply, production, and distribution, the purpose being the improvement of coordination between the manufacturer and its supply chain distribution network. The ultimate goal of JIT is to improve competitiveness and financial performance (Claycomb *et al* 1999).

Leanness means developing a value stream to eliminate all waste, including time, and to enable a level schedule (Naylor *et al* 1999)

The focus of lean manufacture is the elimination of waste or muda (Agarwal *et al* 2006). Lean concepts work well where the demand is relatively stable and hence predictable and where variety is low (Agarwal *et al* 2006). It operates as a pull system where the demand originates from the end customer and is fed through the entire system (Claycomb *et al* 1999). When demand is high and the customer requirement for variety is high a much higher level of agility is required (Agarwal *et al* 2006)

Mitigation tactics are those in which the firm takes some action in advance of a disruption and thus incurs the cost of the action regardless of whether or not the disruption occurs (Tomlin 2006)

Operational contingency – Demand Management Shifting the customer demand from one product to another in the face of a disruption is demand management (adapted from Tomlin 2006)

Operational contingency – Rerouting - This is the ability to reroute production to alternative locations or suppliers, or change the method of transport – example air to ground transport, or rerouting transport or shipment to another location, airport or port in the event of a disaster (adapted from Tomlin 2006)

Operational mitigation - Inventory - The action of investing in extra stock as a buffer or form of protection in the event of experiencing a disruption (adapted from Tomlin 2006)

Operational mitigation - Sourcing - This can include having a multiple supplier or multiple location strategy in the event of a disruption (adapted from Tomlin 2006)

Outsourcing can be defined as the transfer of previously in-house activities to a third party (Lonsdale 1999). The outsourcing of the distribution, manufacturing, accounting and information systems have increased the inter-connectedness of organisations, but it has also increased the risk of not having the control on cost (Christopher 2004, 2005).

Reliability was defined as the probability that a system or component performs its specified function as intended with a given time horizon and environment (Bundschuh *et al* 2003)

Resilience – A notion borrowed from the material sciences, represents the ability of a material to recover its original shape following deformation. For companies, it measures their ability to, and the speed at which they can, return to their normal performance level (production, services, fill rates, etc) after a disruption (Sheffi 2005c, 2006),

Risk is used in the sense that something – a product, process, organisation etc – is 'at risk', i.e. 'vulnerable; likely to be lost or damaged' (Peck 2005).

Robustness deals with the impact of failures on the performance of a system (Bundschuh *et al* 2003)

Uncertainty exists when there is no understanding of even the distribution of potential outcomes (Wei-Jiat & Enderwick 2006)

The supply chain is defined 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 (Peck 2005).

Supply chain risk can be defined as 'any risks for the information, material and product flows from original supplier to the delivery of the final product for the end user'. This is the possibility and effect of a mismatch between supply and demand (Juttner *et al* 2003)

Volume flexibility is the supplier's ability to temporarily adjust capacity (Tomlin 2006)

Supply Chain vulnerability is defined as an exposure to serious disturbance, arising from risks within the supply chain as well as risks external to the supply chain (Christopher and Peck 2003).

CHAPTER 1

1. INTRODUCTION

The turbulent business environment can be considered the cause of supply chain risk, not only is demand volatile; but also, the increasing global network and shorter clock speeds have made supply chains much more vulnerable (Christopher and Peck 2003) Notwithstanding, supply chains are now required to respond even faster to changes in the competitive environment. Disruptions can take many forms, for example, natural disasters such as the Taiwan earthquake in September 1999, which affected the global semi-conductor industry (Kleindorfer, Saad 2005); accidents, such as the fire at the Phillips plant (Sheffi 2005a, c); terrorist activities, e.g., the attack of the World Trade Center on September 11, 2001; new product and process technologies (McDermott & Hanfield 2000); regulatory and legal changes (Marwick 1996) and technical and operational problems from equipment malfunctioning (Kleindorfer, Saad 2005).

Companies now need to be able to respond to these challenges at a moment's notice, being able to provide the same level of service to customers as soon as possible, especially in very competitive environments where companies can quite easily lose their advantage if they are unable to satisfy their customers' requirements (Sheffi 2005c). A company that fails to adjust to its changing environment soon loses its relevance, its customers, and ultimately, the support of its stakeholders (Hamel & Valikangas 2003). Strategies such as rationalising the supplier base or moving to single source suppliers, outsourcing and the adoption of 'lean' practices through inventory and capacity reduction have increased the supply chain risk (Waters-Fuller 1995, Christopher 2005, Sheffi 2005a, Sheffi 2005c). So ironically, the focus on efficiency and cost reduction has made chains more vulnerable (Waters-Fuller 1995m, Christopher 2005, Sheffi 2005a, Sheffi 2005c).

The topic of supply chain risk, vulnerability and resilience has risen out of the need for organisations to pay more attention, not to the regular moderate risk that may come around due to daily operations such as employee absenteeism, poor quality and machine breakdowns, but it has risen out of the need to plan for low probability/ high impact risk events. The fact is that though a company may not be under the threat of every possible type of disaster or disruption, some member of its supply network may be under some threat, which can then have an adverse effect on the focal company. This becomes even more critical for companies with far reaching global networks. Thus companies now need to increase their understanding of their supply chains and possible risks they may be exposed to.

The challenge then is to manage and mitigate risk though creating more resilient supply chains. For companies, resilience is a measure of their ability to, and the speed at which they can return to their normal performance level (production, services, fill rates, etc) after a disruption. However, Sheffi has said that, resilient companies are not only able to endure the unpredictable nature of globalisation, but are also able to gain competitive

advantage from it (Sheffi 2005). Not only do they need to be able to respond to changes, but they need to be able to gain competitive advantage from these disruptions (Sheffi 2005).

The aim of this report then is to survey the literature to draw out the components and techniques that have been described to create a resilient supply chain. To this end, this report engages in a discussion which takes the following format.

Chapter two focusses on situating the research where it discusses the basic tenets of supply chain management (SCM) and risk. It then discusses how supply chains are made vulnerable, which is then followed with a discussion on the antecedents of supply chain risk and business continuity such as disaster management and crisis management. Along with the discussion on supply chain risk management, this chapter will conclude with a discussion of the research rationale and a presentation of the research question along with its supporting questions.

Chapter three, the methodological chapter, discusses the benefits of the systematic review process over the traditional literature review process and presents the methodology used in carrying out this research.

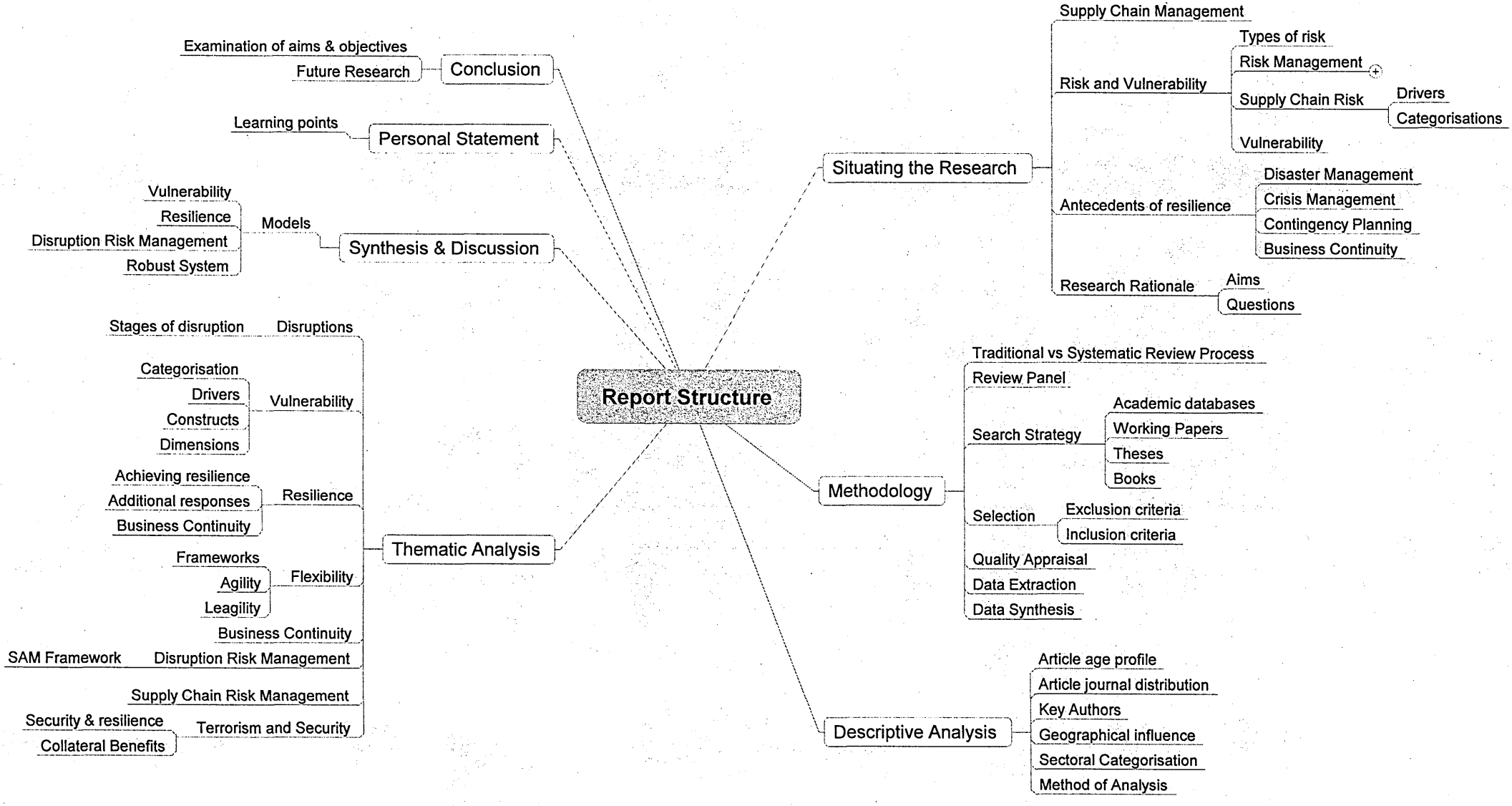
The synthesis of the primary research papers takes place in chapters four, five and six. Chapter four provides the descriptive analysis of the field which includes the age profile of the articles, the areas of contribution, the major contributing authors and journals to the field and other such information. This chapter justifies some of the conclusions (Tranfield *et al* 2003) made in the review. Chapter five reports the thematic analysis of the findings, derived from an aggregative approach, outlining what is known and established from core contributions (Tranfield *et al* 2003). Chapter six, the Synthesis and Discussion chapter, presents models which synthesise the findings of the previous two chapters.

Chapter 7 provides the learning experience of the author which seeks to describe the challenges faced and the learnings obtained through this process. Some limitations of process have also been discussed.

The body of the report ends with chapter 8, the conclusion, which summarizes the findings and limitations of the research and the potential research questions that have evolved out of this review piece and the author is interested in pursuing at the PhD stage.

Figure 1 presents and overview of the various areas that are presented in the report.

Figure 1: Mind Map of Report Structure



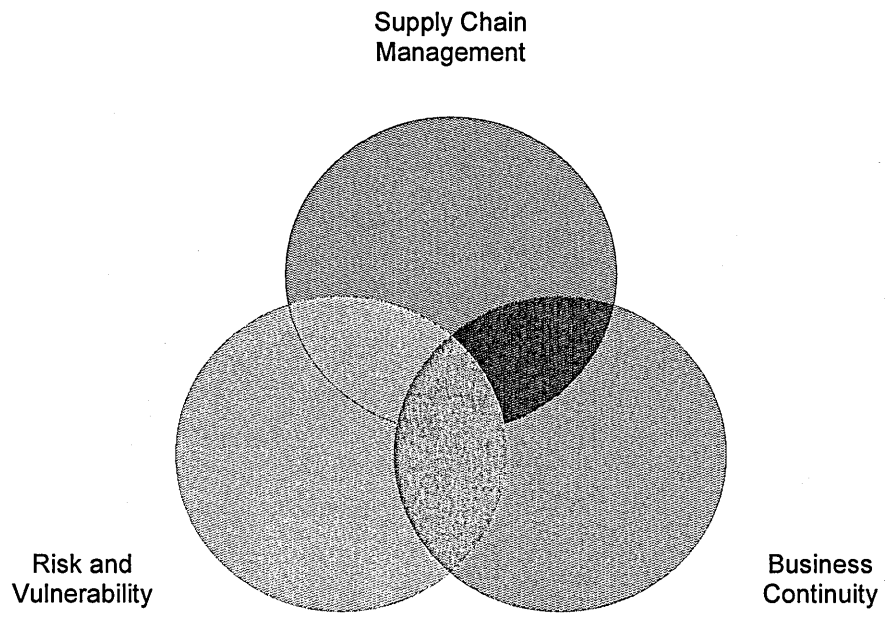
CHAPTER 2

2. SITUATING THE RESEARCH

2.1 Introduction

This section seeks to locate the research in its broader perspective. It briefly and broadly discusses the field of supply chain management, risk management, disaster preparedness and crisis management vulnerability and disruptions. Thus, the research is situated in the key fields as illustrated in the following Venn diagram (Figure 2).

Figure 2: Venn diagram of the fields influencing the research topic



Source: The Author 2006

* Referred to business continuity to represent the wider perspective of disaster management, crisis management and contingency planning

The research question is also presented at the end of this chapter. The aim is to not only scope the field, but to provide the background against which supply chain resilience has and will continue to develop and evolve.

2.2 Supply Chain and Supply Chain Management

There are varying perspectives on what is Supply Chain Management (SCM). SCM first appeared in the 1980s when writers used it to describe an amalgamation and re-labelling

of established business activities, i.e., logistics (transport, warehousing and distribution) and manufacturing based operations management (purchasing, order and inventory management, production planning and control). This encompassed the concepts of information sharing, and system integration. Since then SCM progressively developed to include marketing, new product development, order management and payment, (Peck 2006). Business trends of the 1990s created the need for SCM and advances in information technology created the opportunity (Kopczak & Johnson 2003). Shorter product life-cycles and greater product variety increased supply chain cost and complexity. Outsourcing, globalisation and business fragmentation made it imperative that this increased supply chain cost be addressed through the entire supply chain rather than from the individual company. Advances in IT allowed for real-time information sharing, coordination and decision making among companies. Kopczak & Johnson (2003)

Christopher (1998) used the value-based approach and defined the supply chain as the network of organisations that are linked through upstream and downstream relationships in the different processes and activities that produce value in the form of products and services in the hands of the ultimate customer (Peck 2006). There is also the value-adding[1] process perspective as well as the inter-organisational network perspective[2]. For Handfield & Nicholas (2002), supply chains are essentially a series of linked suppliers and customers; where every customer is, in turn, a supplier to the next down stream organisation until a finished product reaches the end-user. It is evident then that there exist many definitions of supply chain. It has been put forward by Haywood (2002), that the absence of a common understanding of the term does represent a significant barrier to defining supply chain vulnerabilities and the implementation of the appropriate risk mitigation strategies (Peck 2006).

According to the Oxford concise dictionary, a network is a group or system of interconnected people or things. Thus, companies that are connected in a network can affect each other and, hence the reason for using this definition of the supply chain as the risk experienced by one company, can ripple through the network and be a source of disruption to another company. For the purposes of this discussion we will use the approach taken by Christopher.

With respect to Supply Chain Management (SCM), Kopczak & Johnson (2003) have taken the view that Supply Chain Management (SCM) has been considered to address the fundamental business problem of supplying product to meet demand in a complex and uncertain world from the point of view of the entire supply chain. Ellram and Cooper (1993) consider that SCM is an integrating philosophy to manage the total flow of a distribution channel from supplier to ultimate customer, while Monczka and Morgan (1997) have put forward that integrated supply chain management is about going from the external customer and then managing all the processes that are needed to provide the

[1] In the value-adding perspective they may multiple value streams each representing a product or product family (Peck 2006)

[2] In the inter-organisational perspective supply chains become scalable aggregations of three or more cooperating organisations (Peck 2006)

customer with value in a horizontal way. Stock and Lambert (2001) says that it has become 'the integration of key business processes, from end user through original suppliers that provides products, services and information that add value for customers. Christopher (1998) assumes the relational, value-added perspective which looks at 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. Zsidisin *et al* (2005) sees the integration of the integrated supply chain as the linkage of upstream suppliers and downstream customers with the firm.

Though clarity does not exist on one scope and definition for Supply Chain Management it is clear though, that the ultimate goals of SCM are 'lower costs, increased customer value and satisfaction, and ultimately establishing a competitive advantage (Peck 2006). Though the integrated supply chain may lead to enhanced flexibility, reduced costs, improved quality, reduced lead-time and improve competitiveness (Zsidisin *et al* 2005), its integration has affected risk management (Zsidisin *et al* 2005), which leads to the next topic of discussion.

2.3 Risk and Vulnerability

2.3.1 Introduction

This section engages in the discussion of various types of risk, and provides a brief overview of the risk management process and supply chain risk. This section then concludes with a discussion of supply chain vulnerability.

2.3.2 A brief description of risk

Managing supply chains in today's competitive world is increasingly challenging (Christopher, Lee 2004). There are varying types of supply chain risk, which will be briefly mentioned. *Financial risk* which is often quite significant can exist in the form of inventory costs due to obsolescence, markdowns and stock outs. *'Chaos' risk* is brought on by uncertainty and complexity within the supply chain and can result in overreaction, unnecessary interventions, second guessing, mistrust and distorted information throughout a supply chain. *Political Risk* depends on government actions and the political climate of the countries at the time (Gattorna, Walters 1996). The supply chain is exposed to *market risk* which is missing the market opportunities that may exist. If the market signals cannot be recognised, then the supply chain will not be able to respond to changing market trends and customer preferences. Finally, problems and events in the Supply Chain make it difficult to make optimal decisions at each stage in the supply chain. This *decision risk* then becomes the inevitable consequence of making ineffective decisions. However, disruptive events such as the closure of US airspace in response to the terrorist attack on September 11th 2001, the longshoremen's strike in California in 2002 and the outbreak of Sars in 2003 have introduced yet another type of risk and hence vulnerability to be considered by managers. According to Hutchins (2006) the US faces chemical, biological, radiological, nuclear and explosive threats, more commonly called CBRNE threats, and so, CBRNE, border and transportation security, emergency

preparedness and response and infrastructures protection are hot areas for quality professionals.

Risk and uncertainty have no generally accepted definitions (Zsidisin *et al* 2004). Hutchins (2003) defines risk as the probability that an event or action may adversely affect the organisation. Zsidisin *et al* (2004) described risk as variability in outcomes or results. It is the product of two separate, but interrelated elements: uncertainty and impact. The two aspects of uncertainty that are relevant are lack of awareness of all the events that might occur and cause a supply disruption and the probability of occurrence of those events. Impact refers to the potential cost that comes about due to the disruptive event. Risk then, is viewed as the product of the impact and probability (Zsidisin *et al* 2004). This follows the generally held concept that risk is the probability that a given event will occur, by the severity (the negative business impact) of the risk once it occurs (Peck 2006). Common elements of most risk definitions include the ability or inability to meet contract, process and product requirements; the possibility of harm or loss if requirements are not achieved; the probability of an undesirable event with consequences and the variation away from a specification or requirement (Zsidisin *et al* 2004).

According to Juttner *et al* (2003) supply chain risk is anything that presents a risk to information, material and product flows from the original supplier to the delivery of the product to the end user. For the purposes of this report we will use risk in the sense that that something – a product, process, organisation etc – is 'at risk', i.e. 'vulnerable; likely to be lost or damaged' (Peck 2005).

According to Hallikas *et al* 2004. The typical risk management process consists of risk identification[3], risk assessment[4], decision and implementation of risk management actions[5] and risk monitoring[6].

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[3]Risk Identification is the identification of risk and being conscious of the phenomena that cause uncertainty. Have to take into account the dependencies on other organizations, interruptions, quality failure and delivery fluctuations are signs of the risk management in the production system (Hallikas et al 2004). This category was further categorized into two groups, the demand problems, which refer to problems in fulfilling customer deliveries and cost management and pricing and secondly weaknesses in resources, development and flexibility (Hallikas et al 2004).

[4] Risk Assessment is the assessment and prioritization needed to choose the correct mitigation strategies according to the risk factors identified (Hallikas et al 2004). Risk assessment tends to be comprised of the two components of risk, the probability and the consequence of risk. The companies experience and other companies' performance are utilized at this stage and the potential consequences considered from the viewpoint of the organization. These can be ranked.

[5] Decision and Implementation of risk management actions – the generally used strategies for risk management include: risk transfer (from one company to another), risk taking for an investment, the key being that the company taking the risk is able to handle the impact of it, risk elimination, risk reduction and further analysis of tasks. In network environment, the objectives of different networks may cause contradictions for am enterprise (Hallikas et al 2004)

[6] Risk Monitoring – as with any system, monitoring keeps a focus on trending to see if there is an increase or decrease in the types of risk being experienced. Also there may be new risk introduced to the organization or network and these will need to be identified (Hallikas et al 2004)

Most types of risk assessments tend to try and determine the probability of the risk event happening and rate that against the impact (in financial terms) that the event would have if it were to actually happen. The risk can then be presented in risk diagram to gain a better understanding of the positioning of all the risk to each other with their potential for impact to the company. This too helps in the prioritization of the risk

2.3.3 Supply Chain Risk

According to Hauser (2003), 'risk management in the supply chain does not equate to disaster response. Rather, it means keeping and increasingly complex process moving efficiently at the lowest total cost and without compromising the quality of the product or customer satisfaction. A 2004 survey of purchasing executives conducted by 'Purchasing Magazine' found that only half of all respondents reported monitoring supply chain risk often. The others monitored the risk 'somewhat' (17.4%), rarely (29.6%), or never (3.6%). Additionally, seemingly, supply chain risk management was covered from the supplier to the company, but not from the company to the customers (Atkinson 2006). However, according to Economist Intelligence Unit, boards are taking risk more seriously, even though this may be largely due to the governance and regulatory factors rather than their recognition that the overall business strategy would benefit from fully integrating risk management into the board level decision making.

Supply chain risk management requires a close working relationship between risk managers and others in the organisation (Atkinson 2006). Risk management provides the traditional expertise and information while other functions such as purchasing, sales, logistics and transportation can bring additional expertise and information on supply chain dynamics to the table.

Supply chain risk can arise from many sources, and sometimes without warning. These disruptions can be external such as natural disasters as well as internal to the organisation from the failure to integrate the functions of the supply chain (Hauser 2003). With regard to IS areas of risk, Finch (2004) considered the company to be divided into three levels, the application level, the organisational level and the inter-organisational level where risk included natural disasters, accidents and deliberate acts, as well as risk from information security, management issues such as skill acquisition and retention, competition and competitor's action, legal issues such as violation of rights and intellectual property, strategic and sustainability risk and risk from strategic alliances and new product development (McDermott & Handfield 2000).

Effective supply risk required the identification and monetization of risk events, probability of occurrence and the firm contingencies for alternative sources of supply (Barry 2004). Hauser presented the Risk adjusted SCM framework to provide the business case for evaluating risk where, as Barry, the first components of the framework consisted of identifying the process risk and then identifying which of these were actual supply chain vulnerabilities. As Hauser indicated, the operational business processes identifies the supply risks, but not all the risks are classified as vulnerabilities. Hauser then defined vulnerability as a risk, which upon the occurrence of an adverse event can

cause a significant disruption or interruption to the supply chain. The distinction between a risk and vulnerabilities is determined by the financial impact if the adverse event were to occur (Hauser 2003).

2.3.4 Supply Chain Risk Categorisation

Supply chain risk can also be categorised based on a framework proposed by Mason-Jones & Towill, (Christopher and Peck 2003) and which has similarly been suggested by Geary *et* al (2002) where risk is categorised into three types of risk that can be sub-divided to produce a total of five categories:

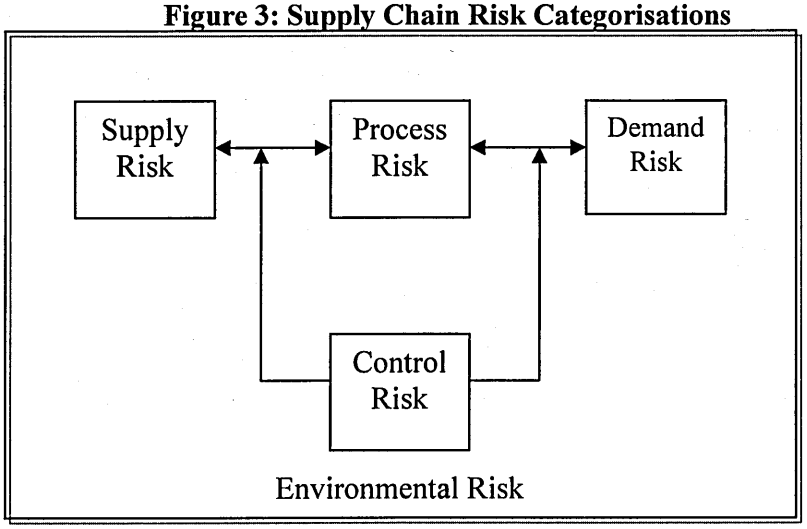
- Internal to the firm
    a. Process risk which can come about through the sequences of value-adding and managerial activities undertaken by the firm
    b. Control risk which comes about through the assumptions, rules, systems and procedures that govern how an organisation exerts control over the processes

- External to the firm but internal to the supply network – through which materials, products and information flow
    a. Demand risk is the potential or actual disturbance to the flow of product, information and cash emanating from within the network, between the focal firm and the market
    b. Supply risk is the potential or actual disturbance to the flow of product or information emanating from within the network, upstream of the focal firm

- External to the network
    a. Environmental risk relates to the disruptions that are external to the network of the organisation through which the value-streams/product supply chains flow.

Figure 3 summarizes the linkages between these risk categories

Figure 3: Supply Chain Risk Categorisations



Source: Christopher & Peck 2004

2.3.5 The drivers of supply chain risk

Chopra and Sodhi (2004) have identified risk categories and drivers that can make an organisation very vulnerable. These are presented in Table 1.

Table 1: Supply Chain Risk and Their Drivers

Category of Risk	Description	Drivers of Risk
Disruptions	These are unpredictable and rare and can be quite damaging.	• Natural disasters • Labour dispute • Supplier bankruptcy • War on terrorism • Dependency on a single source of supply as well as the capacity and responsiveness of alternative suppliers
Delays	Delays in material flow occur when supplier cannot respond t the changes in demand. This may be due to high utilization or another cause	• High capacity utilisation at the supply source • Inflexibility of supply source • Poor quality or yield at supply source • Excessive handling due to border crossings to the change in transportation modes
Systems	These can be attributed to a breakdown in the communication systems and information infrastructure. This is especially crucial as many companies have networked their information systems	• Information infrastructure breakdown • System integration or extensive systems networking • e-commerce
Forecast	Forecast risks results from a mismatch between the company's projection and the actual demand. Forecast inaccuracies can also result in information distortion within the supply chain. This then leads to the bullwhip effect as information distortion increase the further away from the end customer	• Inaccurate forecasts due to long lead times, seasonality, product variety, short life cycles, small customer base • 'Bullwhip effect' or information distortion due to sales promotions, incentives, lack of supply chain visibility and exaggeration of demand in times of product shortage
Intellectual Property	As companies become more global and as they outsource to the same manufacturers used by competitors intellectual property risk has become an issue	• Vertical integration of supply chain • Global sourcing and markets
Procurement	This is the unanticipated increased in acquisition costs resulting from fluctuating exchange rate and supplier price hikes	• Exchange rate risk • Percentage of key components or raw material procured from a single source • Industry wide capacity utilization • Log term versus short term contracts
Receivables	The possibility of being unable to collect on receivables, can torpedo the performance of any company	• Number of customers • Financial strength of customers
Inventory	Inventory Risk is the risk associated with having excess inventory which can negatively affect any company's financial performance	• Rate of product obsolescence • Inventory holding cost • Product value • Demand and supply uncertainty
Capacity	Capacity can only be increased or decreased over a period of time. Thus, building excess capacity usually becomes a strategic choice. Thus, excess, underutilized capacity can adversely affect financial performance	• Cost of capacity • Capacity flexibility

Source: Chopra & Sodhi 2004

Managing risk can be difficult because often, mitigating one risk can exacerbate others (Chopra and Sodhi 2004), for example, lean supply and single sourcing strategies were intended to increase the efficiency of the firm, but in so doing can increase its vulnerability. How a company fares against disruptive events depends on the type of disruption and the organisation's level of preparedness (Chopra and Sodhi 2004). Most companies develop plans to deal with recurrent low impact risk, but many companies ignore the impact of low probability, high impact risk (Chopra and Sodhi 2004). Table 2 gives examples of how these risks can be manifest in the supplier-related, internal, and customer related aspects of the supply chain.

Table 2: Supply Chain Risk Examples

	Supplier-related	Internal	Customer-related
Disruptions	• Supplier of a key part shuts down plant for month or at a key part of the production cycle • Supplier capacity drops by 20% overnight	• Key plant shuts down unexpectedly for one month • Capacity at a key plant drops by 20% overnight	• Demand goes up by 20% .... For all products ... for a key product ....across the board • Demand goes down by 20%
Delays	• Purchase orders of key parts or raw material delayed by month	• Distribution of production orders delayed by a month	• Customer orders delayed by a month
Systems	• Supplier's order-entry system goes down for a week	• Key customer's procurement systems inside your company goes down for a week • Company's inventory/ accounts system goes down for a week	• Order entry system not working for a week • Key customer's procurement system inside your company down for a week • Credit card information stolen from hacked e-commerce system
Information Processing	• Supplier rations supplies by 20% • Supplier increases minimum order size by 20% then 100%	• To take advantage of volume discounts, company begins to order in quantities twice as large as usual, but half as frequently, which impacts supplier's ability to forecast	• Key customer begins to order in batches that are twice as large as usual but less frequent
Intellectual Property	• Key supplier redesigns parts and creates a new product		
Procurement	• Supplier delays in processing returns by twice as long • Supplier forced to increase price of key components by 20% • Transportation costs go up 20% overnight	• Unforeseen cash squeeze required month-long delays in paying key suppliers	
Receivables			• Key customer withholds payments one month longer than usual • 20% of receivable payments delayed by one month

Source: Chopra and Sodhi 2004

The following sections provide some background information to the antecedents of Business Continuity and Disruption Risk Management which include Contingency Planning, Disaster Preparedness and Crisis Management.

2.3.6 Vulnerability

Supply Chain vulnerability is defined as an exposure to serious disturbance, arising from risks within the supply chain as well as risks external to the supply chain (Christopher and Peck 2003). Supply chain vulnerability is a relatively new and unexplored area of management research, though one that is in the ascendancy (Svensson 2002a, Peck, 2005).

Most of the inventory and production management is done under the assumption that normal conditions will apply, not paying attention to events that may hinder the flow of materials and components. Additionally, particularly in global supply chains that are in highly competitive environments, the last two decades have experienced a growing emphasis on just-in-time, single supplier strategies and other lean manufacturing principles in their supply chains, which, while making the supply chains much more efficient and effective have, inadvertently, made them more vulnerable (Svensson 2000, Christopher 2005, Christopher and Peck 2003).

The causes of this vulnerability can be attributed to the widespread adoption of lean inventory practices (Mello 2001; Norrman, Jansson, 2004; Christopher 2005), the globalisation of supply chains (Norrman, Jansson, 2004; Christopher 2005, Drickhamer 2005), focussed factories (Norrman, Jansson, 2004; Christopher 2005), centralised manufacturing (Lee 2004), centralised distribution (Lee, 2004, Christopher 2005), reduction of supplier base (Norrman, Jansson, 2004; CLSCM 2003, Christopher 2005, Tang 2006), shorter product life cycles (Norrman, Jansson, 2004), more intertwined and integrated processes between companies (Norrman, Jansson, 2004). These initiatives have created longer and more complex global supply chains (Tang 2006).

Vulnerability is also increased as companies are unaware of which goods and materials are in their supply chain and where they are (Mello, 2001). Lean manufacture, especially for Japanese companies, allowed them to produce high quality products with just-in-time flow from suppliers to assemblers. This was also a cost-effective and efficient means of managing their inventory as they minimised the inventory of parts stored on their plant by synchronising their supply chain so that parts could be delivered just in time to be installed. However, in 1995 the Kobe earthquake highlighted the vulnerability of this model (Sheffi 2005a). Lead times are longer and inventory levels higher in international supply chain compared with domestic examples (Levy 1997).

Large scale disruptions showed the dependencies on the infrastructure such as phone lines, power lines, water lines, gas lines, rail lines, highways, and ports that connect companies to critical services, suppliers and customers. In the case of the Kobe earthquake the Osaka plant was not damaged during the quake, but there was the loss of gas and water supply to the plant and thus they were unable to continue production.

Unfortunately, the Osaka plant was the sole supplier of brake shoes used by Toyota. Consequently, this halted the production in a number of Toyota's factories as they soon ran out of parts and the Osaka plant was their sole supplier (Sheffi 2005a).

In the UK, the need to focus on supply chain vulnerability was amplified with the fuel protest in 2000 and the outbreak of Foot and Mouth Disease in 2001 (Peck 2005). The topic of vulnerability and resilience is now finding itself as a major concern in supply chain management. Additionally, according to Peck (2006), supply chain vulnerability is benefiting from a more general upsurge in interest in risk management in several other overlapping areas of commercial concern and public policy. Other areas of growth include Corporate Governance, Business Continuity Management, Emergency Planning and National Security.

2.3.7 Summary

This section took a look at the wider risk perspective before narrowing the focus to supply chain risk, risk categorisations and drivers of supply chain risk. It then concluded with a discussion on the causes and effects of supply chain vulnerability. The following section will discuss some of the evolutionary concepts and actions of the antecedents of business continuity and resilience as they sort to 'battle' or mitigate against these risks as described.

2.4 Antecedents to Resilience

2.4.1 Introduction

While in the previous section of this chapter the focus was on Supply Chain Management, Risk Management, Supply Chain Risk Management and Vulnerability, the aim of this section is to give a brief description of the antecedents of business continuity and resilience. This is important as some of the strategies used to create a resilient supply chain come out of the discipline of business continuity (which will be further described later in the report) and thus it is considered fitting to get a sense of what led into the development of this area called business continuity.

2.4.2 Contingency Planning

Berman (1996) defined contingency planning as that which 'specifies a series of events that are designed to take full advantage of a business opportunity or to reduce the impact of an event that generally will be disastrous to the firm (Svensson 2002), or according to Goldberg *et al* (1999), it involves the proactive preparation of alternative work processes in the event of possible system or process failures.

For many decades in the post-war era contingency planning considered that threats would be from 'external' aggressors and not from critical failures in infrastructure. On a

national level in the public sector, contingency planning was dominated by the Cold War mentality and the view that preparations for conventional and nuclear war could 'double up' as preparations for chemical spills, urban riots and the like (McConnell & Drennan 2006). In the mid-1980s, high profile disasters caused many leaders to think as it provided a warning that critical failures can resonate in the industry and across nations. Many crises in one country can rapidly spill over to others in a 'World Risk Society' via interconnections through air travel, electronic communication and transportation of goods (McConnell & Drennan 2006).

The coming of the Year 2000 caused a further shift in thinking as it was thought that there would be a higher likelihood of information system failures across the globe affecting all IT and electronic systems, as well as the possibility of electricity outages, telecommunication failures, transportation failures, failures of building environmental and security systems, electrical equipment failure including manufacturing and safety equipment and general disruptions in the supply of goods and services (Goldberg *et al* 1999). Thus, the traditional model of information systems contingency planning based on off-site data storage and computer hot sites were inapplicable. Contingency planning included making plans for potential systems failures as well as disruptions to utilities, in communication and with business partners (Goldberg *et al* 1999). Preparation included the assessment, planning, execution and recovery stages as well as scenario planning for the best and the worst circumstances.

The September 11th attack on the World Trade Center caused another shift in thinking that the 'unthinkable' can happen and needs to be anticipated and prepared for (McConnell & Drennan 2006). Incidents that have since added to this include the destruction of New Orleans on 2005 by Hurricane Katrina, the longshoreman's port strike (Sheffi 2005, Peck 2005), the fire at the Phillips factory and the London terror attacks on July 7th 2005.

Thus, according to Ferris (2002), plans need to encompass the diversification of operations, preparing for an extended disruption (probably lasting not less than four weeks), training and awareness for emergency preparedness, communication, and a focus on end results. However, critical to the contingency plan, is preparing for the people issues (King 1993) which, for Morgan Stanley, included expanding capabilities for working at home, advanced planning with employee counsellors, striving to get people back to work earlier, enhanced communication, strategies for temporary housing, transportation, communication and other services such as grief counselling (Ferris 2002). These helped them recover from the effects of the attack on the World Trade Center much faster than other companies.

Contingency planning has thus become a much more relevant issue. According to McConnell & Drennan (2006), a crisis can be characterised by three sets of conditions: those that are severe and largely unexpected threats, of high uncertainty and the need for urgency in the decision making. Thus came the need to develop contingency planning to encompass not only preparations for 'simple' or traditional risks, but for the unexpected,

unthinkable risks, which have now caused firms to pay more attention to supply chain security and disaster management.

2.4.3 Disaster Preparedness

As firms continue to pay more attention to supply chain security and the development of comprehensive disaster management processes, little help can be found in the logistics and supply chain management literature (Hale, Moberg 2005). According to Hale, Moberg (2005) a review of four top journals (Journal of Business Logistics, International Journal of Physical Distribution & Logistics Management, International Journal of Logistics Management and Supply Chain Management Review), in logistics and supply chain management since 2001 resulted in few academic articles on disaster planning with supply chains. Instead, logistics and supply chain managers must rely on information from the disaster management and emergency preparedness literature (Pelland 1997).

Much of the research on the disaster management field is targeted at public servants, government agencies and insurance firms which had the responsibility or responding in a crisis. The focus had traditionally been on hurricanes, earthquakes, flooding and fires. According to Hale, Moberg (2005), the models and guidelines in these fields can be applied to disaster management planning by firms within supply chains that have awakened to recent world events and are now confronted with new government regulations. One study by Richardson (1994) suggested that carriers needed to develop redundancy in their information, telecommunication and energy systems as part of their contingency plans for unplanned disasters.

After the September 11th terrorism attacks, the Council of Logistics Management sponsored research on securing the supply chains during a crisis and the recommendations made to logistics managers about implementing disaster management programmes included the FEMA Emergency Management Guide for Business and Industry which involved the three stages of planning, response and recovery. However, the model used by Hale and Moberg (Table 3) includes the mitigation and detection stages which were added by Helferich and Cook to provide a better fit for today's very complex environment. Mitigation is necessary to lessen the impact of disasters on supply chain continuity and the length of disruptions, while detection is there in the hope that disasters may be identified in a timelier manner (Hale, Moberg 2005).

According to De Tura *et al* (2004), the disaster recovery process is a continuous loop of planning, execution and feedback to refine and optimise the plan through each cycle. Without these elements the disaster recovery plan becomes either ineffective or quickly outdated. Thus, disaster Planning consists of activities, programs and systems developed prior to a catastrophic event that are used to support and enhance mitigation, response and continuity in the face of potential business disruptions (De Tura *et al* 2004).

Table 3: Disaster Management Process Overview

Planning	Mitigation	Detection	Response	Recovery
1. Establish a planning team	1. Define mitigation opportunities	1. Develop detection plan	1. Implement response plan	1. Review and implement recovery plans
2. Analyse capabilities and hazards	2. Develop mitigation plan	2. Acknowledge warnings	2. Evaluate direction & control	2. Ensure continuity of management
3. Develop the plan	3. Initiate development	3. Evaluate and act on observations	3. Evaluate communication	3. Maintain employee support
4. Implement the plan	4. Continuous improvement program	4. Decide on need for further action	4. Evaluate life safety	4. Resume operations
		5. Continuous improvement	5. Evaluate property protection	
			6. Evaluate public service	
			7. Evaluate community outreach	

Adapted from Hale & Moberg (2005)

Contingency planning and disaster preparedness form part of a crisis management strategy which will be discussed in the following section.

2.4.4 Crisis Management

Crisis management should be high on institutional and policy agenda as there is the need to give serious consideration to strong well-resourced and forward thinking contingency planning to gain control over a crisis when it happens (McConnell & Drennan 2006). As such, the key task for crisis managers and policy makers is to establish institutional procedures and create cultural climates which develop capacities to cope with whatever extraordinary threats come their way (McConnell & Drennan 2006).

There may be varying definitions of a crisis; crises will tend to be characterised by three sets of conditions: severe and largely unexpected threats, high uncertainty and the need for urgency in decision making (McConnell & Drennan 2006). There are no universal guides as to how organisations should prepare for a crisis. Rather, there are very broad definitions or guidelines which then need to be translated into 'good practice' (McConnell & Drennan 2006). Please refer to Appendix 1 for a sample of these guidelines developed by Perry and Lindell (2003) for pre-crisis planning. Boin and Lagadec (2000) (McConnell & Drennan 2006) have indicated however, that preparation is more than simply planning. It is about anticipation and developing strategies to ensure organisation resilience in the event that a crisis presents itself.

The key imperatives identified include:

- Being on the agenda of decision-making elites, raising awareness through workshops, simulations etc
- Organisations should facilitate resilience through systems for detecting weak and non-conventional signals, being able to process relevant information to and from central authorities, having the capacity for alertness and mobilisation of crisis units, being capable of relating technical matters to strategic issues in order to handle new types of crises, and promoting the capability of actors to deal with decentralised crisis situations
- Organisations being engaged in continuous efforts for preparation. These included continuously learning from experience, running tests and simulations to prepare for destabilising surprises, providing appropriate training, promoting learning within and across networks, personally involving organisational leaders in preparation, careful and progressive scheduling of preparatory efforts to avoid 'big bang' exhaustion, and ensuring that crisis management processes are embedded in core organisational processes

However, firms exhibit a varying approach to crisis management. The least prepared organisations tend to be dismissive of threats and have little or no contingency planning. Mid-range organisations give fair consideration to threats and the need to have plans to mitigate against them. However, their preparedness tends to be an 'add on' to what already exists. High preparedness organisations give high priority to threats and the need for contingency planning. Their crisis planning tends to be embedded in all aspects of organisation structures, practices, policies and culture (McConnell & Drennan 2006).

Many organisations have found it far from easy to get the financial support to implement crisis management strategies. Because crises are low probability events, contingency planning amounts to a demand for resource to cope with an event or events that may never happen (McConnell & Drennan 2006, Sheffi 2005). In the face of these events companies may suffer from a range of maladaptive behaviours stemming from bureaucratic policies, poor intelligence gathering and professing, cultural 'blind spots' or even an 'it couldn't happen here' mentality (McConnell & Drennan 2006), causing many organisations to suffer in the event of a disruption. However, in the post 9/11, even insurance companies are expecting both private and public sector companies to have contingency and business continuity plans.

A crisis can come in many forms as previously identified. Specific threats often require specific, measures to contain or quell them (McConnell & Drennan 2006), accordingly, different areas have taken a differing perspective in managing crises. Sweden takes the 'total defence' perspective, the UK takes the 'integrated emergency' perspective and the US and Australia take the 'all hazards planning' approach. The underlying philosophy in these however is that regardless of the type of disaster, shared planning and coordination should be the basis of the emergency preparedness (McConnell & Drennan 2006). There still exists the need to determine how organisations should be prepared for disruptive events.

2.4.5 Summary

The section presented the antecedents of business continuity and resilience which included disaster preparedness and contingency planning. It highlighted how the environment and thus the type of risks have changed and thus the risk management strategies that were used in the past are no longer applicable in the current business environment. The following section provides some information and definitions of Business Continuity Planning.

2.5 Business Continuity Planning

2.5.1 Introduction

While the previous section consisted of the antecedents of business continuity, this section will delve more into the field that is business continuity. This is considered important as resilience, as an evolving field, has borrowed some of the elements from this field.

2.5.2 Business Continuity

Today's challenging world is continually exposing many companies to challenges and risks that can seriously undermine the business at any time if they are not identified and addressed (Dawes 2004). These threats of course include fires, crime, terrorist activities, natural disaster, cyber crime and virus attacks and are possible, irrespective of company size, location or business sector, and these threats can come locally, nationally or internationally (Dawes 2004). So companies need to better understand how these risks have increased their vulnerabilities and to then allow them to take decisive action in addressing these issues (Dawes 2004).

Norrman & Jansson (2004) define business continuity as the development of strategies, plans and actions which provide protection or alternative modes of operation for those activities or business processes which, if they were to be interrupted, might otherwise bring about a seriously damaging or potentially fatal loss to the enterprise. Thus, BCP includes crisis management, disaster recovery, business recovery and contingency planning (Norrman & Jansson 2004).

Business continuity planning (BCP) means developing plans to be resilient (Rice & Caniato 2003). A lack of BCP can cause companies to experience serious financial loss (Zsidisin *et al* 2004, Elliott *et al* 1999). BCP, developed primarily by practitioners, was been adopted to deal with disruptions that are difficult to predict, but once they do occur have immediate and a catastrophic effect (Goldberg *et al*, 1999, Zsidisin *et al* 2004). Companies and communities with recovery plans are better poised to be up and running after a disruption with limited damage to their long-term success (Engle 2005).

BCP, a high-profile, mission–critical task, has supplanted disaster recovery planning which fell under the umbrella of building security or human resources (Rodetis 1999).

Elliott *et al* (1999) viewed BCP from a finance market perspective as 'Planning which identifies the organisation's exposure to internal and external threats and synthesising hard and soft assets to provide effective prevention and recovery for the organisation whilst maintaining competitive advantage and value system integrity. Goldberg, *et al* (1999) also said that BCP includes determining the potential risk business partners presented if they were not prepared to deal with disruptive events. BCP, by Shaw and Harrald (2004) was recognised as being a part of business continuity management which consists of business practices that allow firms to mitigate, prepare for, respond to, resume, recover, restore and transition form the disruptive event (Zsidisin *et al* 2004). As described by Rodetis, BCP is, at the heart, a form of risk management whose objectives were expressed as:

> 'To ensure that an organisation can mitigate and manage identified risks, maintain service continuity and integrity, retain business and customer confidence and protect their employees and fully recover in the event of a problem, failure or crisis.' (Dawes 2004)

Disaster Recovery Planning, the precursor to BCP focussed on tangible assets such as backing up data, securing copies and spare equipment off site and other techniques relying on redundancy (Rodetis 1999). BCP is not just focussed on IT. It encompasses projects, change programmes, logistics, outsourcing, quality supply chain management, health and safety, reputation and brand protection and people (Dawes 2004) and focusses on processes, networks, flows, procedures and affiliations essential for an organisation's survival and ongoing prosperity (Rodetis 1999). Close relationships with suppliers and customers have also become more important and as such BCP has now expanded to include relationships in the supply chain (Rodetis 1999). Besides the damage disasters and disruptions can cause other problems can include: relocation, repairs, regenerating lost data and replacing lost business income which all take time and money (Rodetis 1999). Intangible assets such as loss of market share, image and credibility, reduced customer satisfaction, lost research data or strained relationships with suppliers and customers can all be effects of being subject to disruptions (Rodetis 1999).

A business continuity programme outlines the steps to be taken to identify the risk of potential losses and develop recovery plans to ensure continuity of service (Hutchins 2006), it tends to include back up plans for key business processes and supporting infrastructure, employee safety and well being, management succession, communication, information technology, manufacturing and supply chain (Engle 2005). The steps in business continuity plan follows the framework of risk management and can be categorised into (Zsidisin *et al* 2004) risk identification, risk assessment, risk rankings and risk management

The Centre for Logistics and Supply Chain Management undertook exploratory research in the area of Supply Chain Vulnerability on behalf of the UK government's Department for Transport, Department of Trade and Industry (DTi) and The Home Office. Along with the conclusions drawn on the lack of research in the area of vulnerability and resilience the report also highlighted that many were unaware of the need to consider supply chain resilience as part of their approach to risk and business continuity (Christopher and Peck 2003), thus creating that link between supply chain risk, resilience and business continuity.

2.5.3 Resilient Organisations

There are a few definitions of resilience. According to Arminas (2004) resilience is the ability of a client and its suppliers to withstand major economic, political and natural disruptions.

A resilient organisation aligns strategy, operations, management systems, governance structures and decision support capabilities to uncover and adjust to continually changing risks, and to create advantages over less adaptive competitors *(*Starr *et al* 2003*)*. Establishing greater resilience has become necessary in this current economic and security environment which is a challenge to executives. The resilient organisation addresses risk across the external enterprise by increasing supply chain visibility (Mello 2001) and establishing transparency and controls for Boards and company to address issues such as improper fraudulent behaviours, IT infrastructure failures, disruptions and interdependent supply chain or customer channels, intellectual property theft, adverse economic conditions and other discontinuities *(*Starr *et al* 2003*)*.

Though senior executives have renewed their attention to conventional risk mitigation programmes, these are no longer applicable in the current networked global economy (Mitroff & Alpaslan 2003, Starr *et al* 2003). Risk management models have not kept pace with the shift from centralised to network organisations (Starr *et al* 2003). Though the organisational and economic impact of networks is well known, their vulnerabilities are largely unexplored by businesses (Svensson 2002, Peck 2005).

Resilience results from a planned series of safeguards against discontinuities encompassing everything from logistics, inventory control, and distribution channels to relations with government agencies, customer and suppliers. It better aligns risk management activity and spending with the most fundamental components of corporate strategy and performance: corporate growth and profit drivers, earnings consistency and shareholder value *(Starr et al 2003)*.

2.5.4 Summary

This section provided some information as to business continuity planning and management and gave a flavour to some of the key concepts and themes that are coming out of the study of supply chain resilience. This section also introduced the 'resilient organisation', mentioning what were some of the key characteristics required of organisations that work in the network environment. The following section provides the rationale for this body of research along with the research question.

2.6 Rationale for the Study

In 2001 the Centre for Logistics and Supply Chain Management undertook exploratory research in the area of Supply Chain Vulnerability on behalf of the UK government's Department for Transport, Department of Trade and Industry (DTi) and The Home Office. This study was prompted by the widespread economic disruption experienced by the fuel protests in September 2000 and the outbreak of Foot and Mouth Disease in February 2001. The aim of this study was to determine the state of knowledge within the industry on Supply Chain Vulnerability and where possible to identify the 'best practice' tools and approaches. The study found that in the UK public sector, the Emergency Planning and Management is a well established discipline (Christopher and Peck 2003). However, although issues of terrorist attack on infrastructure were dealt with at length, specific reference to disruptions to the supply chain were absent (Christopher and Peck 2003).

The report also highlighted some key points: that the primary sector companies have been aware of the need for crisis management and disaster recovery planning for some time, though this still remains primarily a single firm operation, that supply chain vulnerability and resilience lacked the necessary research base to comprehend the breath and importance of the subject, that many were unaware of the need to consider supply chain resilience as part of their approach to risk and business continuity (Christopher and Peck 2003).

Additionally, there is generally the lack of understanding of the wider supply/demand network amongst managers as many managers who manage supply chains are not really aware of the risk that their supply chains are opened to. While they may be aware of the threat due to wars, epidemic etc, they are less clear about the risk that exists within the supply/demand network (Christopher and Peck 2003). Peck has also highlighted that there exists a significant 'disconnect' in organisations between the determination of business strategy and the recognition of the impact of those strategic decisions upon supply chain vulnerability.

The above discussion makes clear that there still needs to be an increased understanding of supply chain risk, vulnerability and resilience. As such this body of research seeks to synthesis some of the previous work that has taken place in these areas as it attempts to answer the following questions:

Disruptive Risk Management: What makes supply chains resilient to low probability/high impact disruptions to the inbound and outbound aspects of the supply chain?

Essentially, the tenets that create a resilient supply chain are being investigated. To this end, the report identifies and examines:

1. Previous works within this discipline and others that have experience dealing with risk, vulnerability and mitigation of their effects.
2. What is supply chain resilience and what makes them resilient.

3. The various effects of disruptions on the inbound and outbound aspects of the supply chain.

The supporting questions included:

1. How are vulnerability and resilience related in the supply chain context?
    a. What are the definitions of a resilient supply chain and the global resilient supply chains?
    b. How do you create resilient supply chains?
    c. Is there a framework for resilient supply chains?
    d. Are resilient strategies the key approach to managing disruptions?
    e. How do you define vulnerability?
    f. Have the supply chain strategies such as single sourcing and lean manufacture truly made the supply chain more vulnerable to the types of risk under discussion? Are there other factors that cause systems to be vulnerable (besides lean strategies)?
    g. How were risk and vulnerability managed before the emergence of lean strategies and such other strategies?
2. What are resilience considerations for the inbound and outbound aspects of the supply chain?
3. How are Business Continuity and Supply Chain resilience related?

However, this body of research has two main aims. Firstly, it is to frame and answer a specific research question which has been described above. Secondly, it is intended to provide the research questions that will take the centre stage of the PhD.

2.7 Conclusion

A lot of work was covered in this chapter. The intention was to identify the problem and situate it in the wider research field. To that end it was highlighted that many companies need to understand the risks and disruptions that can potentially affect their supply chains. It was identified that the traditional or conventional risk management techniques were insufficient due to the network and extended nature of the supply chain and that a seeming key to be able to mitigate against these disruptions is through establishing a resilient supply chain. Additionally, this chapter gave insight into the 'foundation elements' or antecedents of business continuity and resilience such as crisis management and disaster preparedness. Finally, the review objectives which include the research questions and providing a basis to establish PhD questions from the review were presented.

The following section gives a full description of the methodology used to carry out the systematic review.

CHAPTER 3

3. METHODOLOGY

3.1 Introduction

The previous chapter provided the problem definition and located it in the relevant literature fields of supply chain management, supply chain risk and vulnerability and business continuity. This then lends to the discussion on how the research was carried out given the findings already obtained. Thus, this chapter describes the techniques and means by which the primary research data was gathered, sorted, assimilated, synthesised and then presented in its final format. The aim of the research and the techniques used can be considered to be comprehensive if not exhaustive (Finch 2004).

3.2 Benefits of the Systematic Review over the Traditional Review Process

The evidence-based approach has been adopted to address the disconnect between academic research and practice. The key stages to an evidence-based approach include turning a 'real world' problem into a research question; locating all existing research related to that problem; ascertaining the strength of the evidence; synthesising the information into a coherent whole; integrating the findings with practitioners knowledge and applying the knowledge base in practice (cranfieldonline.com).

Management research is considered to be a relatively young field and as such there tends to be little consensus on the formulation of the research questions and methods to synthesis (Tranfield *et al* 2003). Additionally, researchers' bias always plays a part in choosing what information or data is used and referenced. Researchers also tend to rely on quality ratings of particular journals rather than applying quality assessment criteria to individual articles and the data extraction process was often not comprehensively recorded or guided by explicitly chosen inclusion or exclusion criteria. The synthesis process tended to lack explicit descriptive and thematic analysis (Tranfield *et al* 2003). So the challenge was to develop a process that was rigorous, complete and transparent enough for the search and synthesis of information.

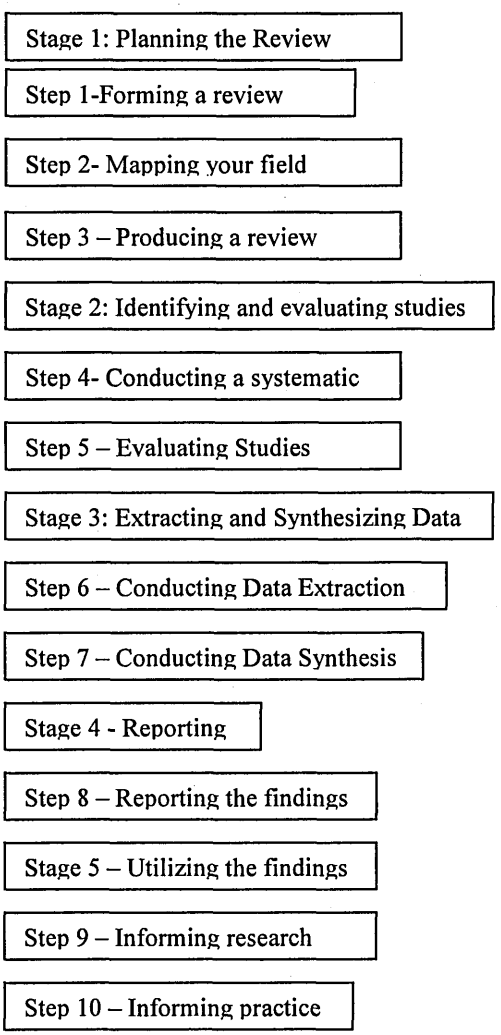
With this growing concern about the rigour and reliability of the process applied in the traditional literature review (Tranfield *et al* 2003); the systematic review process was borrowed from the field of medicine in an attempt to address this. A comprehensive, unbiased search is one of the fundamental differences between a traditional narrative review and a systematic review. The systematic review, now regarded as a scientific activity (Mulrow 1994, Tranfield *et al* 2003) built on the evidence based approach, sort to improve the quality of the review process by synthesising research in a systematic, transparent and reproducible manner. It is a detailed technology that aims to minimize bias through exhaustive literature searches of published and unpublished studies and by providing an audit trail of the reviewer's decisions, procedures and conclusions (Tranfield *et al* 2003). It has been argued to provide the most efficient and high quality method for identifying and evaluating extensive literatures (Mulrow 1994)

Following is a description of the protocol used to carry out the research. The protocol specifies the plan which the review will follow to identify, appraise and collate evidence (Boaz 2002). The protocol's main strength is to encourage the review to be explicit about how the review will be carried out and is useful in promoting transparency, transferability and replicability (Boaz 2002).

3.2.1 The Systematic Review Process

The systematic Review Process adopted to fulfill the needs as described above is identified in Figure 4 below.

Figure 4: Cranfield Systematic Review Process



Source: cranfieldonline.com

3.3 The Review Panel

During the MRes Review it was suggested that the review panel was too academic and Cranfield-focussed. That comment was taken on board and while it was the intention of the author to incorporate others beyond the realm of Cranfield University and the academic community, due to the lack of time it was not possible at this stage to communicate with others beyond the boundaries of the academic institution. The fact is though, that the area of supply chain risk and vulnerability is very much a new area and much of the work done and articles put forward thus far have originated from Cranfield! However, I do hope that these academic advisors will form the nucleus of what will become a larger, and more integrated, expert panel (Richardson 2005), (Table 4).

Dr. David Denyer provided great help in conceptualising and clarifying the form and direction of the dissertation. He shed light on how I should structure the systematic review. Ms. Heather Woodfield gave very clear guidance on the method of developing the key words, the search strings and performing the database searches. Both Ms. Woodfield and Dr. Denyer were absolutely instrumental in refining the scope of the eventual systematic review, clarifying what could reasonably be systematically researched given the very short timeframe with which I had to work. Without this guidance I would most certainly have been lost.

Table 4: Review Panel Members

Supervisor	Professor Richard Wilding Senior Lecturer, Cranfield School of Management
Library Support and other support	Ms. Heather Woodfield Cranfield University Library Dr. David Denyer Senior Research Fellow, Cranfield School of Management Dr. David Partington Senior Research Fellow, Cranfield School of Management
Academic Panel Members	Professor Alan Harris Senior Lecturer, Cranfield School of Management Professor Martin Christopher Professor of Marketing and Logistics Dr. Paul Chapman (was not on original expert panel) Lecturer, Cranfield School of Management Dr. Denyse Julien Senior Lecturer, School of Applied Science (SAS)

Source: The Author 2006

All the academic panel members recommended papers that should enrich the research information. They also contributed to:

- The way I thought of vulnerabilities, which should not be limited to disruptive events such as fires, terrorist attacks etc, but should include other dynamics such as new product development, innovation, and any other event that could cause a disruption to the supply chain
- Looking for the 'dissenting' voice in the literature.
- The understanding of resilience through the business continuity, or the supply chain perspective

3.4 Search Strategy

The purpose of the search strategy is to seek all relevant knowledge that informs the systematic review. While limitations exist, it is important that the researcher be able to attest, with a degree of confidence, that all reasonable avenues of information have been explored.

The research process was mainly facilitated by database searches. Considering the newness of this topic, virtually no core contributions came from the text books. Cross-referencing highlighted important references that fell outside of the database search process. The number of search approaches and sources used are described below.

3.4.1 Academic Databases

The academic databases provided most of the core research articles (Table 5). The rationale for the keywords was based on the effective mapping of the field and analysis during the scoping study and the key concepts in books and papers. Developing insightful and complete keywords and hence search strings was very much a challenge. This was due to the author's inexperience in developing search strings, and due to the newness of the field. The keywords chosen needed to examine the antecedents of the field to build an evolutionary picture of what now exists of supply chain vulnerability and resilience, hence the need for key words and search strings that not only focussed on resilience and vulnerability, but also included disaster management and business continuity.

Originally, the idea was to do an individual topic search (on advice from the panel) for supply chain, disaster management, contingency planning, resilience, vulnerability, lean and single sourcing, but these terms and phrases were generating thousands of responses which were just not manageable. The keywords for the topics were then linked to form search strings that allowed for depth of information, while providing a more manageable number of hits to investigate. Thus the final search strings were then developed through the scoping process, the key concepts in journal articles, and the refinements of the concepts and ideas with the panel. Table 6 provides the list of the keywords used and the rationale for inclusion in the search.

Table 5: Selected Electronic Databases

ABI ProQuest	For the vast amount of journals. If it is not covered here then it virtually will not be covered elsewhere. ABI ProQuest contains the most comprehensive writings and empirical research in operations and supply chain management
EBSCO Business Source Premier	Virtually all business related areas are covered in this area with some journals being related to operations management and supply chain management
Google Scholar	This website is proving to provide interesting information on the topic being researched. However, the number of articles found tends to be very high, but the first few pages are found to provide useful information
Science Direct	Recommended to possibly source articles that may not come up in ABI ProQuest and EBSCO

Source: The Author 2006

Table 6: Group of Keywords

Keywords	Rationale for inclusion in search
Supply Chain, Demand Chain, Logistics, Distribution, Production	The main area of research is within supply chain management; however the other terms were used before the concept of supply chain management rose in importance. In some instances these words are still being used.
Uncertainty, Risk, Vulnerability, Resilience, Flexibility	These key words were chosen since the research is centred around risk, vulnerability, uncertainty and resilience
Contingency Planning, Mitigation, Disaster Preparedness, Crisis Management, Management of Crises	These key words were identified as being associated with Business Continuity in the search databases. It is anticipated that in conjunction with the first set of keywords we should be able to identify how uncertainty mitigated in other fields
Inbound, outbound	These were chosen as a focal point of the area of research to the supply chain
Lean manufacture, JIT, Just in time, inventory management, inventory control, planning, single supplier, suppliers	Supply chain vulnerability is increased due to the use of some of these supply chain strategies

Source: The Author 2006

The keywords, when combined, formed four broad categories of resilience, vulnerability, disaster management and contingency planning. These then gave rise to a total of eight search strings as detailed below in Table 7.

Table 7: Search strings used in the electronic databases

Topic	Search String	Rationale for use of search string
Resilience	((Supply OR demand OR Logistics OR Distribution OR Production) AND (Chain or network)) and ((Resili* OR robust OR reliable OR (ultra reliable) OR flexib*))	This is a more general search string used to identify papers focussing on resilience, flexibility and reliability on supply chain and related areas.
	((Supply OR demand OR Logistics OR Distribution OR Production) AND (Chain or network)) AND ((Lean AND (thinking OR manufactur* OR produc*)) OR (just-in-time OR JIT) OR (Toyota production system OR TPS)) AND (Resili* OR robust OR reliable OR (ultra reliable) OR flexib*)	This was used to identify papers that express the effects of lean and related supply chain strategies on supply chain vulnerability
	((Supply OR demand OR Logistics OR Distribution OR Production) AND (Chain or network)) AND ((single AND (sourc* OR supply)) AND (Resili* OR robust OR reliable OR (ultra reliable) OR flexib*)	This was used to identify papers that express the effects of single sourcing and related supply chain strategies on supply chain vulnerability
Vulnerability	((Supply OR demand OR Logistics OR Distribution OR Production)) AND (Chain or network) AND (Vulnerab* OR risk OR exposure OR uncertain*)	This is intended to identify papers that relate vulnerability, risk and uncertainty with supply chain and related areas
	((Supply OR demand OR Logistics OR Distribution OR Production) AND (Chain or network)) AND ((Lean AND (thinking OR manufactur* OR produc*) OR (just-in-time OR JIT) OR (Toyota production system OR TPS)) AND ((Vulnerab* OR risk OR exposure OR uncertain*))	To identify how vulnerability, risk and uncertainty have been linked or related to the lean and related strategies on supply chain and related areas
	((Supply OR demand OR Logistics OR Distribution OR Production) AND (Chain or network)) AND ((single AND (sourc* OR supply)) AND (Vulnerab* OR risk OR exposure OR uncertain*)	To identify how vulnerability, risk and uncertainty have been linked or related to the single sourcing and related strategies on supply chain and related areas
Disaster Management	((Supply OR demand OR Logistics OR Distribution OR Production) AND (Chain or network)) AND ((Disaster OR crisis OR event OR catastrophe OR emergency) AND (preparedness OR management OR planning OR study))	This is intended to highlight or identify literature that has brought together disaster management in the supply chain and related areas. The intention also, was to highlight the impact of disaster management in the management of the supply chain
Contingency Planning	((Supply OR demand OR Logistics OR Distribution OR Production) AND (Chain or network)) AND (Contingency planning) OR (risk AND (mitigation OR avoidance OR removal))	This is intended to highlight or identify literature that has brought together contingency planning in the supply chain and related areas. The intention also, was to highlight the impact of contingency planning in the management of the supply chain

Source: The Author 2006

The more traditional electronic databases such as ABI ProQuest and EBSCO, and in most instances, Google Scholar, provided a manageable number of journals to peruse and, as such, the search was not restricted to title only searches. In the case of Google scholar, where the number of articles identified was overwhelming, it was decided to do the search on the first ten (10) pages since this database does not allow one to do the search on the title only, or the title and abstract only. For Science Direct however, a restriction was placed on the title only and title, abstract and keywords, since most of the search strings were yielding over 5000 articles each. Table 8 outlines the results from the search process.

Table 8: Electronic Database Search Results – No. of articles generated

Search Strings	1	2	3	4	5	6	7	8
ProQuest	1026	41	34	922	8	52	300	39
EBSCO	1401	47	53	1485	34	50	425	499
Science Direct	571	729	3731	1502	5	27	424	15
Google Scholar	14	2	7	22	0	21	101,000	7060

Source: The Author 2006

3.4.2 Books

As was evident from the scoping study, the area of supply chain risk, vulnerability and resilience for which the author was interested is yet to be covered in the supply chain literature texts. As such, the author did not rely on books to bring adequate definition to the topic. However, supply chain books were used for the theoretical underpinnings of supply chain strategy. Though topics such as Risk Management and Crisis Management are covered in books, the author hardly used those resources in this instance, relying mainly on papers that were identified through the academic databases.

3.4.3 Selected Journals

Journals formed the core of the research and were mainly sourced via the academic database search. Other journals and articles were recommended through the panel and through the cross referencing process. The top journals proved to be 'International Journal of Physical Distribution & Logistics Management', 'Supply Chain Management Review', the 'International Journal of Logistics Management' and the 'International Journal of Logistics'. The selection of the journals was based on the research activity, theoretical or conceptual information and the recommendation of the panel. However, the contributions of the last three journals were small in number which substantiates Hale and Moberg's (2005) findings, that the review of the four top journals in logistics and supply chain management since 2001, resulted in few academic articles on disaster

planning with supply chains. The following section summarises the number of articles contributed per journal.

3.4.4 Working Papers

In an attempt to cover all the bases a search of the Cranfield database for the working papers was performed. Eight papers with the general topic of Supply Chain Management were identified, of which none were relevant to the topic being researched. The list of papers held at the Birkbeck Library was also examined and this produced about four papers of which none were used as core review papers. Working papers were also sort through the Judge Business School Library, which is part of Cambridge University. This database tended to include works from UK institutions as well as other overseas academic institutions and other sources which include banks, government agencies. No papers were generated from these sources.

3.4.5 Theses

Nine theses were identified in the searches. While they were not used as part of the core literature in the study, they did contribute to either the form or structure of the report or provide further source of articles that formed part of the core research papers.

3.4.6 Other Sources

Reports from institutions such as the Cranfield Centre for Logistics and Supply Chain Management and from the MIT Center for Transportation and Logistics did provide a very rich source of information, especially since, for the moment, these two institutions are leading in the study and research in supply chain vulnerability and resilience, as well as in supply chain security. Though only one article each was obtained from each institution most of the authors that provided articles that formed the core research are from these institutions. No conference papers or unpublished papers were used to contribute to the main body of research.

3.5 Selection

The selection process proved to be very challenging and was thus a very iterative process. One of the major factors with research is to define its limits. As identified earlier, the area of supply chain vulnerability and resilience, in the context of low probability/high impact events is an unexplored, underdeveloped area. Therefore, the author was very open to finding whatever information was available in this subject area. Once an assessment of the information was made, the author was then more discriminating in the information and papers to be used for the systematic review to ensure that only high quality papers made it through to the final stage. These papers tended to focus on vulnerability and ways of conceptualising vulnerability, methods of and frameworks for increasing flexibility and agility, supply chain resilience, business continuity and supply

chain security and terrorism. These papers however, were not limited to the study of disruptive events to the supply side as authors still looked at developing generic frameworks.

3.5.1 Broad Selection Criteria

In actual fact, the author performed a double selection process. The first being on the titles and abstracts on the database, which, as illustrated in table 8, generated over 6000 articles. Appendix 2 gives the breakdown for this table. Numerous articles were rejected at this stage. The remaining articles were approximately three hundred and seventeen three (317) in number not including duplicates.

3.5.2 The selection stage

The titles and abstracts were further considered to determine which other articles could be eliminated. This was reduced to 167 articles which were then considered according to their full body content. This was done according to the inclusion and exclusion criteria (Tables 9 and 10).

Selection criteria for full text papers included:

1. Conceptual / theoretical papers must contain (Coelho 2005)
   - The aim of the model and relationship with existing theory and previous work
   - The assumptions of the model being developed
   - The variables use, parameters and equations must be clearly stated and defined
   - Its contribution to existing knowledge
   - Explicit proofs of the most important results and theorems
   - Possibly limitations of the research

The hope was that the papers would include the following, but this was not always evident:

- The implication of the finding to further research and/or industry
- The opportunity for further research

Risk Management and Disaster Management papers must include:

- Theoretical framework for the specific area

Table 9: Inclusion Criteria

Criteria	Rationale
Academic papers in scholarly journals, books, professional reports, conference proceedings and government reports	These form the most reliable source of field-specific data which are necessary to build the foundations of my research.
No geographical restrictions	Because of the scarcity of work in this area no geographical restrictions used, however, not withstanding though, that the studies thus far are located in the UK, Europe and the US.
Companies that are part of the global supply network	These companies tend to be much more affected by low probability/high impact events as: • Other network members may be affected which in turn will affect their business. • The transportation and communication lines may be severely affected • The government may impose measures that may affect their business.
Hi-technology companies	This is preferred due to the complexity in their global supply chain, but the research will not be limited to such company types.
Sectors	At the moment I am not sector specific as there isn't much information about. However, research so far has been mainly in the automotive industry (Sweden), aerospace (UK), chemical industry (US), defence (US)

Source: The Author 2006

2. Empirical Papers needed to provide (Coelho 2005):
   - A clear definition of the sample used (sectors included, nationality of the sample firms, descriptive characteristics such as size, distribution, etc)
   - A clear definition of the variables and methodologies employed
   - The relationship with exiting theory and previous work
   - Contribution to existing knowledge
   - Clearly state the empirical results and their significance. The paper must also provide a clear interpretation of the results in the context of the existing literature and relevant theory
   - The methodological shortcomings that may reduce the possibility to generalize from the results presented

The hope was that the papers would include the following, but this was not always evident:

- The implication of the finding to further research and/or industry
- The opportunity for further research

Table 10: Exclusion Criteria

Criteria	Rationale
Studies that use pre-1980 data are going to be excluded from the review	Supply Chain Management really came into being after this time, especially with the use of JIT and other strategies which are now showing that they make less resilient supply chains.
Studies that use pre-1995 data for risk management in the supply chain	The main body of research on Supply Chain Risk Management came after this time.
Non-English Papers	As there was insufficient resources to allow for a translation of such articles.
Supply Chain Management Papers that	• Focussed mainly on e-business • Focussed on traditional supply chain problems • Described frameworks and their application that did not have any bearing on my area of interest • Emphasised buyer-supplier relationships • Focussed on the economic cost of a disruption • Looked at managing demand risk • That focussed on fuzzy logic • Supply chain, risk management sustainable development • Focussed on remanufacturing • Focussed on Cyber attacks

Source: The Author 2006

3. Methodological Paper

Ideally the author would have preferred to include papers that considered the issues of how to construct a model or conduct appropriate statistical analysis or qualitative analyses. However, as empirical data in this field is sparse, all contributions, qualitative and quantitative, theoretical and empirical papers were considered.

The remaining articles, which were in the vicinity of one hundred (100), not including cross-referenced articles, or articles recommended by the panel, were then passed through the quality criteria which will be described in the following section. All the articles that were recommended by the panel and those that were obtained through cross-referencing did pass through the quality criteria.

3.6 The Quality Appraisal

It was not the intention to discount works on the basis of empirical methodology as the empirical work in the field is relatively scant. Thus contributions were assessed based on their theoretical contributions to understanding in the field. The author attempted to systematically and objectively appraise the papers, but felt that there was a cause for concern due to perceptions of the area, mindset and biases. This subjective fact was always a point of concern.

The quality criteria being measured included:

- Relevance[7] the work has to the field on enquiry.
- Theoretical and conceptual contributions[8]
- The research methodology[9] used.
- The data analysis process.
- Limitation and future research[10].
- Contribution, originality, appropriateness and significance.

Each criterion as described was ranked on scale between one and five, where one represents the poorest response and five represents an excellent response. From this three levels of papers were established, those that were accepted, those that were rejected, and those that could be used as reference papers in other parts of the report. These papers did not necessarily contribute anything new, or they probably were neither theoretically or methodologically sound, but did make some contributions to the thinking process. Please refer to Appendix 5 for further details on how the scoring system was operationalized.

3.7 Data Extraction

Descriptive information was extracted from the 148 articles (including the cross referenced articles and articles recommended by the panel) that passed through the inclusion and exclusion criteria. This information, which was stored on the Excel spreadsheet included the Author, Title, Journal Name, Source (database, panel recommendation, researcher recommendation, reference recommendation), Themes (Supply Chain Management, Resilience, Agility), Country, Service context/industry, Research Category (empirical theoretical), Sample Size and comments. Articles that pass the quality criteria were transferred to the Procite database in accordance with the work form as shown in Table 11. The notes and coding of the papers at this stage formed the basis for the synthesis of the information later in the review.

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[7] Of the data sources selected through the inclusion/exclusion criteria some will be more relevant than others. In essence this is what will be rated.

[8] Theoretical and conceptual contributions made in the area of supply chain risk and vulnerability, supply chain flexibility, resilience and security.

[9] A consideration of the research methodology used, not with a view of discounting the work, but rather with the view of examining its appropriateness of use

[10] It was preferred that the paper included limitations of the study and possible areas of future research as this shows an understanding and appreciation that there is still a lot of work or research to be covered in the area.

Table 11: Data Extraction Form

Author of Article:
Title of Article:
Journal Title:
Date of Publication:
Volume:
Month or season:
Part:
Page Numbers:
Empirical or Theoretical?
Where was the study located?
What was the context/industry?
What was the sample size?
Method of data collection:
Method of data analysis (quantitative/qualitative):
Study Characteristics:
Quality assessment 1/Relevance to review: (Score 1 – 5):
Quality assessment 2/Contribution to theoretical and/ or conceptual understanding: (Score 1 – 5):
Quality assessment 3/Research Methodology (Score 1 – 5):
Quality assessment 4/Data analysis process (Score 1 – 5):
Quality assessment 5/Limitations of study (Score 1 – 5):
Quality assessment 6/Significance of research (Score 1 – 5):
Include Yes/No:
Reason for exclusion:
Key Findings:
Short Abstract:
Keywords:

3.8 Data Synthesis

In retrospect, this would have been an ideal opportunity to use the QSR NVivo software to create a thematic structure, but due to the limitation of time it was not possible to restart and code all the papers to build the information inductively. Hence the author utilised the technique of mind mapping to capture and represent the information. Buzan (1993) describes the mind map as an expression of Radiant Thinking and is thus a natural function of the human mind.

The gathering, collation and synthesis of the information was very much an incremental and iterative process. Maps were created to represent the main areas of concern and findings for risk, supply chain risk, flexibility, agility, vulnerability, disruptive risk, disruptive risk events and resilience. This allowed the data to take its own form, though, based on the author's understanding; the maps were built from the articles found, and thus were a useful mechanism for understanding the totality and the nature of the evidence in the field (Richardson 2005). It also provided the framework for presentation of the findings in the review (Richardson 2005). This was extremely helpful in linking information and concepts in the final synthesis and writing-up stage.

3.9 Conclusion

This chapter provided, with some detail, the methodology used to generate the primary research papers used for this analysis. The search strategy and search stings were detailed, the inclusion and exclusion criteria were discussed and the quality appraisal system was presented. Finally, the data extraction and synthesis stages were outlined.

The following chapter is the first of three that discusses the findings derived from the primary research papers. Chapter 4 presents a descriptive analysis of the papers used in the review and thus will cover elements such as the years of research, the geography concentration of the research papers, the main authors and journals that have contributed to the research, and other such information.

CHAPTER 4

4. DESCRIPTIVE RESULTS

4.1 Introduction

The methodology used to generate the findings was presented in some amount of detail in the last chapter. That chapter covered the search strategy employed, the selection criteria, the quality appraisal as well as the data extraction and synthesis stages.

This chapter is the first of three that synthesizes and presents the findings. According to (Tranfield *et al* 2003), a good trait of the systematic review is to make it easier for the practitioner to understand the research by synthesising the extensive primary research papers that were derived. Thus the descriptive analysis gives a detailed review of the papers used for the analysis. This data was gathered as part of the data extraction process and provides useful insight into the field.

4.2 Descriptions

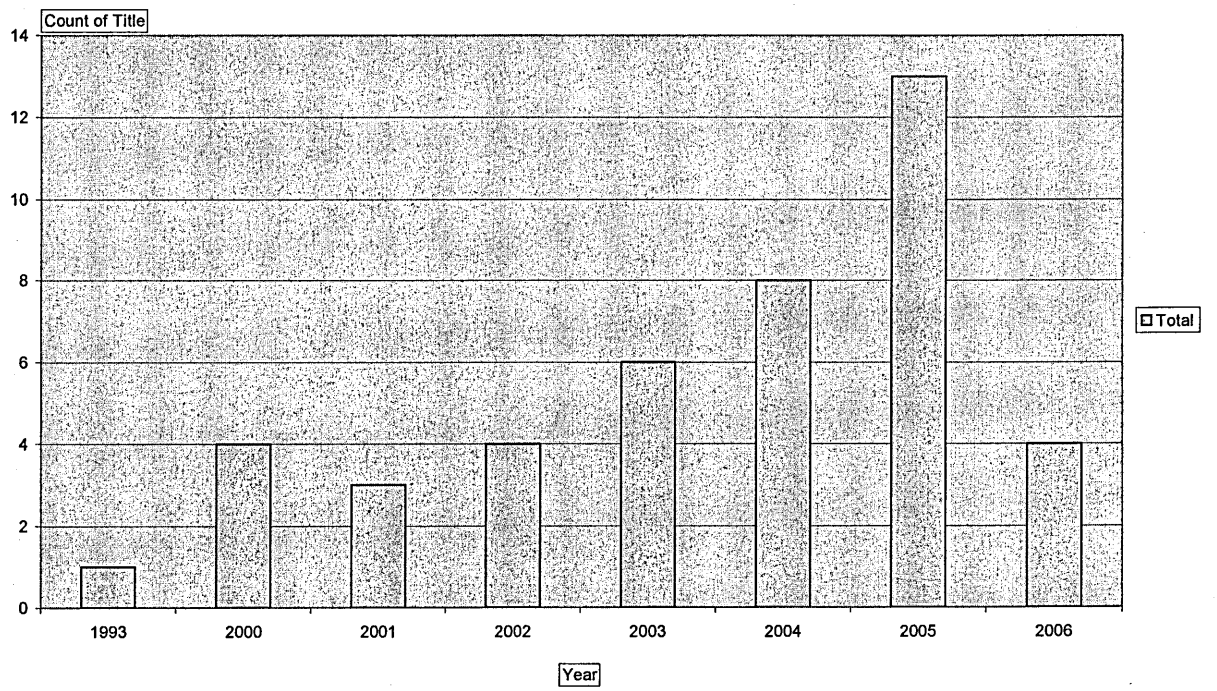
4.2.1 Age Profile of Articles

Table 12: Age Profile of Articles

Year	Count
1993	1
2000	4
2001	3
2002	4
2003	6
2004	8
2005	13
2006	4
Grand Total	**43**

Source: The Author 2006

Table 12 highlights a few points. The research does not date back beyond 1993. One relevant paper is produced in 1993 and the next relevant paper was produced in 2000. This confirms what previous authors have written, that supply chain risk, vulnerability and resilience are relatively new fields, and thus, there is a paucity of research in those areas. Though there is a decline in 2001, the published papers have progressed steadily from 2000 to 2005. The low rating in 2006 could be due to the fact that this is the current year and researchers and authors have not completed publishing for the year. Please refer to Figure 5 for a graphical representation of the results.



Source: The Author 2006

Figure 5: Age Profile of Articles

4.2.2 Distribution of papers according to journals

Table 13 shows that the International Journal of Physical Distribution & Logistics Management is the journal that provided most of the academic articles. International Journal of Logistics and the International Journal of Logistics Management were distant seconds, with each providing three core articles each. The International Journal of Agile Management Systems, the International Journal of Production Research, Supply Chain Management Review, and the MIT Sloan Management Review provided two core articles each.

Table 13: Distribution of papers according to journals

Journal	Count
Bell Labs Technical Journal	1
Chief Executive	1
Computers in Industry	1
Ecosystems	1
Financial Times	1
Harvard Business Review	1
Industrial Management & Data Systems	1
Industrial Marketing Management	1
Industry Week	1
Information Systems Management	1
International Journal of Agile Management Systems	2
International Journal of Logistics	3
International Journal of Operations & Production Management	1
International Journal of Physical Distribution & Logistics Management	7
International Journal of Production Research	2
Journal of Corporate Real Estate	1
Management Science	1
MIT Center for Transportation and Logistics	1
MIT Sloan Management Review	2
Production and Operations Management	1
Report produced by the CLSM for department of transport	1
Risk Management	1
Supply Chain Management Review	2
Supply Chain Management: An International Journal	1
The International Journal of Logistics Management	3
Thunderbird International Business Review	1
Unpublished paper	1
World Trade	1
www.exel.com	1
Grand Total	**43**

Source: The Author 2006

4.2.3 Key contributing authors

Table 14 shows that the key contributing authors are Martin Christopher, Helen Peck, Yossi Sheffi, James Rice Jr. and Goran Svensson. Thus, most of the research thus far has originated from the institutions for which they are affiliated and includes the Centre for Logistics and Supply Chain Management, Cranfield University, UK; the MIT Center for Transportation & Logistics, USA and Vaxjo University, Sweden.

Table 14: Key Contributing Authors

Author	Count
Bundschuh et al	1
Carpenter, et al	1
Chopra, Sunil & Sodhi, ManMohan	1
Christopher, M	2
Christopher, M	1
Christopher, M & Peck, H	1
Cranfield CLSM	1
De Tura, N et al	1
Drickhamer, D	1
Duclos et al	1
Ferris, G	1
Finch, P	1
Foster, S & Dye, K	1
Hale, T & Moberg, C	1
Juttner, U	1
Juttner, U, Peck, H & Christopher, M	1
King, J	1
Kleindorfer, P. & Saad, G	1
Lee, H	1
Lummus, R et al	1
Martha, J & Subbakrishna	1
Mason-Jones, R et al	1
Norrman, A & Janssonm U	1
Peck, H	1
Peck, H	1
Prater et al	1
Rice Jr., J & Caniato, F	1
Rice, Jr J	1
Sheffi, Y	3
Sheffi, Y & Rice Jr, J	1
Svensson , G	4
Tan, W & Enderwick, P	1
Tang, C	1
Tomlin, B	1
van Hoek, R	1
Wu, T et al	1
Zsidisin, G et al	1
Grand Total	**43**

Source: The Author 2006

4.2.4 Geographical Influence

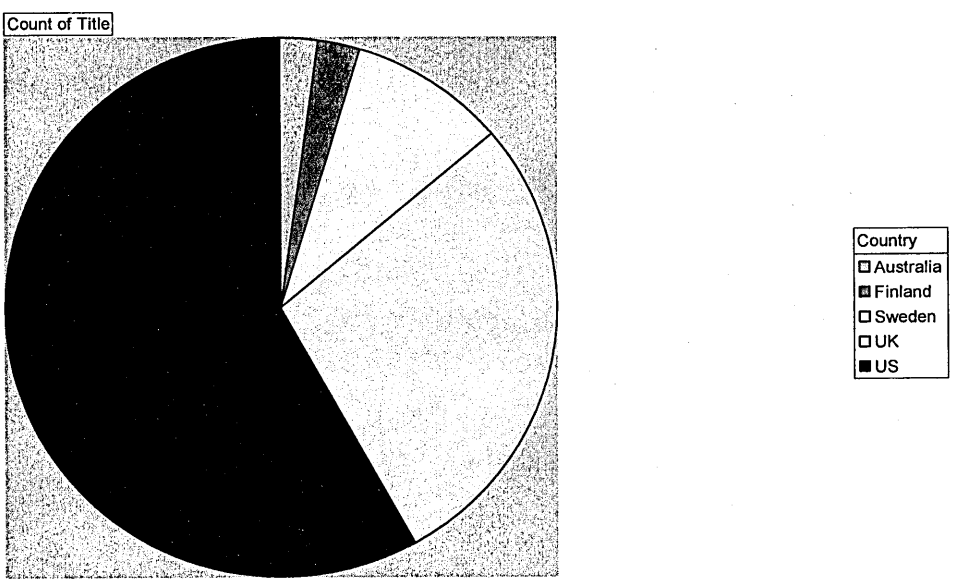
The results represented in Table 15 and Figure 6 make it clear that most of the research is out of the US with the UK being a distant second.

Table 15: Geographical Influence

Country	Count
Australia	1
Finland	1
Sweden	4
UK	12
US	25
Grand Total	**43**

Source: The Author 2006

Figure 6: Geographical Influence



Source: The Author 2006

4.2.5 Sectoral categorisation

No sector is mainly represented (Table 16). This may be attributed to the newness of the field and the need for more empirical research. The sector with the most research was the

automotive industry. This can be attributed to Goran Svensson and his work in Sweden in understanding and conceptualising the vulnerability constructs.

Table 16: Sectoral Categorisation

Sector	Count
Aerospace	1
Aerospace and other industries	1
All Industries	1
Automotive	4
Computer	1
Corporate Real Estate and Workplace Resources, Energy, Financial Services, Technology, Telecom	1
Electronics	1
Financial	1
General	24
Health, Tourism, others	1
Industrial, consumer and service industries	1
Not specified	1
Telecommunication	1
Varying	4
Grand Total	**43**

Source: The Author 2006

4.2.6 Method of analysis

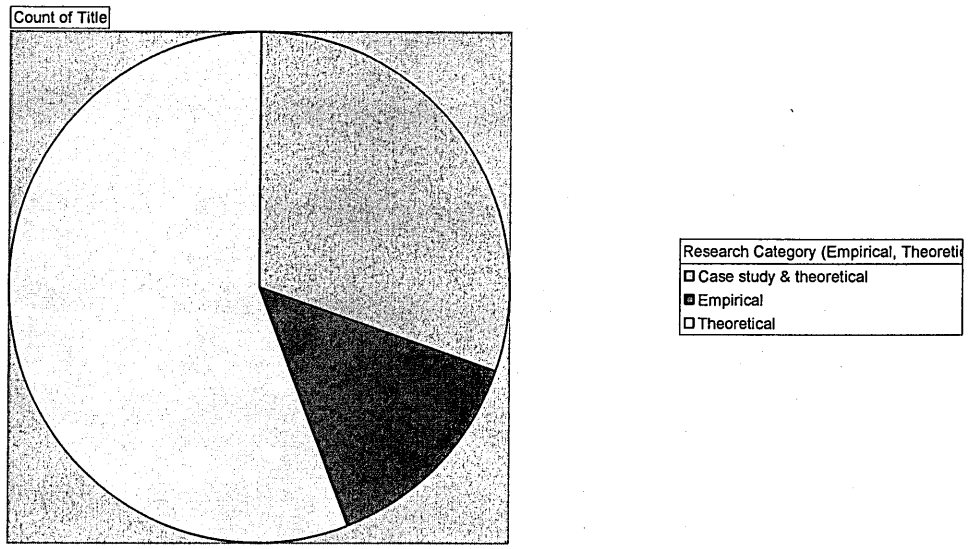
The results show that most of the research is still theoretical, thus indicating that there is ample scope for empirical research (Table 17). For the purposes of this analysis, the case study research was counted separately from empirical research which tended to be more quantitative (Figure 7).

Table 17: Method of Analysis

Research Method	Count
Case study & theoretical	13
Empirical	6
Theoretical	24
Grand Total	**43**

Source: The Author 2006

Figure 7: Method of Analysis



Source: The Author 2006

4.3 Conclusion

In the previous section we looked at the descriptive findings which indicated a few things:

- That the study of supply chain risk, disruptive risk, vulnerability and resilience are relatively new areas of research and thus there has been a steady increase in research and articles from 1993 to the present. This did also indicate that the major contributions were made post 2000 and hardly before 1993.
- The major contributing journal was the *International Journal of Physical Distribution & Logistics Management.*
- Very little empirical work has been done and thus most of the research is still theoretical or conceptual in nature
- Most of the work is coming either out of the US or the UK

The following chapter will discuss the various aspects of disruptions. It looks at the crucial area of supply chain vulnerability and how to create resilience through the concepts of flexibility, redundancy, agility, strategy and culture. The chapter also presents findings in relation to resilience by failure mode analysis, Business Continuity, Disruption Risk Management, Supply Chain Risk Management and the overlap in the development of secure and resilient supply chains.

CHAPTER 5

5. THEMATIC FINDINGS

5.1 Introduction

The previous chapter presented a description of the primary research articles that were used for this analysis. Some key points to note is the newness of this field as illustrated by the age profile of the papers found, the lack of empirical research and the concentration of either Cranfield University, the MIT Center for Transportation and Logistics and Vaxjo University.

This chapter can be considered to be core to the research as it seeks to examine and present the findings on:

- Supply chain disruptions and stages of a disruption
- The various facts of vulnerability including the categorisations, drivers, constructs and dimensions of vulnerability
- Supply chain resilience and the perspective of various authors on how to create a resilient supply chain
- The framework for creating a flexible supply chain
- Business continuity and its relationship with supply chain resilience
- A description of disruption risk management
- A brief description of Supply Chain Risk Management
- The similarities in creating a secure and resilient supply chain.

5.2 Disruptions

5.2.1 Introduction

This section introduces the categorisation of the supply chain and thus how this is linked to supply, internal and demand disruptions. It also introduces the concept of the various stages of a disruption.

5.2.2 Supply Chain Disruptions

Disruptions can occur at any part of the supply chain. However, the supply chain is often divided into three main categories: the inbound or supply side, the internal processes, and the outbound or customer-facing side. Firstly however, events such as SARs and similar pathological disruptions, global terrorism, computer viruses etc were identified as uncertainties,[11] not risks,[12] as they cannot be anticipated; they change form and evolve,

[11] An uncertainty is considered to exist when there is no understanding of even the distribution of the potential outcome (Wei-Jiat & Enderwick 2006)

and do not simply recur. Additionally, the impact of these uncertainties tends to be concentrated either by sector or by geological location. Thus, the author considers uncertainties to give rise to disruptive events which can be distinguished from risk that occurs from normal supply-demand coordination risks, since this has been extensively covered in the supply chain management literature in general and the literature on supply chain contracting in particular, which tended to be mainly concerned with the on-going volume and earnings risks associated with coordinating demand and supply of multiple supply actors (Kleindorfer, Saad 2005).

5.2.3 Stages of a Disruption

According to Sheffi, the stages of a disruption and the dynamics of the company response can be characterised by the following eight phases (Figure 8):

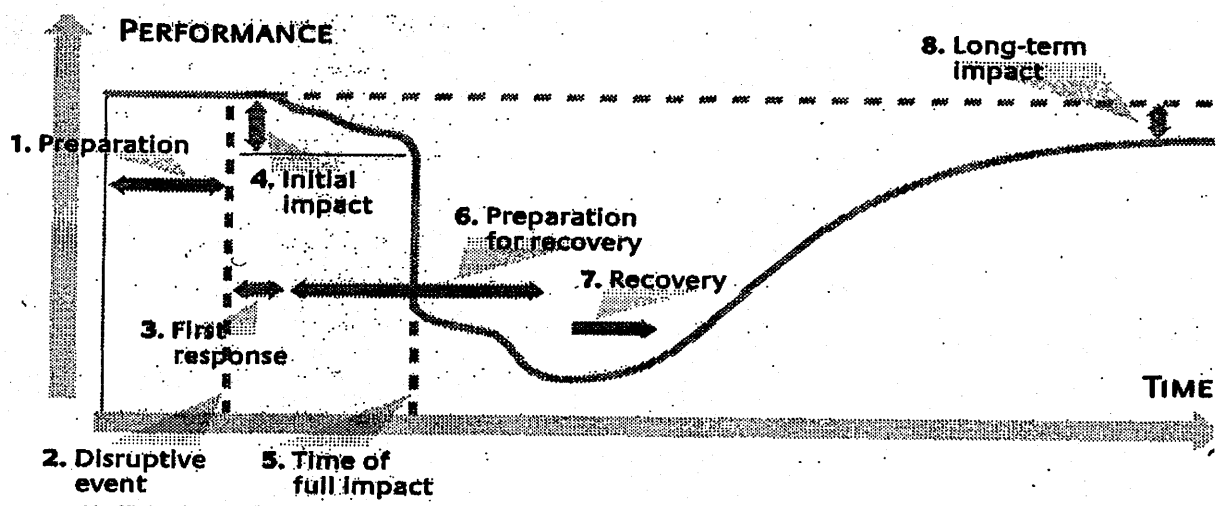
1. The preparation stage, where the company foresees the disruption and minimises its effect (Sheffi & Rice 2005). For storms and hurricanes there may be a preparation time of some days, for industrial disputes the warning time may be some months, but in the instance of terrorist attacks such as the London bombings in July 2005, there is virtually no preparation or warning time.
2. The disruptive event which is the actual event itself such as an explosion, when the hurricane hits or the beginning of a strike.
3. The first response aimed at controlling the situation, saving or protecting lives, shutting down affected systems and preventing further damage.
4. Some disruptions take a time to affect the company. In this delayed response or initial impact the performance of the company usually starts to deteriorate.
5. With the full impact there is the dropping off of performance.
6. The recovery preparations which often start in parallel with the first response. This may involve redirecting the suppliers' source (Sheffi & Rice 2005), finding alternative transport modes (Sheffi & Rice 2005) or alternative suppliers (Tomlin 2006).
7. The recovery phase is often marked by companies trying to make up for lost production by working overtime (Sheffi & Rice 2005), or using suppliers' or customers' resources (Tomlin 2006, Sheffi & Rice 2005).
8. The long-term impact could occur if the relationship is so critically damaged that the company loses its customers (Sheffi & Rice 2005). However, the long term impact can also be positive where there is an increase in the market share as was the case with Nokia that was able to capitalise on the situation, and losses to Ericsson that came about with the fire at the Philip's factory.

[12] Wei-Jiat & Enderwick defined risk as the variation in potential outcomes to which an association probability can be assigned (Wei-Jiat & Enderwick 2006)

5.2.4 Summary

While this section discussed where disruptions can occur and how they are phased, the following section goes in-depth in the discussion of vulnerability considering the sources, categorisation and dimensions of it.

Figure 8: Disruption Profile



Source: Sheffi & Rice 2005

5.3 Supply Chain Vulnerability

5.3.1 Introduction

The disruptions companies experience can be attributed to their size, scope and structure, that is, the extent to which they are connected to the world and therefore the events throughout it (Sheffi 2005b). The Kobe earthquake also demonstrated the connectivity of the global industry. Many companies that had factories in Kobe, such as Procter & Gamble, Caterpillar, and IBM were directly affected by the earthquake, however, many suppliers to multinationals companies, even those without companies in Kobe, also felt the impact. Apple had to slow down its production of PowerBook computers as a result of the interrupted production of display monitors in Kobe.

While the likelihood of any one event may be small, the collective impact that any one of the vulnerabilities can occur at any part of the supply chain, is high (Sheffi 2005a). Thus, as General Motors (GM) did, companies need to collect the information across the vastness of the business or supply chain to have a full picture of the vulnerabilities which the supply chain is subject to (Sheffi 2005a). This section seeks to describe the categorisation, sources and dimensions of vulnerability.

5.3.2 Categorising Disruptions and Vulnerability

Figure 8 attempts to capture the various categories of disruptions. Sheffi (2005a) has categorised vulnerability into three main groups, natural disasters, accidents and intentional disruptions, which all require a different course of action or attention. These categories vary in the roles human beings and random factors play in their cause and thus the way of estimating their likelihood of occurrence will differ.

Natural disasters such as floods, earthquake, lightning strikes and tornadoes for disaster prone areas tend to be frequent and this can be statistically modelled to estimate their likelihood of occurrence and magnitude. Such is the case where the US Geological Survey is able to estimate the areas that are most susceptible to earthquakes in the United States. Accidents, such as fires and explosions can be analysed and assessed through the analysis of near miss incidents. Planning for and reducing these incidents is a way of reducing the accident rate and eliminating severe accidents (Sheffi 2005a).

Intentional disruptions, which can be broken down into terrorist and non-terrorist events, are quite difficult to plan for, as those involved seek to ensure that the attacks are successful and that the damage is to its maximum. Non-terrorist events include labour strikes, such as the Longshoreman's and Warehouse Union strike in summer 2002, which staged a work slowdown in the pacific coast ports to hamper shipments from Southeast Asia before the holiday shopping season in the US, and the plan by Britain's Transport and General Workers' Union to strike against the country's biggest ports at the start of the Christmas season (Sheffi 2005a). Terrorist activity includes the bombing of the World Trade Center in September 2001 and the attacks in London in July 2005. In the first two categories companies are better able to estimate or assess the likelihood of the random disruptions occurring, but this is not the case in the third category as these attacks adapt to defensive measures (Sheffi 2005b).

Other disruptions include pathological disruptions such as those due to SARs and Avian Flu in Asia, and Foot and Mouth disease in the UK (Staples 2006). Supply disruptions do not necessarily have to be from the first tier supplier, but can come from the second or third tier supplier, for example, GM experienced disruptions when a chemical spill at a chip plant shut down production of a second tier supplier. Supply disruptions could also be due to tight capacity or shortages such as the steel shortage that caused Nissan to suspend operations in three of its four Japanese plants. Power shortages and loss of phone lines can all affect the inbound or supply side of the chain.

Events can cause internal disruptions, for example, the tornado that hit the GM assembly plant at Oklahoma City in 2003 caused second quarter losses of $140 - $200 million related to lost production (Sheffi 2005a). The bombing of the World Trade Center and the loss of life is another example of an internal disruption. Besides the human toll there is the loss of relationships with employees, customers and suppliers that may be crucial to recovery. The use of IT also causes vulnerability to computer viruses, software problems, cyber attacks (Warren & Hutchinson 2000, Haimes & Longstaff 2002), information theft (Price 2004) and other technical outages. Disruptions in demand can be

as a result of massive unexpected declines in demand for products and services due to technical changes, competitors, disruption to major customers or a sudden loss of customer confidence (Sheffi 2005a), or new product development (McDermott & Handfield 2000).

However, assessing the probability of failure in the supply chain requires information that is not normally available to managers and often enough; companies do not have the formal processes for anticipating disruptions and estimating their likelihood. Those companies that do have that information still rely on the manager's subjective estimates, which then tend to be a relative ranking in terms of their likelihood. This manner of estimating the likelihood and effect of specific disruptions then means that focus should be placed on redundancy and flexibility measures (Sheffi 2005a).

5.3.3 Drivers of Supply Chain Vulnerability

An exploratory case study of commercial supply chains engaged in the manufacture and assembly of high performance military aircraft was carried out to provide insight to improve the resilience of the nation's supply chain networks (Peck 2005). When asked to identify the sources of risk, the aerospace managers did not refer to low probability/high impact events such as earthquakes or terrorist attacks, but rather made reference to consequential risks[13] arising from specific managerial decisions, requirements or industry trends. The sources of risk identified in the case study included shorter lead times. Outsourcing and increasing use of global sourcing and supply all contributed to uncertainty (Peck 2005). Regulatory changes as well as managing across legal, cultural environments made the setting for supply chain management a lot more difficult. However, through works with the aerospace industry, the sources and drivers of supply chain risk operating at several different levels were identified.

Level 1 – the value stream/product or process

Vulnerability can be examined at the value stream, product or process level. Ideally there should be the perfect flow of information and materials with partners thinking and acting as one – all to attain an efficient, value based design and management of processes. The risk extends to the financial and commercial consequences of inefficiencies or sub-optimal supply chain performance

Level 2 – assets and infrastructure dependencies

The supply chain is seen in terms of the assets and infrastructure required to carry goods and information flow in level 1. The nodes represent the fixed commercial assets, sites or facilities as well as IT assets such as hardware, communications and service centres. The facilities and commercial assets are connected to national and international communication infrastructure e.g. cables, radio mast and satellites through nodes and links. They are also connected to transportation and distribution infrastructure such as pipelines, power grids, roads, rails, waterways through nodes and links as well as the mobile assets such as trucks, trains, boats and planes. Resilience at this stage should be

[13] Consequential risks are risks that are anticipated side-effects to the supply chain processes, arising from specific managerial decision, requirements or industry trends (Peck 2005)

assessed according to the loss of the links, nodes and other essential operation assets and skilled workers.

Level 3 – organisation and inter-organisational networks

At this level the supply chain is viewed as an inter-organisation network. Hence supply chain vulnerability is moved to the level of corporate risk management, business strategy and microeconomics. The nodes are the organisation, commercial and public sector. It is necessary, or rather it is the hope, that the strong organisations do not abuse their power and dominate the weaker ones.

Level 4 – the environment

The environment consists of the wider macroeconomic and natural environment within which the organisations do business. Political, economic, social and technological elements of the operating environment and the geological, meteorological and pathological phenomena are all factors that need to be considered. Disruptions at this level may be beyond the direct control of the supply chain managers and the business strategist.

5.3.4 Vulnerability Constructs

To answer the question 'What makes supply chains resilient?' then one needs to consider what are the risks involved and what makes supply chains vulnerable. According to Svensson (2004), research of the vulnerability construct in the supply chain is limited. Considering that vulnerability was an unexplored concept that lacked conceptualisation and had an unclear and ambiguous meaning, Svensson (2000), Svensson set out to develop a framework for analysis of vulnerability in supply chains. This model consisted of three principal components, source of disturbance, category of disturbance and the type of logistics flow. This conceptual framework however (Figure 9), was limited to the inbound logistic flow of vehicle manufacturers. The conceptual framework for the analysis of vulnerability in the supply chain and the model for the analysis of vulnerability consist of the following components:

Source disturbance, consisting of atomistic and holistic sources of disturbance. Atomistic sources of disturbance deal with the direct cause of disturbance which can include the first-tier subcontractor or transport. The components and materials are general in nature, of low value and not complex. Holistic sources have an overall perspective, dealing with indirect sources that may affect the supply chain between the first-tier sub-contractor and the manufacturer, which may include second tier as well as other subcontractors. The components and materials tend to be of high value, complex and rare.

Category of disturbance which is subdivided into quantitative and qualitative disturbances. The quantitative disturbance emanates from sources of deviation that leads to stock-outs, a lack of availability or volumes in the inbound logistics flow of materials in the supply chain and delays and breakdowns which for example, can be contributed to poor transportation. A qualitative disturbance comes from sources of deviation that lead

to a lack is accuracy, reliability and precision of the components and material in the supply chain.

The type of logistics flow which looks at their complexity, inventory buffers, materials and components.

The outcome of the model presents four vulnerability scenarios that are based on the three components in the model.

As earlier indicated by Svensson, most of the inventory management and production planning in supply chain management was carried out under normal conditions, not taking into account that unplanned events that disrupt the supply chain can occur. Thus this framework allows the company to consider or examine the source of disturbance for the first tier suppliers and the second and other tier suppliers.

Figure 9: A Conceptual framework for the analysis of vulnerability in supply chains

		Categories of disturbance	
		Quantitative	*Qualitative*
Source of disturbance	*Atomistic*	Quantomistic	Qualitomistic
	Holistic	Quantolistic	Qualitolistic

Source: Svensson 2000

In 2002, Svensson introduced a different conceptual framework for the vulnerability construct that consists of two components: disturbance,[14] and the negative consequence of disturbance[15]. The intention was to determine how the vulnerability in the firms' inbound and outbound logistics flow can be conceptualised, measured and evaluated.

Svensson, in the case of analysing the Swedish automotive industry, realised that there seemed to be a potential association between the existence of vulnerability in the inbound and outbound logistics flow (Svensson 2002). The inbound and outbound vulnerability in logistics flows appeared to be closely related to the potential occurrence of disturbances in supply chains, and the impact of these disturbances in the firms' performances is also a crucial feature of inbound and outbound vulnerability.

[14] A disturbance is defined as a random quantitative or qualitative deviation from what is normal and expected (Svensson 2002)

[15] A negative consequence of disturbance refers to a deteriorated goal accomplishment in terms of economic costs, quantitative deviations – such as increase cycle times and down times – and qualitative deviations (Svensson 2002)

It is proposed that the vulnerability in the inbound logistics that flows from the sub-contractor, and the vulnerability in the outbound logistics that flows to customers may be measured and evaluated by four principal dimensions, service level – the absence of disturbances, i.e. the degree of reliability in the firms inbound and outbound flows, deviation – the presence of disturbances and the degree of non-reliability in the inbound and the outbound flows, consequence – the negative consequence of disturbances, i.e. the degree of negative impact in the firms inbound and outbound logistics flows and trend – the direction in change in terms of the occurrence of disturbances in the firms' inbound and outbound logistics flows. This was to measure and evaluate vulnerability in the inbound and outbound flows. Hence the dimensions of service level and deviation contribute to the estimation of the disturbance in the vulnerability construct, while the dimension of consequence contributes to the estimate of the negative consequence of disturbance and the trend dimension provides an estimation of disturbance issues (Svensson 2002).

Again in 2002, Svensson developed another conceptual framework for the vulnerability construct based upon time-dependence and relational-dependence (Figure 10), where time-dependence refers to sequential-dependence between business activities in supply chain, while relational-dependence refers to the interaction process between business activities in supply chains (Svensson 2004) (Table 18).

Figure 10: A Conceptual framework for the analysis of vulnerability in supply chains

		Relationship dependence	
		Low	*High*
Time-dependence	*Low*	Dynamic Vulnerability	Elastic Vulnerability
	High	Non-elastic Vulnerability	Static Vulnerability

Source: Svensson 2002

In 2004, the research focussed on the construct of corporate vulnerability in supply chain that consists of three components, time-dependence, functional-dependence and relational-dependence in companies upstream and downstream the supply chain.

Table 18: Managerial implications based upon the lessons learned

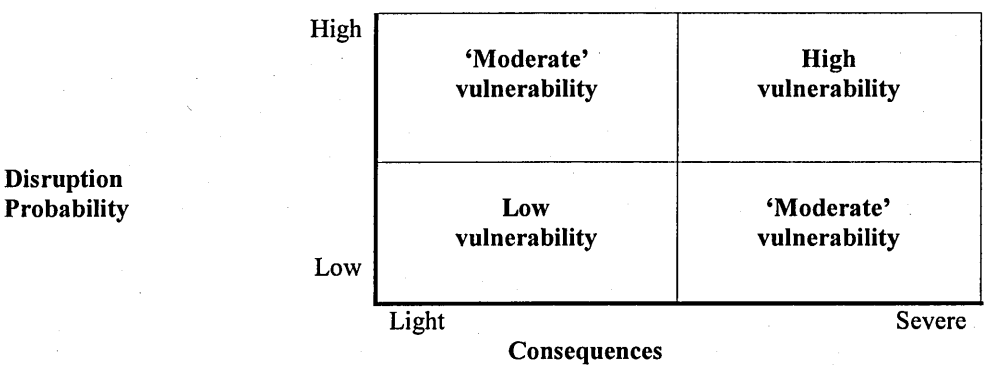
Lessons learned	Managerial implications
Towards suppliers	
High time dependence High relationship dependence	Causes (static vulnerability scenario) e.g. unique product needs limited supplier sourcing, low inbound inventory buffers and high degree of outsourcing. Negative consequences, e.g. upstream dependence upon resources, activities and actors. Contingency planning, e.g. inbound and internal preventive activities, cooperation, coordination and partnering
Towards customers	
High time dependence High relationship dependence	Causes (static vulnerability scenario) e.g. few customers, few products, few markets and low outbound inventory buffers Negative consequences, e.g. downstream dependence upon resources, activities and actors. Contingency planning, e.g. internal and outbound preventive activities, cooperation, coordination and partnering

Source: Svensson 2000

5.3.5 Dimensions of Vulnerability

According to Sheffi (2005a) a firm's vulnerability to a disruptive event can be viewed as a combination of the likelihood of a disruption and its potential severity. Vulnerability is assessed by determining: what can go wrong, what is the likelihood of that happening and what are the consequences if the event does happen. This is illustrated in Figure 11 below.

Figure 11: Dimensions of Vulnerability



Source: Sheffi& Rice 2005a

Vulnerability is the highest when both the likelihood and the impact are high, while vulnerability is the lowest when both the likelihood of its occurrence and its consequences are low. However, the two quadrants of 'moderate' vulnerabilities will still have very little in common. A high probability/low consequence event tends to be part of the daily management issues such as employee absenteeism, product quality and random deviations in demand, whereas, the low probability/high consequence event may be due to natural disasters, terrorism or any event that is outside the scope of daily management tasks, and thus will require a different assessment and mitigation techniques.

The focus of this report though, has been on low probability/high impact risk as it is the area that most managers still struggle with in determining how to mitigate against these risks.

5.3.6 Summary

This section sort to describe the various facets and ways of considering and investigating supply chain vulnerability. This is a crucial part in developing the resilience strategy. The following section discusses the various perspectives and ways put forward by various authors for developing a resilient supply chain.

5.4 Supply Chain Resilience

5.4.1 Introduction

This section describes the various recommendations to achieving supply chain resilience. It also considers the use of business continuity methods for this cause, as well as achieving resilience through failure mode analysis.

5.4.2 Achieving Resilience

As companies cannot afford to interrupt business applications given the intensity of the competition and the pressure they are under (Sheffi 2005a, Sheffi 2005c), more companies are now looking for strategies to increase their resilience. A resilient company is not only able to endure the unpredictable nature of globalisation, but is also able to gain competitive advantage from it (Sheffi 2005a, Sheffi 2005c). According to (Sheffi 2005c, 2006), resilience, a notion borrowed from the material sciences, represents the ability of a material to recover its original shape following deformation. For companies, it measures their ability to, and the speed at which they can return to their normal performance level (production, services, fill rates, etc) after a disruption. This section considers various methods of dealing with supply chain disruptions and creating a resilient supply chain. To this end the author considers the recommendations made by various authors (Figure 12).

Bundschuh *et al* (2003) looked to gain resilience through developing flexible systems based on reliability[16] and robustness[17]. Robustness focussed on building redundancy in the form of increased number of suppliers, so in the event of failure the unaffected suppliers can still provide their share of the total demand of the critical supply (Bundschuh *et al* 2003).

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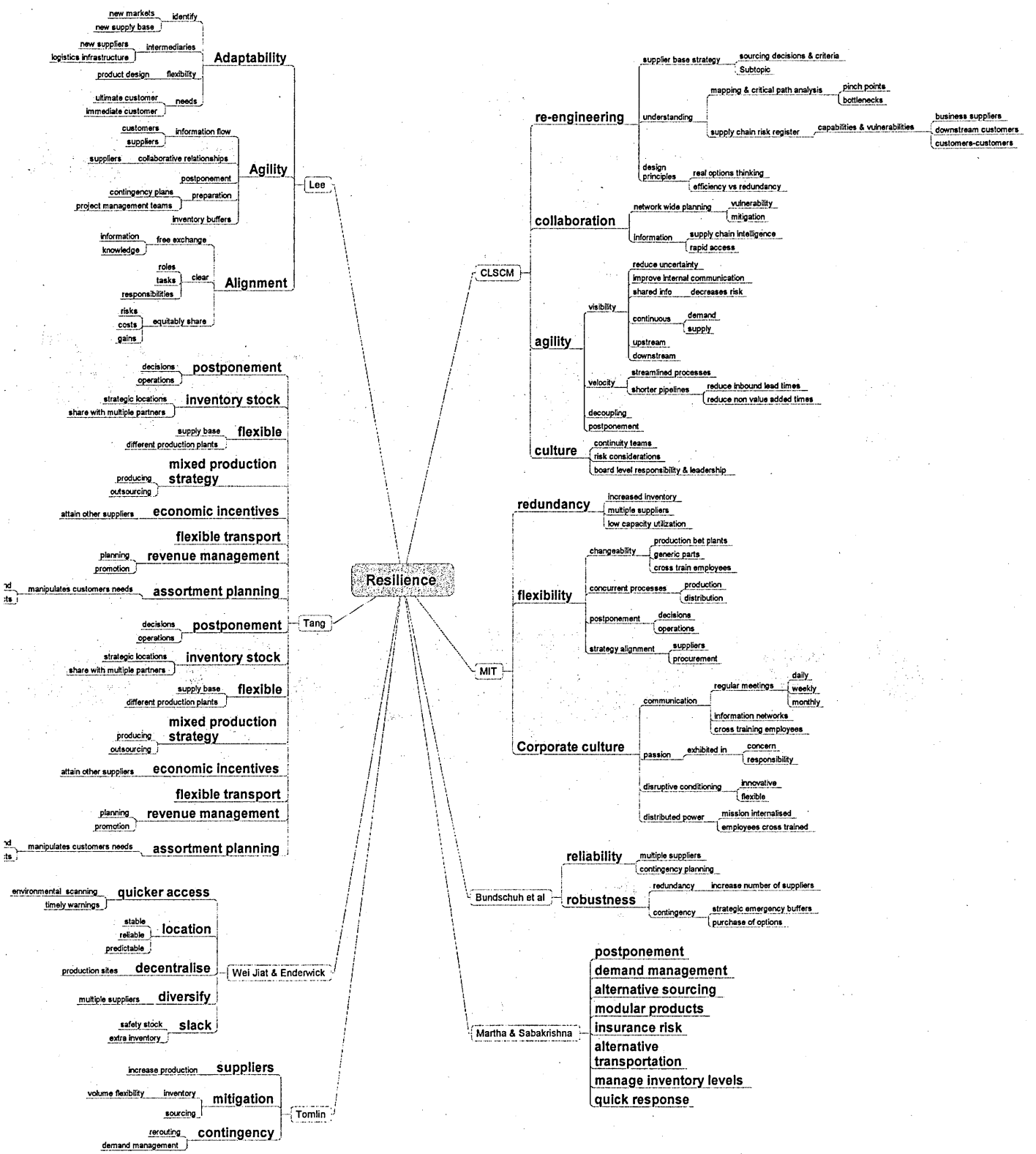
16 Reliability was defined as the probability that a system or component performs its specified function as intended with a given time horizon and environment (Bundschuh *et al* 2003)

[17] Robustness deals with the impact of failures on the performance of a system (Bundschuh *et al* 2003)

Figure 12: Mind Map of Resilience



This reduces the amount to which the supply chain can be completely disrupted. The second method of increasing robustness is through having a contingency supply in case of failure. This can be either through having Strategic Emergency Buffers (SEBs) which are to be used only in the event of a disruption. This was recommended by Sheffi (2001). SEBs consists of critical items that may be required in the event of a loss of supply. This inventory is not to be used for regular production, but can be very costly as there needs to be sufficient coverage for the loss of supply. Thus the second option, which is more cost-effective as it guards against the large accumulation of emergency inventory, is the purchase of options on additional supply in case of a loss. In the event of failure the unaffected supplier provides more than their contractual supply. As this supply though, is not in the chain, it can cause a lead-time in the contingency supply. Reliability focusses on the probability that the supplier is able to provide the supply when required. The failure to do this can result from any of the disruptions discussed throughout this report. Reliability of the system is then increased through customer relationships and having multiple suppliers.

Through their study of the events and actions during the outbreak of SARs, Wei-Jiat and Enderwick identified some strategies that should be put in place to create a more responsive supply chain by increasing its flexibility. Wei-Jiat & Enderwick (2006) suggested ways in which companies could prepare for these disruptions. Firstly, companies need quicker access to and action that will provide timely warnings based on environmental scanning of the local political, regional and global environments. Information also needs to be channelled to affiliates in other parts of the world, thus the importance of establishing an integrated global network and facilitating intra-company learning (Wei-Jiat & Enderwick 2006). Secondly, they suggested that when companies are choosing locations and sites the stability, reliability and predictability of the location, in addition to the cost benefit, need to be taken into consideration. Thirdly, it may be advisable to decentralise their production sites from one location (such as China) to smaller, multiple sites and facilities around the world, creating the global network of manufacturing facilities. Fourthly, diversifying the supply base and sourcing from multiple locations, thus reducing firm dependence on a single location was recommended. Possible locations besides Asia include Latin America and Eastern Europe. Finally, they recommended loosening the supply chain to allow for slack to accommodate delays and potential problems through the use of buffer inventory and safety stock. This may be considered costly, but the cost of an unresponsive supply chain in the face of disruption can be more severe than carrying excess stock.

Martha and Subbakrishna 2002, described the 'just-in-case' strategy. In addition to the recommendations of alternative sourcing arrangement as previously mentioned, they also recommended having alternative sources of transportation, particularly for critical components whether by land, sea or air. This may mean using air cargo if ports are closed, or rail, land or sea transport in the event of an air band. Thirdly, they recommended the use of demand management where the company is able to shift customer demand away from an affected product to an unaffected product. Fourthly, the use of modular products allows for quick response as well as makes it easier to shift demand. The postponement approach has been highly recommended and will be

discussed in some more detail later. Lastly, they have also recommended increasing inventories to the 'right' level and having supplier and transport relationships that will facilitate the movement of the inventory in the event of disaster.

Researchers at the Centre for Logistics and Supply Chain developed a framework for increasing supply chain resilience that looked at supply chain re-engineering, supply chain collaboration, culture and agility.

As supply chains have been designed to optimise cost and/or customer service and rarely with resilience in mind, they need to be re-engineered to reduce supply chain risk (Figure 13). Firstly, the supply chain network that connects a company to its first and second tier suppliers and customers needs to be understood. This should include understanding their capabilities, vulnerabilities (Wu *et al* 2005) and risk awareness (Christopher and Peck 2003). Understanding also extends to the understanding of the 'pinch points'[18] and critical paths of the network, e.g. knowing where there are limited capacity or no alternative options for distribution facilities or no access to ports (Christopher and Peck 2003), for example. Secondly, single suppliers, though cost-effective and good from a quality perspective; often reduces supply chain resilience. Alternative supply sources should be available in the event that the main supply is unable to provide the products or services as required. With multiple sites it may be possible to have a single source for an item or service into each site, thus gaining the advantage of single sourcing (Christopher and Peck 2003). It may also be useful to consider the use of multiple sites in the event that the main site is inoperable. Thirdly, when designing the supply chain one of the principles should be to keep as many options open as possible. They may not be the lowest cost in the short term, but they may provide the opportunity to reduce the impact of vulnerabilities in the long term (Christopher and Peck 2003). There needs to also be the consideration of the trade off between 'efficiency versus redundancy' (Christopher and Peck 2003, Chopra & Sodhi 2004, Lee 2004). Companies may need to consider carrying extra capacity or inventory, which in itself is an extra cost and contradicts the lean strategies that have been well sort after in the 1990s.

According to Christopher and Peck (2004), since improved quality and cost reduction are perceived as a network wide strategy, then supply chain risk management and supply chain resilience too should be a network wide strategy built on sound collaborative relationships to mitigate risk. Rapid access to information (Christopher 2005) increases supply chain intelligence,[19] which allows for greater visibility of the upstream and downstream risk profiles and changes in those profiles (Christopher and Peck 2003).

Creating an agile system is about creating networks that are able to respond quickly to changed conditions. The time to respond to changes is dramatically reduced. Agility is

[18] Pinch points occur where there is a limit of capacity and where alternative options might not be available (Christopher and Peck 2003)

[19] Supply Chain Intelligence is used to describe the process of using knowledge generated and shared by partners in the supply chain (Christopher & Peck 2004)

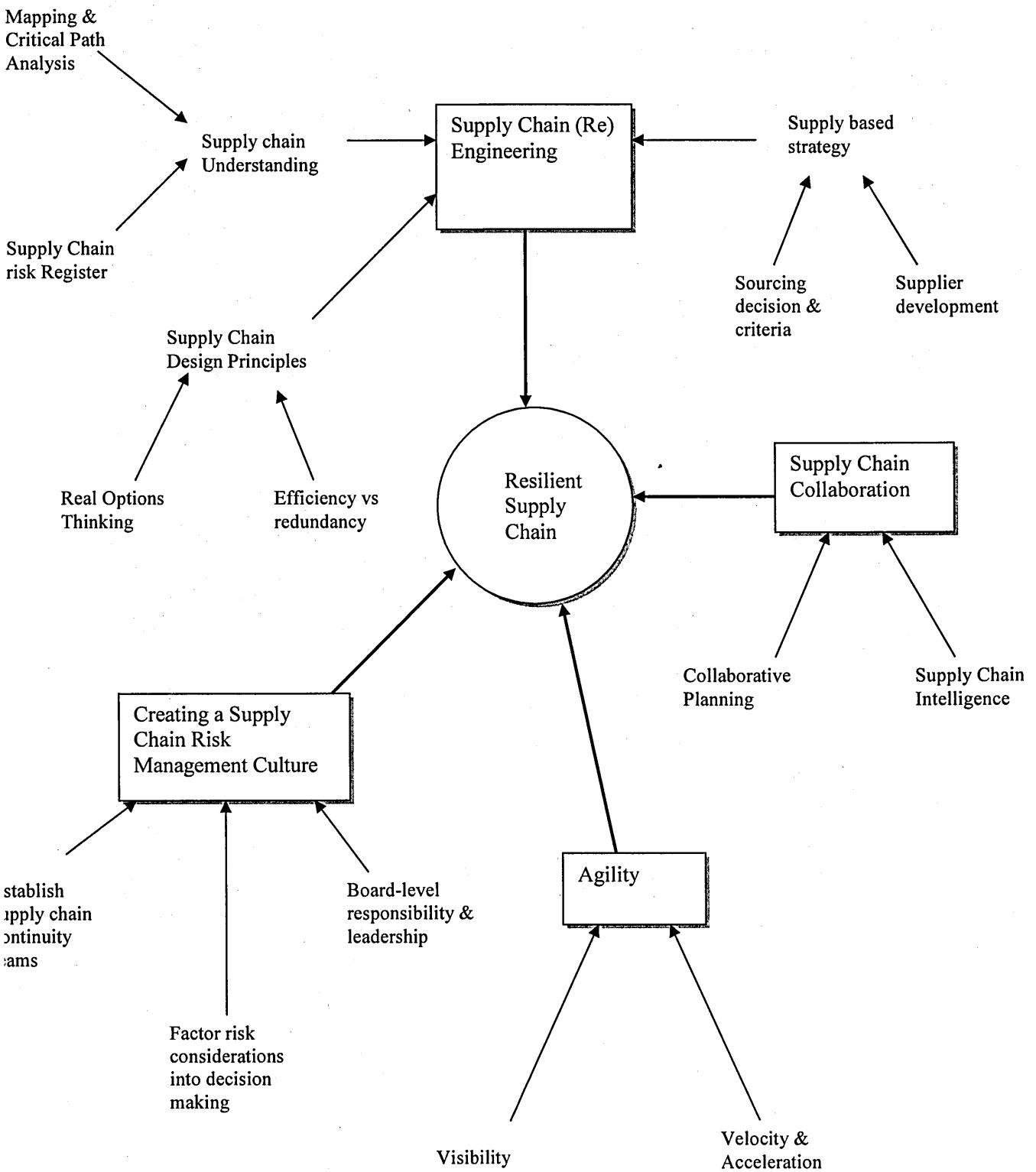
founded on two key principles – velocity[20] and visibility[21]. Velocity requires shorter, streamlined (CLSCM 2003), end-to-end pipelines, which themselves are dependent on sourcing decisions as well as internal process improvement. The focus then is on reducing the inbound lead times and reducing the non-value added activities (Christopher & Peck 2004).

Finally, creating a supply chain risk management culture, which needs to be promoted in the company so that all are concerned about it and the issues, ideas and procedures are internalised so that employees may work to reduce risk wherever possible.

[20] Velocity requires shorter end-to-end pipelines which themselves are dependent on sourcing decisions as well as internal process improvement

[21] Visibility impacts agility by reducing uncertainty and enabling the goal of a demand-driven supply chain to be achieved and by reducing supply chain risk through shred information, both upstream and downstream of the firm's operation.

Figure 13: Creating a Resilient Supply Chain



Source: Christopher & Peck 2004

Sheffi focussed on two main principles for creating resilient systems, redundancy and flexibility. Redundancy can be achieved by carrying extra inventory and finished goods to provide extra cover when a disaster occurs, through the use of multiple suppliers, even when the secondary suppliers have higher costs and low capacity utilization rates. These strategies are effectively an insurance premium which can be very costly, inefficient (due to poor product quality), and thus hard to justify (Sheffi 2005c). Though this was recommended by Sheffi, Christopher and others Sheffi has indicated that this is not a preferred option. Building flexibility into the supply chain is a better way of achieving resilience as it helps a company in two ways. It facilitates the quick response to disruptions in the supply chain and also encourages improved management of day-to-day changes in the market place. According to Sheffi and Rice (2005) 'Flexibility amounts to building organic capabilities that can sense threats and respond to them quickly', thus giving the organisation a competitive advantage in addition to a resilient system.

Flexibility includes firstly, the ability to move products between plants, using interchangeable and generic parts in many products and the cross-training of employees. If the company has the same layout across its plants and uses the same generic parts for its products, and if employees have uniformity in training, it is possible to move production and employees to another plant in the event of a disruption. This was the case with Intel with the 2003 SARS outbreak in Asia (Sheffi 2005c, Sheffi, Rice 2005). Secondly, concurrent processes of product development, production and distribution not only allow the organisation to execute different supply chain processes in parallel by shortening cycle time, but also means that the recovery time could be shorter if a disruption occurs (Sheffi 2005c, Sheffi & Rice 2005). Thirdly, after a disruption the requirements for products may change. Therefore, designing products and processes for maximum postponement of as many operations and decisions as possible increases resilience through flexibility. Having fewer products in their finished state allows for more flexibility in finishing the product according to the new demand. In 1999, Dell was better able than Apple to respond to changes in demand after the Taiwan earthquake disrupted the worldwide supply of memory chips (Sheffi & Rice 2005). Regardless of the procurement strategy chosen, it must be in line with the type of relationship chosen with the suppliers. Therefore, if a company decides to follow an arms length strategy then it is better that they have a high number of suppliers that they are able to turn to the others in times of a disruption. A collaborative relationship however, means that the focal company will have to gain more knowledge of the supplier and their processes, strategies; attitude to risk etc., and they will have to spend more time fostering that relationship, so that in the event of a problem the focal company can rely on the supplier to serve his needs first.

Finally, the Corporate Culture, has been identified as the most important or most crucial factor that allows companies to be flexible and resilient and bounce back from disruptions when they occur (Sheffi 2005b, Sheffi 2005c). Continuous communication of the way things are to be done and the regular transmission of information throughout the organisation are key. It is important that the people on the front line are able to respond and take action when a potential problem is imminent. This allows for the containment of the problem. Employees must have the training, have internalised the company

mission and must have the authority and the support from their organisation to take corrective action. Additionally, passion for work was also found to be of great importance.

For supply side tactics, Tomlin has recommended to deal with disruptions production should be increased at some of the company's other suppliers in the region (Tomlin 2006). Firms can also use either mitigation[22] or contingency[23] tactics. Thus, operational tactics for mitigating against disruptions include operational mitigation in the form of inventory and sourcing and operational contingency in the way of rerouting and demand management[24]. Inventory mitigation is not an attractive strategy in an environment of rare but long disruptions as a significant amount of inventory will need to be carried for extended periods without a disruption (Tomlin 2006). If however, there is advanced warning of a disruption, such as a labour dispute, then there may be ample time to employ the mitigation inventory in advance of the disruption (Tomlin 2006). Volume flexibility[25] provides an alternative to inventory in managing temporary imbalances in supply and demand which can arise because of supply side disruptions or temporary shifts in demand (Tomlin 2006). Volume flexibility is important as it can allow for contingent rerouting, thus making it part of the firm's strategy.

While Lee may not have explicitly called it creating a resilient supply chain he sought to develop a responsive and competitive supply chain through agility, adaptability and alignment (Lee 2004). Lee states that only those companies that build all three into their supply chain will be ahead of the competition. The concepts are captured in Table 19 below. An examination of the methods of achieving competitiveness and responsiveness will highlight that these tend to mirror some, if not most, of the recommendations to achieve a resilient supply chain as mentioned above.

Tang (2006) put forward a 'robust supply chain strategy' which has tended to mirror some of the suggestions for developing a resilient supply chain as mentioned above. The supply chain issues were classified into two major groups, supply management issues including supplier selection, supplier relationships, supply planning, transportation and logistics etc., and demand management issues including new product introduction, product line management, demand planning, product pricing, promotion planning etc. The nine robust strategies included postponement; storing inventory stock in strategic locations to be shared by multiple supply chain partners; having a flexible supply base, e.g. having different plants for production, in the event of a disruption the other plant can ramp up their production; using a mixed strategy of producing some products and outsourcing others; providing economic incentives to cultivate additional suppliers; flexible transport arrangement; revenue management via dynamic pricing and promotion;

[22] Mitigation tactics are those in which the firm takes some action in advance of a disruption and thus incurs the cost of the action regardless of whether the disruption occurs (Tomlin 2006)
[23] Contingency tactics are those in which a firm takes an action only in the event a disruption occurs (Tomlin 2006)
[24] Demand Management is the ability to shift customer demand to alternative products, particularly in the face of a disruption to the supply chain (Tomlin 2006)
[25] Volume flexibility is the supplier's ability to temporarily adjust capacity (Tomlin 2006)

assortment planning, which manipulates customers' product choice and demand by reconfiguring the set of products on display and the silent product roll over.

Table 19: Building the Triple-A Supply Chain

	Objectives	Methods
Agility	Respond to short-term changes in demand or supply quickly, handle external disruptions smoothly	• Promote flow of information with suppliers and customers • Develop collaborative relationships with suppliers • Design postponement • Build inventory buffers by maintaining a stockpile of inexpensive but key components • Have a dependable logistics system or partner • Draw up contingency plans and develop crisis management teams
Adaptability	Adjust supply chain's design to meet structural shifts in markets; modify supply network to strategies, products, and technologies	• Monitor economies all over the world to spot new supply bases and markets • Use intermediaries to develop fresh suppliers and logistics infrastructure • Evaluate needs of ultimate consumers-not just immediate customers • Create flexible product design • Determine where companies' products stand in terms of technology cycles and product life cycles
Alignment	Create incentives for better performance	• Exchange information and knowledge freely with vendors and customers • Lay down roles, tasks and responsibilities clearly for suppliers and customers • Equitable share risks, costs and gains of improvement initiatives

Source: Lee 2004

Interestingly, Carpenter *et al* 2001, studying socio-ecological systems, have taken a different perspective on the topic of resilience. They described resilience as the magnitude of disruption that can be tolerated before a socio-ecological system moves to a different space controlled by a different set of processes. They looked at measuring resilience, and though this is beyond the scope of this report, they did introduce two interesting concepts. Firstly, the concept that the socio-ecological system can be resilient at one time scale due to the technology it adopted and can be completely 'un-resilient' in another time with the use of that same technology. Thus in measuring and planning resilience the timescale is an important factor to be considered. Secondly, resilience can be achieved in one time period at the expense of resilience in a succeeding period.

5.4.2.1 Corporate Culture

Sheffi carried out a case study analysis of three companies that were identified as being resilient in the face of disruptions and he found that culture contributes to resilience by endowing employees with a set of principles regarding the proper response when the

unexpected does occur (Sheffi 2005b). The companies studied were Dell, United Parcel Services and the Military Aircraft carrier operations. The case study highlighted two main themes, flexibility and high service. Flexibility was obtained through being result-focussed, having high levels of and constant communication, the use of information networks and strong leadership. High service included communication, training empowerment and the following of strict procedures.

In being result-focussed the emphasis was on fast problem solving, execution of solutions and accountability for actions. High levels of communication included having frequent meetings and company updates where the attendees were prepared with notes prior to the meeting, and the minutes were disseminated after the meeting. Most of the work was done through teams, but for one organisation this was a very fluid or dynamic phenomenon where teams were created as soon as required and disbanded once the task had been completed. This was also supported by the informal network structure within the organisation which allowed for the easy flow of information. Where leadership was concerned members were encouraged to be innovative and enterprising in solving problems. Besides being empowered, they were encouraged to make immediate decisions which are necessary traits in the face of a disruption. The training was often rigorous and complete with a set of procedures to follow. Thus employees required very little supervision, which worked well in transferring the companies' espoused values. Though these companies were in essence very different, he found that there were a few common traits that made them resilient organisations.

Communication

Fast and flexible organisations continuously transmit information throughout (Sheffi 2005). This may be through regular daily, weekly or monthly meetings to keep all employees updated, and through information network systems such as the cell phone, e-mails and other media to keep persons in constant communication. The values of the organisation were communicated and reflected in the job descriptions and formal learning sessions. Additionally, employees changed jobs within the organisation to increase job flexibility and enhance their understanding.

Passion

Employees possessed passion for their jobs and the organisation and believed that what they did was important. They had a personal, deeply-felt concern and responsibility to serve the objective of the firm (Sheffi 2005b). Additionally, employees were never satisfied, always recognising that they could do better and that the company will do better. This went beyond trying to align or train the employees in the artefacts and espoused values of the firm.

Disruption Conditioning

Employees are trained and conditioned to respond to disruptions. They are encouraged to be innovative and flexible when disruptive events occur. This conditioning drives these firms' culture and identifying how to respond to disruptive events (Sheffi 2005b).

Distributed Power

The mission and the objectives of the organisation are internalised. Each employee is trained and empowered to work in the best interest of the firm, so that when there are early signs of a disruption the first respondent possesses the orientation and authority to take action. This eliminates the time that is often wasted in getting approval from those higher up the line of authority.

5.4.3 Additional Responses to Create Resilience

This section describes the possible areas and the effects the disruptive events can have to the supply chain. It has been suggested by some that rather than focus on the risk of a terrorist attack or other disruption, it may be wise to aggregate the various sources of disruptions and instead analyse the risk of disruption (Rice 2003) for example, the slowdown of goods entering the US after September 11 was not very different from the impact of the 1998 Quebec ice storm on Canadian imports or the west coast port lockouts in October 2002 (Rice 2003). Hence, while there are varying forms of risk, there are a limited set of potential outcomes or impacts to these various risks (Table 20)

Table 20: Disruption by failure mode

Failure Mode: A disruption in	**Description**
..... Supply	Delay or unavailability of material from suppliers
..... Transportation	Delay or unavailability of the transportation infrastructure or various modes. Firms showed more concern for the inbound flows than the outbound flows.
.... Facilities	Delay or unavailability of plant, warehouses, office buildings, facilities used in converting products
..... Communications	Delay or unavailability of the information and communication infrastructure
.... Human Resources	Delay, loss or unavailability of human resources to continue operations

Source: Chopra & Sodhi 2004

From the research project initiated by the Massachusetts Institute of Technology (MIT) to understand how organisations were responding to the new environment respondents reported that they responded by having a range of differing actions as identified in the Table 21 below. This suggests that no singular approach fits all situations (Rice & Caniato 2003). While there are a range of disruptions, the effects or failure modes are limited, so the data is presented by failure mode.

Table 21: Supply Chain Resilience Responses by Failure Mode

Resilience to disruption in ...	Action	Advantages	Disadvantages
Supply	Use multiple and/or local sources in different locales.	Spreads risk across two firms, two locations. Local source protects against international supply shortages.	Higher cost to qualify supplier, lower volume leverage, no assurance additional supplier is more resilient.
	Use single source.	Known supplier, high supplier commitment, leveraged volumes.	Vulnerable to disruption unless supplier as multiple flexible sites, backup plans.
	Contract for supplier flexibility	Contract obligates supplier in advance	Potentially higher cost per unit, may entail fixed costs for 'take or pay committed volume.
	Modify inventory levels	Right parts inventory and risk pooling may reduce inventory costs.	Requires periodic analysis by item as conditions change
	Modify product to use standard parts	Reduces part and inventory cost, complexity.	Costly to modify existing materials standards
Transportation	Prepare for and use multiple modes and carriers	Pre-disruption relationship ensures support in crisis	May need commit volume ti the alternate modes to get access in a disruption.
	Use spot market for capacity	Efficient transaction with no upfront or lasting commitment.	Unknown carrier means added risk, potential for exceptional high pricing.
	Use logistics providers to source transportation	Providers may have greater leverage access	Requires commitment (volume, cost) and relationship with logistics provider
Production Facilities	Use multiple sites, each making multiple products	Enables shifting production around locations	Requires standardization in production operations, additional capital for additional facilities.
	Modify inventory level and policies	Right finished-goods-inventory levels and risk pooling may reduce inventory costs	Requires periodic analysis, potential redesign of supply networks
	Modify product to use standard processes	Leverages common processing capabilities for lower cost, easier backup available.	Costly to modify product and production processes
	Identify and contract backup production facilities	Committed backup assured, potential to co-locate at supplier or customers	Not dependable without contingency contract for the facilities in disruption
Communication	Use range of communication media	Communication in nearly any event.	Must maintain broad range of old and new technology.
	Back up data	Protects against data loss	Still requires physical system in event of system loss.
	Contract for backup IT system	Provides for near-term system availability.	Potential delay in immediate response to massive system disruption.
	Set up and operate parallel or mirrored IT system	Affords immediate systems availability	Required cost to build, operate ad maintain separate system in protected environment
Human Resources	Develop cross-trained workers	Enables shifting of employees and production as needed.	Must cross-train employees, and modify work system to utilize multi-skilled employees.
	Modify production process for unskilled labour	Allows rapid increase or decrease in capacity	Requires simplification of production process (not always feasible)
	Back up knowledge	Best practices captured and document	Requires significant investment to capture and maintain knowledge in useful form

Source: Rice & Caniato 2003

5.4.4 Summary

The previous section discussed some of the theories put forward by various academics as they seek to describe ways in which to create a resilient supply chain. These theories were mainly focussed around flexibility, culture and communication. The following section will consider how to operationalise this flexibility that is sort after.

5.5 Supply Chain Flexibility

5.5.1 Introduction

In the previous section flexibility was considered to be imperative in creating a resilient supply chain. This section serves to consider frameworks that can be used to achieve this flexibility. Three main strategic imperatives that emerged in the last few decades are low cost, high quality, and improved responsiveness (both delivery and flexibility of product delivery) (Duclos, Vokurka, Lummus 2003). Environmental uncertainty requires a firm to be more flexible to be able to respond to the changes to make the firm both efficient and effective. In general, flexibility reflects an organisation's ability to effectively adapt or respond to change (Vickery *et al* 1999). The relationship between uncertainty and flexibility is a critical issue since flexibility is often viewed as an adaptive response to environmental uncertainty (Vickery, Calantone, Dröge 1999). In the growing turbulence in the business environment and competition shifting to the supply chain level, supply chain flexibility is emerging as one of the key competitive priorities for the future (Rao & Wadhwa 2002). As the supply chain extends beyond the enterprise then supply chain flexibility must also extend beyond one firm's internal flexibility (Lummus et al 2003).

There are a few ways that supply chain flexibility is perceived. Much of the practitioner literature emphasises the importance of supply chain flexibility for successful operation in the global environment however, little research has been done to define what constitutes supply chain flexibility (Duclos *et al* 2003). Understanding supply chain flexibility is important to understanding supply chain vulnerability which can then help managers to produce more resilient supply chain networks.

5.5.2 Supply Chain Flexibility Frameworks

Supply Chain flexibility tended to take the perspective of implementing flexible manufacturing systems such as Enterprise Resource Planning systems (ERP systems) (Van Weele, 2005), or MRP and MRPII and DRP systems and techniques against the correct educational and organisational background to make a sound flexible system (Gattorna, Walters 1996). These flexible manufacturing systems were toward improving the markets' responsiveness by striving for improved quality, minimizing stocks and higher turnover rates in production. These are Manufacturing Resource Planning, KANBAN and just-in-time Scheduling (Van Weele 2002).

Vickery *et al* (1999) suggests that supply chain flexibility should be examined from an integrative, customer oriented perspective, thus encompassing those flexibilities that directly impact a firm's customers and are the shared responsibility of two or more functions along the supply chain, whether internal or external to the firm. They categorised their flexibility in terms of product flexibility, volume flexibility, access flexibility and market (the responsiveness to target market) flexibility. Theirs was the more traditional view of flexibility based on flexibility dimensions (Lummus *et al* 2003). Christopher & Towill (2000), Mason *et al* (2000), and Naylor (1999) are examples of those who thought to create flexibility through the use of lean, agile and leagile systems and decoupling points (Rao & Wadhwa 2002). Fisher looked at creating flexibility with respect to product demand, having a flexible strategy that is market responsive. Prater 2001 defined flexibility as the capabilities of promptness and the degree to which a firm can adjust its speed, destination and volumes. For Adrian (2001) the emphasis was on quick and inexpensive restructuring for enhanced flexibility, e.g. being able to change to alternative suppliers quickly if the current ones are unable to honour supplies. Rao and Wadhwa (2002) proposed a conceptual framework based on resource, transformation, process and product interdependencies.

However, Duclos *et al*, (2003) defined a model of supply chain flexibility to consider vulnerability and risk. Six components of supply chain flexibility were identified from the literature on manufacturing flexibility, strategic flexibility and supply chain flexibility. Lummus *et al* (2003, 2005) looks at characteristics of flexible chains, e.g. the ability to add or remove suppliers, ability to postpone product differentiation etc. Certain characteristics or capabilities will lead to improvements in performance and thus it was felt that this provided the better framework in which to consider flexibility.

The flexibility framework is important as it is the medium or structure through which companies can achieve the required flexibility for resilience as described by Christopher, Peck and Sheffi. Lummus *et al's* (2003, 2005) (Figure 14) framework for flexibility provides the best framework to achieve these same said characteristics that have been identified as being important for supply chain resilience. They seem to be more encompassing and not limited to day-to-day demand/supply variations.

Operations system flexibility is the ability to configure assets and operations to react to the emerging customer trends at each stage of the supply chain. Inflexibility includes the inability to transfer production from one plant to another and the inability to successfully respond when capacity is restrained.

Market Flexibility is the ability to mass customise and build close relationships with customers, including the designing and modifying of new and existing products. Hence the responsiveness to changing market conditions and customer needs after some form of disruption or disaster to the supply chain is important.

Logistics flexibility is the ability to cost effectively receive and deliver products as sources of supply chain customer change (customer location changes, globalisation,

postponement). This includes all the processes of transporting goods from suppliers to manufacturers, distribution centres and the final consumption points. However, it may be possible to extend this definition to transportation infrastructure, which may be affected in a disruption, such as roads, rail, air and sea transport and ports.

Supply Flexibility is the ability to reconfigure the supply chain, altering the supply of product in line with customer demand. Therefore as one member sees the need to add partners to complete a task, new partners with the required capabilities must be found.

Organisation flexibility is the ability to align labour force skills to the needs of the supply chain to meet customer requirements. This is the flexibility that is achieved through the workforce and the organisational structure, business practices and culture within which the workforce operates. Reconfiguration and adjustment of operations will only be as successful as the flexibility of the workforce and organisational environment allows.

Information systems flexibility is the ability to align information system architectures and systems with the changing information needs of the organisation as it responds to changing customer demands. Change within the supply chain may be inhibited if the information system cannot respond to these changing needs. Supply chain partners must be willing to adapt their information systems to meet the needs of all partners and upgrade the business processes as the market evolves.

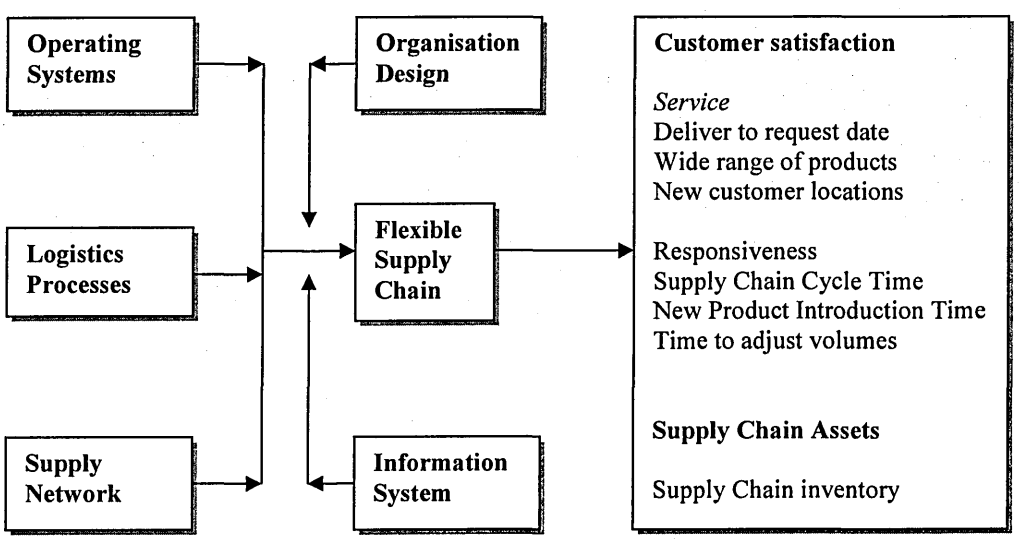
Table 22 below summarises the flexibility framework as just described and also includes the references from which the authors have drawn in developing this framework.

Table 22: Supply Chain Flexibility Components and Key Characteristics

Supply Chain Flexibility Component	Supply Chain Flexibility Characteristics Ability to ...	Reference
Operations Systems	Reconfigure Assets Change processes Dynamically adjust capacity	Anderson (2000), Radjou (2000), Allnoch (1997) Radjou (2000)
Logistics Process	Adjust to global requirements Serve customer's distinct needs Vary warehouse space Vary transportation carriers Introduce product postponement	Bradley (1997) Fuller et al (1993) Richardson (1998) Huppertz (1999), Doherty (998), Swaminathan (2001), Van Hock (2000)
Supply Network	Add and remove suppliers Select suppliers with fast ramp up Vary supplier relationships Have suppliers vary capacity	Jordan (2000), Rich (1997), Burt and Soukup (1985), McGinnis and Vallopra (1999), Fisher et al (2000) Bensaou (1999), Mason et al (2002), Cooper (1993), Choi and Hartley (1996)
Organisational Design	Change organisational structure Change human resource practices Change workforce capabilities Link workforce between nodes Change culture	Miles (1989), Andrews (1994), Lau (1996) Zhang (2001), Power et al (2001), Mac Duffie (1995), Wright and Snell (1998), Upton (1995) Vokurka and O'Leary-Kelly (2000), Miles (1989), Hall and Parker (1993), Kalwani and Narayandas (1995), Moller and Wilson (1995), Hult et al (2002)
Information Systems	Synchronise information systems with partners Interface internal processes Share information with partners	Dabbiere (1999) Vokurka and O'Leary-Kelly (2000), Magretta (1998)

Source: Lummus *et al* 2003

Figure 14: Model of Supply Chain Flexibility Characteristics



Source: Lummus *et al* 2003

5.5.3 Agility and Leagility

A key characteristic of an agile organisation is flexibility (Christopher & Towill 2000). The concepts of agility also provide a foundation for understanding flexibility (Lummus et al 2003). According to Prater *et al* (2001), agility is the ability of an organization to thrive in a continuously changing, unpredictable business environment, i.e., an agile firm is one that has designed its organization, processes and products such that it can respond to changes in a useful timeframe (Hormozi, 2001). However, as organisations and networks become more complex their agility decreases (Christopher 2002). Agility is needed in less predictable environments where demand is volatile and the requirement for variety is high, whereas 'lean' works best in high volume, low variety and predictable environments. However, agility needs to be thought of from two perspectives, from the production side and meeting customer demand, and from the perspective of being able to deal with disruptive events through multiple sourcing, emergency stock and other strategies.

Leagility is the combination of the lean and agile paradigm within a total supply chain strategy by positioning the de-coupling point[26] so as to best suit the need for responding to a volatile demand downstream, yet providing level scheduling upstream from the decoupling point. The key principles of the leagile system are postponement and information decoupling (van Hoek, 2000, Mason-Jones *et al* 2000). Billington and Amaral (1999), Mason-Jones *et al* (2000), van Hoek, 2000, Christopher & Peck 2004 all suggest that the combined effect of shared information in the supply chain and delayed configuration through postponement can significantly improve responsiveness. Companies have explored using leagile systems to deal with customer demand fluctuations, but these strategies can also contribute to developing a flexible and thus resilient supply chain.

5.5.4 Summary

This section sort to discuss the possible framework that can be used to promote supply chain flexibility and also to introduce the concept of Leagility which is not new, as a way of increasing resilience. The following section explores achieving resilience through business continuity.

5.6 Business Continuity and Resilience

5.6.1 Introduction

Business continuity can play a significant role in allowing organisations to have a competitive advantage if the organisation takes seriously the principles of Business Continuity Planning (BCP), and if it is fully embedded in the organisation beyond its

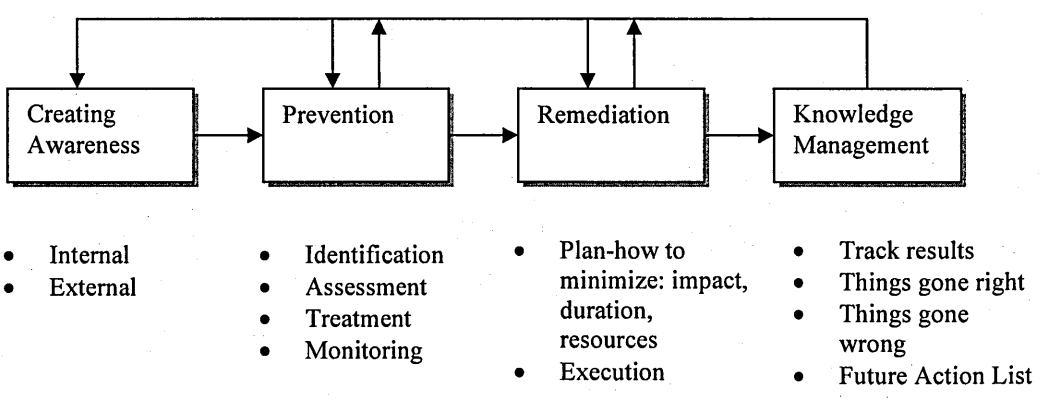
[26] The de-coupling point is the point at which the market 'pull' meets the upstream 'push' (Christopher & Towill 2000)

regulatory nature. The goal of BCP is to preserve and protect the essential elements of an enterprise and maintain an acceptable level of operations throughout a crisis and afterwards, as the company recovers (Rodetis 1999). Many business continuity plans are based in increasing redundancy in several facets of the companies' operations (Sheffi, Rice 2005), thus BCP can speed recovery and resilience (Herbane *et al* 2004). With all the environmental changes, the concept of business continuity is on building resilience and not only on recovery strategies and plans (Foster & Dye 2005). BCP not only allows for resilience, but also for improved security by exposing potential weaknesses in the systems which can then be addressed. It allows for improved decision-making with regards to the level of security and resilience required to achieve target measures.

5.6.2 Creating Business Continuity Plans

Zsidisin *et al* (2004) examined how and why firms create business continuity plans to manage risk. This was done with firms that have established BCP and risk management processes in supply management. Open systems theory was used to provide a framework for studying BCP and for identifying potential factors and constructs to be included in the research protocol. The framework below resulted from the study (Figure 15)

Figure 15: Supply Chain Business Continuity Framework



Source: Zsidisin *et al* 2004

Although the firms operated in very different environments, there was consistency in their approach to continuity planning in the upstream supply chain. Awareness is evident when the business realises that it is vulnerable to supply disruptions. This awareness has to be developed internally at the management level in order to later allocate resources to manage the risk. The awareness then has to be moved external to the organisation to the suppliers and customers in the supply chain to create awareness and to enlist them in an effort to manage risk (Zsidisin *et al* 2004). Preventing Supply Discontinuity involves reducing the likelihood and/or impact of supply chain disruptions which consists of the

risk identification[27], risk assessment[28], risk treatment[29] and risk monitoring[30] (Zsidisin *et al* 2004).

The actions taken to recover from a disruption when it occurs remediate risks. The firm considers how to shorten the disruption, minimize the impact to the business, and identify in advance the resources that will be needed to carry out this plan (Zsidisin *et al* 2004). The firm then has to learn from the experience once a disruption has occurred. This can be in the form of a post-incident audit that identifies important lessons learned; things that went right and things that went wrong, and the results of the remediation efforts, along with feedback to the earlier stages in the continuity planning process (Zsidisin *et al* 2004).

5.6.3 Summary

This section briefly discussed the link between BCP and resilience and the common threads that companies use to form business continuity plans.

5.7 Disruption Risk Management

5.7.1 Introduction

Disruption Risk Management (DRM) is a new and emerging field, gaining importance to many businesses, due to the vulnerabilities supply chains now so clearly experience, and brings together the risk management literature and supply chain coordination. The following sections will briefly discuss how disruptions can be categorized, and the various stages of a disruption.

5.7.2 Types of Supply Chain Disasters and the responses to them

Kleindorfer, Saad (2005) have suggested that to manage disruption risk, companies need to develop a conceptual framework that reflects the effective integration of the joint activities for risk assessment and risk mitigation and provide strategic direction, actions and necessary conditions that help advance cost-effective mitigation practices.

The framework for managing risk developed by (Kleindorfer, Saad 2005) is derived from theory and practice of industrial risk management. It considers the nature of the

[27] Risk identification – enumerating the causes/sources of potential supply chain disruptions (Zsidisin *et al* 2004)

[28] Risk assessment – evaluating the likelihood of occurrence and the impact that event will have on the business for each cause or sources of potential disruptions (Zsidisin *et al* 2004)

[29] Risk treatment – prioritising the causes/sources of potential disruptions and developing strategies for reducing their likelihood and/or mitigating their impact on the business (Zsidisin *et al* 2004)

[30] Risk monitoring – monitoring developments in the supply chain that may increase or decrease risks on an on-going basis. These might included changes in the economic or political environment, changes in supply markets, or the status of individual suppliers (Zsidisin *et al* 2004)

underlying hazard giving rise to the risk. The risk is then quantified through a disciplined risk assessment process which includes determining the pathways by which such risks may be triggered. However, the approach to managing the risk must suit the characteristics and needs of the decision environment. Additionally, appropriate policies and actions need to be integrated with the on-going risk assessment and coordination along supply chain partners.

Key dimensions are fundamental to disruption risk management in the supply chain. The first concerns strategies and actions aimed at reducing the frequency and severity of risk faced at both the firm and supply chain level. The second focusses on increasing the capacity of the participants to sustain/absorb more risk without any serious negative impacts or major operational disruptions. According to Kleindorfer and Saad (2005), the type of low probability/high consequence type of risk cannot be managed with traditional risk management strategies; rather they need to have a very high quality process management in which the process is continually audited.

DRM involves more stakeholders than simply the company's owners and investors. They involve public sector regulators, governments, employees and external stakeholders such as law enforcement official and emergency response teams (in event of terrorist attacks). Given the high stakeholder involvement, care must be taken in the assessment and mitigation of these risks. First focal point of disruption risk management has been facilities and transportation links. Attention is now moving to supply chain wide systems to promote visibility across the supply chain on major sources of disruption and to promote the opportunity for joint problem solving (Kleindorfer and Saad 2005)

5.7.3 The SAM Framework

The foundation of disruption risk management is specifying sources of risk vulnerabilities, assessment and mitigation (SAM). Specifying the sources of risk (S) includes categorizing risks into operational events, natural hazards, earthquakes and hurricanes and finally, terrorism and political instability.

Risk Assessment (A) and Mitigation (M) is the methodology employed in industry from financial services to the process industry and is based on three main disciplines: probabilistic risk assessment using fault and event trees and vulnerability assessment using emerging team based approached for purposeful agents and decision analysis (Kleindorfer, Saad 2005). The process of identifying, assessing, mitigating and monitoring risk bears a stack resemblance to risk management processes which, as described above, have been used in many other fields such as finance, project management continuity planning.

The SAM task can be implemented by following 10 principles (Table 23), which have been based on the industrial risk management and the supply chain literature (Kleindorfer and Saad 2005).

Table 23: Ten Principles to introduce SAM in organisations

	Principle	Discussion
1	Put own house in order	Internal supply chain integration and optimization must precede any inter-firm interfaces, Supplier Relationship Management and Customer Relationship Management. Site/facility management systems to identify and mitigate disruptions are central building blocks
2	Diversification reduces risk.	This diversification is to be extended to include facility locations, sourcing options, products and services produced, logistics and operational modes
3	Try to 'work on' the weakest link in the supply chain as robustness is determined by the weakest link and a weak partner	DRM must provide incentive alignment and collaboration for risk avoidance and reduction among all supply chain partners. Vulnerabilities, early warning and crisis management need to be identified across the entire supply chain
4	Loss avoidance and pre-emption are better than mitigation of losses after the fact	The investment in risk assessment to determine key vulnerabilities as well as worst case scenarios are a critical first step to managing disruptive events
5	'Robustness' versus effectiveness.	'Robustness' to the supply chain in the event of a disruptive event must be considered in light of the effectiveness of the chain. Extreme leanness and efficiency may result in increasing the level of vulnerability at the firm and the supply chain level. There exists a trade-off between efficiency and effectiveness.
6	Maintain reasonable slack	Have contingency plans and back up systems that can increase the level of readiness for managing risk
7	Corporation, collaboration and coordination in the supply chain are critical.	Collaborative sharing of information and best practices among supply chain partners is essential in identifying vulnerabilities and in preparing for and executing effective crisis management
8	Understand the risk that the system is exposed to	Using risk assessment and quantification methods to understand the potential extent of disruptions to the supply chain. These are also critical in developing mitigation strategies to deal with the risk
9	Modularity of product and process designs	This provides the leverage for risk reduction, especially for interruptions involving discontinuities in raw material availability and component supply due to the flexibility which promotes resilience, particularly when resources and essential inputs are interchangeable with other items
10	The use of Total Quality Management (TQM) principles	The TQM principle of prevention and process control rather than inspection increases supply chain security and the reduction of disruptive risks faced while reducing operating costs

Adapted from Kleindorfer and Saad (2005)

5.7.4 Summary

This section discussed Disruption risk management and the SAM framework that was presented by Kleindorfer and Saad. The following section discusses Supply Chain Risk Management.

5.8 Supply Chain Risk Management

Supply Chain Risk Management SCRM seeks to address the issue of vulnerabilities in complex supply chain. Though a study or a discourse on supply chain risk management (SCRM) was not reflected in the research questions and objectives, the research process has identified this as one of the key themes and thus, in pursuing a resilient strategy one will have to consider the concept of supply chain risk management.

Juttner *et al* 2003 define supply chain risk as 'any risks for the information, material and product flows from original supplier to the delivery of the final product for the end user'. This is the possibility and effect of a mismatch between supply and demand. Four basic constructs of supply chain risk management were presented: supply chain risk sources[31], risk consequences[32], risk drivers[33] and risk mitigating strategies[34]. Since all risk will not be mitigated in the same manner, the sources and classification of risk and disruptions provides the basis for risk assessment (Juttner *et al* 2003). The risk drivers tend to lead to a more integrated supply chain and increases the complexity of the supply chain. The risk mitigation strategies identified by Miller 1992 included avoidance, control, co-operation and flexibility and a further illustrated in Table 24 below.

Table 24: Risk Mitigation Strategies

Avoidance	• Dropping specific products/ geographical markets/ suppliers and/ or customer organisations
Control	• Vertical integration • Increased stockpiling and the us of buffer inventory • Maintaining excess capacity in productions, storage, handling and/ or transport • Imposing contractual obligations on suppliers
Cooperation	• Joint efforts in improve supply chain visibility and understanding • Joint efforts to share risk-related information • Joint efforts to prepare supply chain continuity plans
Flexibility	• Postponement • Multiple sourcing • Localised sourcing

Source: Juttner *et al* 2003

[31] Risk sources are the environmental, organisation or supply chain-related variables that cannot be predicted with certainty and that impact of the supply chain outcome variables (Juttner *et al* 2006)
[32] Risk consequences are the focussed supply chain outcome variable like cost or quality (Juttner *et al* 2006)
[33] Risk drivers can be taken as competitive pressures such as globalisation, outsourcing , centralisation strategies etc (Juttner *et al* 2006)
[34] Risk mitigating strategies are the strategic moves organisations deliberately undertake to mitigate the uncertainties identified from the various risk sources (Juttner *et al* 2006)

5.9 Terrorism and Security

5.9.1 Introduction

One aspect that has taken precedence in the recent years, especially after events such as the bombing of the World Trade Center on September 11th 2001 and more recently the London bombing on July 7th 2005, is terrorism and its effects on the supply chain.

Russell and Saldanha (2003) have identified that the aggregate estimated cost as a consequence of new security measures should be in the vicinity of US$151 billion additional costs annually in the US alone, of which US$65 billion can be attributed to logistical changes in the supply chain. It has also been estimated that businesses will carry extra safety stock and inventory that may go up by as much as 5% which would represent a US$75 billion increase in working capital (Russell and Saldanha 2003). Additional cost being added to the supply chain includes tighter security controls and an increase in the shipping and insuring of U.S. imports (Russell and Saldanha 2003).

However, such events have been described as outliers (Stauffer, 2003) quite unlikely to happen regularly even compared to the other events that can be categorised as low probability/high impact events such as hurricanes, earthquakes, fires, to even strikes. However, these events can be quite detrimental to the supply chain once they occur, especially when we consider that the response of the government in the face of such events, such as closing air travel and ports (Sheffi 2005a) can cause the supply chain to immediately grind to a halt. This new operating environment calls for a supply network design that is both secure and resilient (Rice, Canaito 2003).

Rice & Caniato (2003) and Rice & Spayd (2005) have indicated that security and resilience are two different things and as such, should not be used interchangeably[35]. However, some of their strategies, i.e. for ensuring resilience and ensuring security, overlap. Thus, it is believed that some of these strategies are worth mentioning and taking into consideration. It still remains though, that creating a secure supply chain, particularly against the effects of terrorism, is beyond the scope of this report.

5.9.2 Activities to Achieve Security and Resilience

Resilience and security are improved through organisation capabilities. As with any initiative, the company's leadership, attitude, belief and actions are key to ensuring that emphasis is placed on resilience and security. Resilience and security are part of the organisation's culture and are accepted as beliefs, all of which are accomplished through the education and training of employees (suppliers and customers) about resilience, security and supply chain risks.

Secondly, BCP has the dual effect of improving security and resilience as it exposes the potential weaknesses in the systems which can then be addressed. BCP entails

[35] Supply network security can be considered in terms of maintaining the integrity of the product, while supply chain resilience is the ability to react to unexpected disruption and restore normal supply network operations (Rice & Caniato 2003)

establishing layers of security and resilience which can include ongoing assessment of supplier resilience and security by ongoing on-site visits and 'capacity reports', development and maintenance of alternative supply and production systems (Rice & Caniato 2003). As the layered approach is being used it is not necessary that each be perfectly implemented as the layers of resilience and security will mean that the actions will back up each other (Rice & Caniato 2003). The second BCP strategy is the setting up of the established emergency operating centres (EOCs) which is an allocated emergency space that a predetermined set of leaders can meet to plan and strategise once the disaster has occurred (Rice & Caniato 2003).

Thirdly, the new era will call for a change in supplier relationships. This may result in an increase in the long-term relationships and a reconsideration of the balance between offshore and local suppliers. While offshore suppliers may be less expensive, they are more susceptible to disruptions and have higher lead times. Many companies may go for a mixed strategy.

Table 25: Five Tenets of the Security-Aware Logistics Supply Chain Operation

Tenet	Definition	Comments
1	Companies need to partner with local, state and federal government organisation that impact the movement of freight	Forming 'partnerships' with the government and other regulatory bodies such as customs department.
2	Companies need to know their overseas trading partners and take responsibility for securing their cross-border supply chains	• Importers have to be sure of their own employees and security procedures. • Importers must have confidence in their trading partners • Importers must have confidence that their trading partners have security measures in place to ensure that their supply chains are not vulnerable to illegal trafficking of drugs, persons, ammunition etc • Companies should have in place security systems to ensure the exclusion of unauthorised personnel
3	Companies need a mode shifting capability to accommodate unexpected delays, interruptions and disasters	This mainly refers to having the flexibility to change transportation, e.g. flight to truck services in the event that the primary service is unavailable after a disruption
4	Companies need to develop a suite of communication channels and media to manage crises	Part of the crisis management preparation is assigning and knowing who is responsible for communicating, who is told what, when, where, how and by whom. Specific channels of communication in a crisis might include visits from leaders to the crisis site, web sites, response centres, mailers, briefings and educational seminars
5	There is a need to adopt the military concepts of agility, reservists and pre-positioning for the management of business logistics and the supply chain in the new environment	Agility in the sense of the time taken to analyse a situation and adjust their strategic and tactical business plans in a few hours Reservist means being able to replace people, systems, documents quickly to allow the continuation of the business in the time of crisis Prepositioning of safety stock, known as the 'Strategic Emergency Stock' to be used as buffer in times of disruption

Adapted from Russell and Saldanha (2003)

Fourthly, knowledge, information, processes and relationships important to the business must be backed up. These processes include communication protocols, authority chains

and decision-making procedures. Personnel and workers are key to the business, but in the event that they are not there to draw on their expertise, then all critical processes should be documented, ideally employees should be cross-trained so that if persons in critical roles are affected, there are others there to continue the process.

Additionally, Russell and Saldanha (2003) have offered five tenets to help companies ensure continuity and security in the supply chain in the event of a crisis (Table 25).

From the tenets discussed we realise that there is a strong overlap (with the exception of tenet 1) of strategies for the increase in supply chain resilience offered by the likes of Sheffi, Rice, and Christopher & Peck, Lee. Tang and Tomlin.

5.9.3 Security and Collateral Benefits

Collateral benefits are derived from supply chain security investments that may provide valuable benefits in other areas in the firm and vice versa (Rice & Spayd 2005). Enabling private sector firms to improve efficiency and have improved security are the benefits to the. However, collateral benefits in themselves are not solely as a result of a firm's contribution and investment to security, but are as a result of a combined approach to risk management, supply chain security and supply chain risk management (Rice & Spayd 2005) (Table 26).

Table 26: Supply Chain Security Investments that also offer collateral benefits

• Asset Visibility and Tracking • Personnel Security • Physical Security • Standards Development • Supplier Selection and Investment • Transportation and Conveyance Security	• Building Organisational Infrastructure Awareness and Capabilities • Collaboration Among Supply Chain Parties • Proactive Technology Investments • TQM Investments • Voluntary Security Compliance •

Source: Rice & Spayd 2005

While this is very much a current and evolving topic and field, a description of these collateral benefits is beyond the scope of this report.

5.9.4 Summary

This section sort to introduce and briefly discuss the current topic of resilience and security of the supply chain in the face of terrorist activity. Some of the overlapping strategies were identified.

5.10 Conclusion

Much information and research findings were presented in this chapter. It covered the areas of supply chain vulnerability and the various ways and perspectives of determining the vulnerability of the business. How to achieve supply chain resilience through the perspective of various authors and researchers was covered. The key elements that were highlighted were flexibility and organisational culture. This section also tried to link the creation of resilient organisations through business continuity and failure mode analysis. The section

encompassed a discussion on various flexibility frameworks that could be used to achieve the required flexibility. Following on was a discussion of Disruption Risk Management, and the chapter ended with ways of considering the resilience and security of the supply chain in the event of the ever-present threat of terrorism.

The following chapter seeks to synthesise the above findings and discussions into more 'manageable' frameworks.

CHAPTER 6

6. SYNTHESIS AND DISCUSSION

6.1 Introduction

The previous chapter:

- Presented the contributions of various writers to the areas of supply chain vulnerability, flexibility and resilience.
- Considered how an agile and leagile strategy contributes to supply chain resilience.
- Described in depth the importance of the culture of the organisation in creating a resilient supply chain
- Presented the contribution and some related concepts of Business Continuity to achieving resilience.
- Identified the importance of Supply Chain Risk Management to resilience.
- Discussed Disruption Risk Management
- Introduced how some strategies can both increase resilience as well as security with the possibility of terrorist attacks. The concept of collateral benefits was introduced
- Introduced the concept of failure mode analysis as a contribution to increasing resilience.

This chapter synthesises that information presented in the previous chapters. It is comprised mainly of models that are intended to bring the main strands of the findings together. It suggests models that:

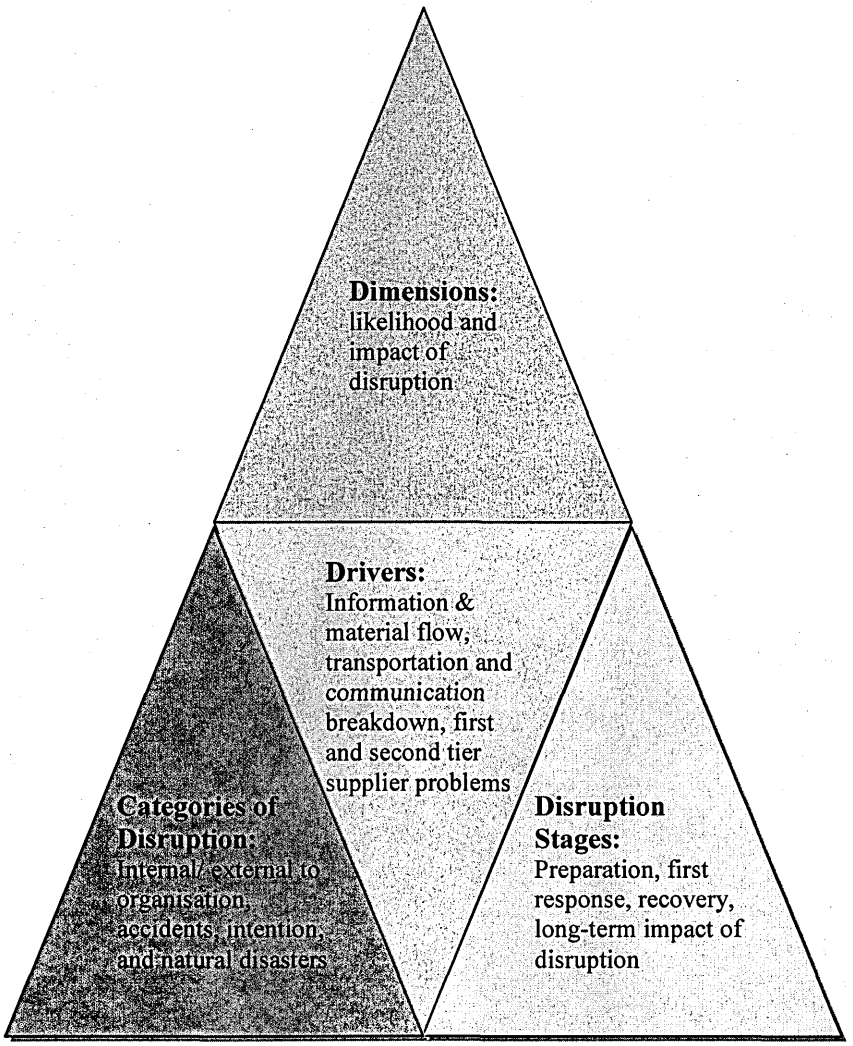
- Encompass the key components in determining supply chain vulnerability
- Consists of the major contributors to supply chain resilience
- Presents a conceptual model of supply chain resilience
- Amalgamates the approaches in considering supply chain resilience.
- Combines the major factors of disruption risk management

The chapter concludes with a tabulated summary of the various potential areas of research that have been highlighted by the various authors through the research process.

6.2 Determining an organisation's vulnerability

As identified, the topic of vulnerability and resilience go hand in hand. However, since this area is a relatively unexplored area (Svensson 2002, Peck 2005) there are still problems in conceptualising how to understand vulnerability, and how understanding it can help in the preparation for and the creating of resilient supply chains.

The model below (Figure 16) amalgamates the contributions of various authors that have set out to understand vulnerability.



Source: The Author 2006

Figure 16: Model for understanding supply chain vulnerability

The first part is to understand the sources of the disruption, i.e. the how and why of how the disruption can come about. This will include an analysis of the information and material flow, a breakdown in transportation and distribution, problems with the first and second tier suppliers, problems with retailers and/or customers, or some form of political instability. Also to be considered are the contributors such as globalisation strategies, 'lean' manufacture, outsourcing and the like, any strategy that can make the supply chain more susceptible to vulnerable events.

The second part considers the stages of the disruption as it is necessary to know how vulnerable the organisation is and where the most damage can occur. This forms part of the foundation for developing business continuity and resilience plans.

Categories of disruption form another key element and consideration will be given to whether the disruptions can come from internal or external sources to the organisation and the supply chain, and whether they can be categorised as accidents, intentional, natural disasters, pathological or operational events etc. It also makes use of the vulnerability constructs and also considers what is disrupted, e.g. transportation and communication infrastructure, power lines, port facilities etc.

The fourth key considers the dimensions in respect to their likelihood of occurrence and the impact in the event that they do occur. From this point it is possible to produce and develop resilient strategies to deal with the disruption.

6.3 Major contributors to supply chain resilience

The findings seem to indicate that there are key characteristics in creating a resilient supply chain which include organisational culture as the core to which are attached four sectors of resilience. Please refer to the diagram below (Figure 17).

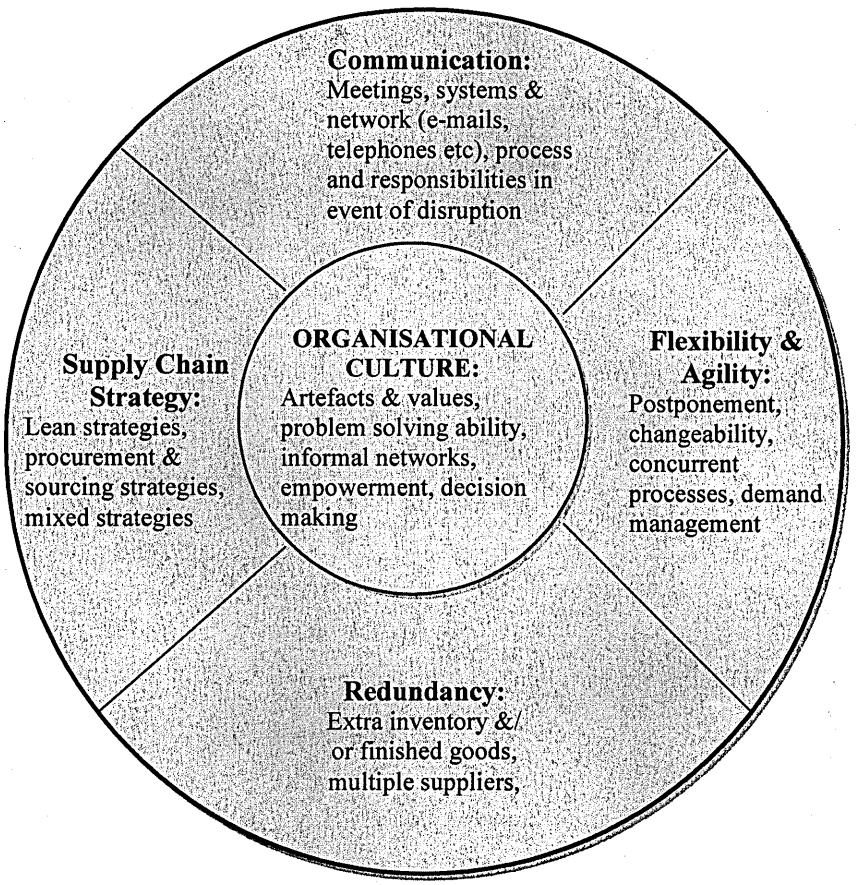
6.3.1 Culture

Many authors concur that having the correct corporate culture is critical to any resilience or disruption management strategies (Sheffi 2005, Christopher & Peck 2004). Choosing culture as the central element seems clichéd as for many models and innovative management techniques, the culture of the organisation has always been presented as being key. The same holds in this instance. While culture was not identified as being important to each of the perspectives used to amalgamate this model of supply chain resilience, it still holds that to achieve the end results as described, these traits and behaviours must be embedded in the culture of the organisation.

Culture, though hard to pinpoint is represented in a tangible form through the artefacts and espoused values of the organisation (Schein 1996, 1984). These artefacts tend to be the manner in which meetings are conducted, the language , dress code, office layout and other 'rituals' that take place in the organisation (Schein 1996, 1984). The espoused values are reflected in the strategies, goals, philosophies, mission statements and credos that the organisation upholds and tries to abide by (Schein 1996, 1984).

To understand how culture impacts on thinking and behaviour the unconscious, underlying assumptions which determine how group members perceive, think, and feel (Schien 1984) need to be understood. Such assumptions are learned responses that originated as espoused values. Values lead to behaviour and behaviour is used to solve the problem. The value is transformed into an underlying assumption about how things really are. As the assumption is increasingly taken for granted, it drops out of awareness.

Thus, as certain motivational and cognitive processes are repeated and continue to work, they become unconscious (Schein 1984).



Source: The Author 2006

Figure 17: Key Components of Resilience

The key components identified as being important include:
Flexibility and problem solving through being results focussed, having the right leadership where the focus is also on innovation and enterprise with the aim of solving problems as quickly as possible. Informal networks also allow for the quick flow of information, problem solving and decision making. Through all of this communication again is key. The ability to work in teams, creating and disbanding teams as required was also identified as being key to problem solving and supporting a quick, flexible and resilient organisation.

Other traits included being conditioned to be innovative and flexible in the event of disruptions. Companies actually prepared for these instances through scenario planning and practising. Power distribution and employee empowerment were also identified as being important. The first response is considered to be critical and thus all are empowered to take action. However, the ability to take the 'correct' action is based on the employees internalising the mission and ethos of the company, on them having a passion and belief for the company, and on employees being adequately and continuously trained and conditioned to the culture, policy and procedures of the organisation.

6.3.2 Flexibility & Agility

In whatever form it has been described, flexibility and agility have been identified by most, if not all, of the authors as being instrumental in creating the resilient supply chain. Some authors do have variations in perspectives as to what the factors are that facilitate flexibility. On the other hand, there are a few characteristics that have been unanimously described as being integral to creating supply chain flexibility.

- Authors agree that some form of postponement of decisions and operations is critical in creating that flexible supply chain. It also has the added advantage of reduced inventory during the course of normal operations as products are stored in their raw or basic form and then built-to-order or configured once the order comes
- Changeability was also identified as being very important. This refers to having interchangeable generic parts that can be used for a number of different items and having the same production layout between plants. With the employees cross-trained across companies this can facilitate moving employees to different plants to work if necessary.
- Running concurrent processes tends to allow for increased production and distribution, but this is also handy as the required production can take place in another plant or location from the one that has been disrupted, thus reducing the required recovery time.
- Demand management (Martha *et al* 2002, Tang 2006, etc) was also identified as one of the (lesser) strategies to increase flexibility. In this instance one is managing demand away from the products that cannot be produced in the crisis to one that can be produced.
- Martha *et al* (2002) and others have also recommended 'just-in-case' strategies that can be used to increase flexibility which include having alternative sourcing, alternative transportation and contractual suppliers (Tang 2006).
- Revenue Management (Tang 2006) through dynamic pricing and promotion to encourage customers away from one product to another.

6.3.3 Redundancy

Redundancy has been described as an insurance premium for the business (Sheffi 2005) and often includes having and increased inventory (Sheffi 2005), multiple suppliers (Bundschuh *et al* 2003, Sheffi 2005), strategic emergency buffers (Bundschuh *et al* 2003,

Sheffi 2001), all with the aim of increasing the supply chain flexibility through increasing the reliability and robustness of the chain (Bundschuh *et al* 2003).

Many of the authors have recommended building redundancy into the system (Christopher and Peck 2004, Bundschuh *et al* 2003 etc). Though redundancy is considered better than having nothing, others have warned against using such strategies as they are very costly and bring a lot of inefficiencies into the system (Sheffi 2005).

6.3.4 Supply Chain Strategy

Strategy refers to whether the company wants to follow lean or other strategies such as having multiple supplier sites, a reduced supplier base, a mixed outsourcing strategy a ~~a~~ decentralised production or distribution strategy. While there are cost and quality benefits to these strategies they can also increase the company's exposure to risk and thus organisations must be aware of the advantages, disadvantages and the risks that may emanate from these decisions.

In terms of the procurement or sourcing strategy, as (Christopher and Peck 2004) suggested, it is not to say that the 'arms-length' strategy is necessarily better than the collaborative strategy, but rather, the strategy employed must be in line with the way the organisation does business. In pursuing the collaborative strategy, the organisation may have reduced its supplier base, and thus, in the time of a disruption the organisation must be certain that the supplier will give them priority. This may mean producing some of the product for them, giving the organisation priority in supplying them, especially if the supplier company is also supplying the organisation's competitor. If the organisation is going to use the 'arms-length' approach, then they will need to have a larger supplier base that they may call on in the event that they are unable to get supplies from some of their usual sources

6.3.5 Communication

While communication has been identified as being an important component in creating the correct culture in the organisation, it goes beyond frequent and formal and informal meetings. Morgan Stanley (Ferris 2002) attributes their fast recovery from the September 11^{th} crisis in part due to their communication systems and networks. Any of the information media could be disrupted and for Morgan Stanley, the telephones were no longer operational, however, they made full use of the intranet, emails and wireless connections (Ferris 2002). They attempted to control inaccurate information through a 'Rumour control' network by issuing information three times per day. They also made use of the crisis hotline, video telecasts, videos and messages sent via voicemail to keep relevant persons informed. The stakeholders such as the directors, staff, clients, regulators, vendors and media were all communicated to.

Additionally, network-wide collaboration, in a crisis or not is crucial. There needs to be quick communication and rapid access to information across the network.

6.4 Supply Chain Resilience: A conceptual model

The information as presented from the various authors has been synthesized and presented below. This is a distillation process that is progressive, but the author presents what she considers to be the key perspectives and themes of resilience in the supply chain (Tables 27 & 28). The perspectives represent the 'strategies' or the 'doing' aspect resilience while the themes represent what the output of this process may be.

Table 27: Key perspectives of resilience in supply-chain

Key perspectives of resilience in supply-chain:

1. Dynamic information interactions –
- External - Quick & timely access of environment (Wei Jait & Endowick 2006)
- Internal - Corporate culture, training and information networks (M.I.T 2006).

2. Collaborative shared strategies –
- Strategic alignment, demand management and network-wide planning (Tomlin 2006, Martha & Sabakhrisna 2002, CLSCM 2003, MIT 2006).

3. Absorptive Capacities–
- Inventory buffering, production mixes, supply and distribution contingency (Lee 2004, Tang 2006, Martha & Sabakhrishna 2002)LSCM 2003, MIT 2006)

Source: The Author 2006

External Dynamic Information Interactions represents the scanning of the environment for relevant information. This can be information on the threat of a natural disaster, a labour dispute, political or economic instability and instability within the supply chain network. This allows for increased transparency and visibility, quicker decision making and hopefully a more proactive response to disasters and disruptions.

The Internal Dynamic Information Interaction represents the bedrock of the organization. It is the culture, training and conditioning of the employees. This incorporates the passion for the business, methods and media of communication, attitude towards problem solving and innovation as well as the company's philosophy to power and command.

Collaborative shared strategies incorporate the various strategies the company will choose to implement and how they will align the business to best utilize these strategies. This considers whether the company wants to use the arms length approach with numerous suppliers or the collaborative approach with a few suppliers. It also includes whether risk management is a network wide affair and to what extent is this so.

Absorptive capacities is the ability of the company to respond to disruptions through inventory buffering system, i.e., if one exist, supply and distribution contingencies, i.e.

where or how the organization continues to receive its supply or distribute its service if the preferred method has been disrupted; and production strategy, i.e. the internal production versus the outsourced production. Absorptive capacities take into account the communication systems, transportation infrastructure, IT infrastructure, human resources and the like.

Table 28: Key themes of resilience in supply-chain

Key themes of resilience in supply-chain:

Robustness – supplier network, contingency planning, production strategy (CSLCM 2003, Tang 2006)

Flexibility – extra capacity, production, procurement & suppliers (Tang 2006, MIT 2005, Lee 2004)

Adaptability – product/service design, cross trained employees, production between plants (MIT 2005, Bundschuh et al 2005, Wei Jiat & Enderwick 2006)

Efficient Communication –responsibility, information networks, supplier & customer relationships, and customer needs (Lee 2004)

Conducive corporate culture – disruptive conditioning, passion, result focused, quick response, empowerment (MIT 2005, CLSCM 2003)

The key themes that have been identified to achieve resilience are robustness, flexibility, adaptability, efficient communication and a conducive corporate culture.

Robustness in the supplier network, considers whether the procurement strategy has been adequately aligned to the supplier network. If the arms length approach is taken, there should be sufficient suppliers to replace a product or service that may have been disrupted. If the collaborative approach is taken then it should be that the focal company is prioritised in the event of a disruption. In the case of production the company may decide to follow a mixed production strategy where some of the production is done in house while the rest is outsourced. This allows for some level of production can still continue if the outsourced supply is disrupted.

Flexibility has been identified as being one key trait of a resilient system and includes concurrent production and distribution processes, multiple suppliers, extra capacity and inventory buffer stock possibly stored in strategic locations.

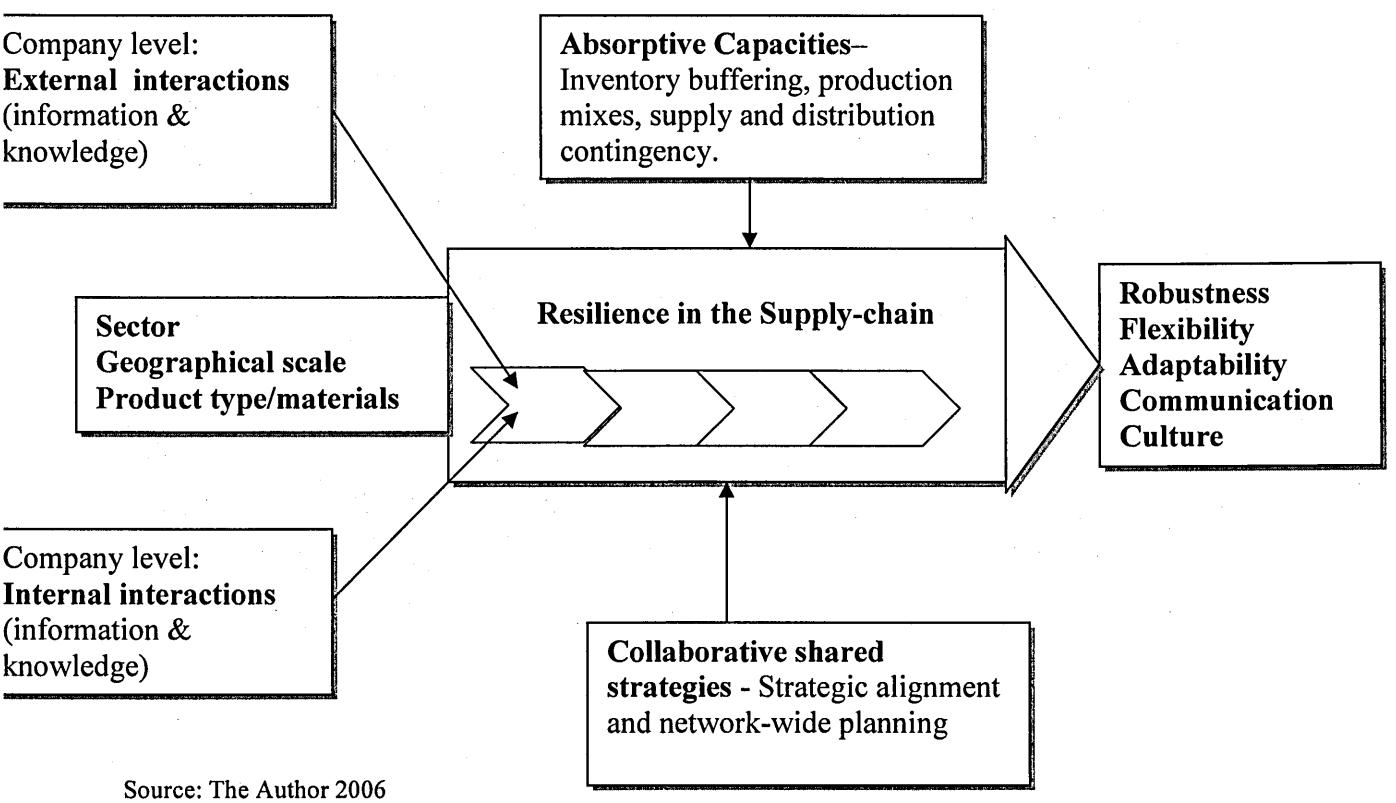
Adaptability refers to the ability of the system to adjust or adapt through the use of modular products or generic parts, the movement of trained employees to different plants or the movement of cross trained employees to perform varying jobs. It also includes the ability of the company to move production between plants as may be required.

Communication continually finds itself to be important throughout any disruption. Information needs to be quickly communicated through the communication network. With the correct network infrastructure and well established supplier and customer relations there is the rapid access to information and increased supply chain intelligence. It is often necessary to determine before hand who are the people or what teams are responsible for communication and through what forum and media.

The passion exhibited by employees, their ability to act quickly, be empowered, be well trained, innovative and results focused all provide the conducive environment that all are able to respond immediately and appropriately in the time of distress. This was evident in the cases discussed by Sheffi (2005), Ferris (2002) that allowed the respective companies to steer their way through the disruptive events.

The above concepts have been synthesized and presented in the model below (Figure 18).

Figure 18: Factors affecting Resilience in the Supply-chain – a conceptual model



Source: The Author 2006

The internal and external interactions are the capabilities of the organisation, i.e. the culture, training, knowledge and information that the organisation possesses and thus are central to the supply chain.

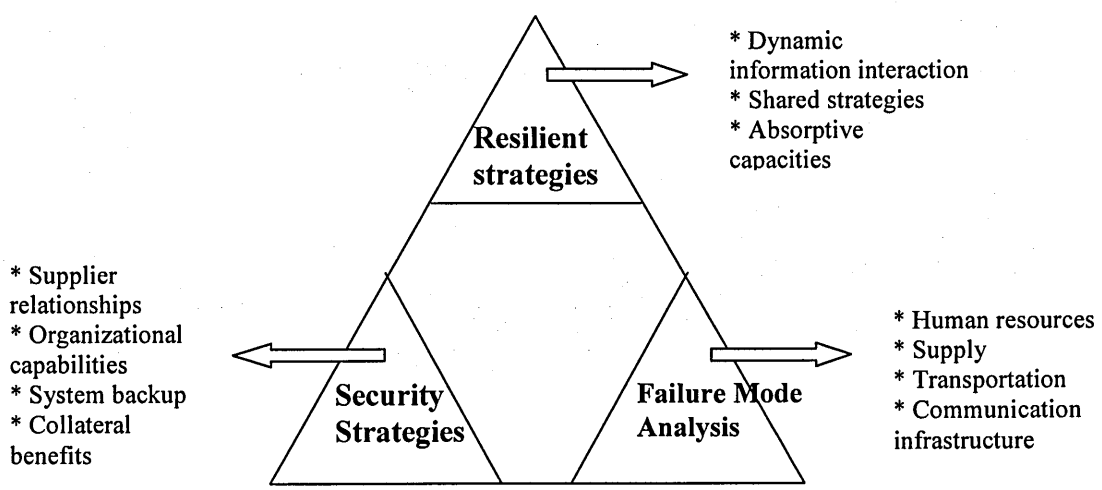
The absorptive capacities and shared strategies are those which are implemented by the organisation and the effectiveness of these strategies are based on the company's internal and external capabilities.

The application of these strategies have to be applied in the context of the sector, product type; geographical location and scale as these influence how the organisation will achieve resilience.

The internal and external interactions or capabilities, the absorptive capacities and shared capacities need to be coordinated and worked together within the context of the sector, location etc to achieve the desirable outcome of resilience, which include robustness, flexibility, adaptability, efficient communication and a conducive culture.

6.5 Approaches to Resilience

Figure 19: Approaches to resilience



Source: The Author 2006

The author also considers that there are varying dimensions companies employ to achieve supply chain resilience (Figure 19). This is through the combined efforts of the supply chain strategies as discussed in chapters five and sections 6.3 and 6.4 above, the use of the failure mode method of analysis and the various methods that provide supply chain resilience as well as security.

The resilient strategy has been comprehensively discussed and thus will require no further elaboration. However, section 5.4.3 identifies that the research has shown that companies also consider what can fail as opposed to how the failure can occur. To this end the failure mode analysis considers:

- Modifying inventory levels, using generic or modular parts and supplier alignment strategy to mitigate against a supply failure.
- Multiple modes of transportation, spot market capacity and the use of logistics providers can be used to mitigate against transport failures.
- Employee cross-training and the modification of production processes for flexibility with human resources
- That communication failure can be mitigated against through the use of a range of media, the back up of data and the installation of a mirrored IT system.
- The use of multiple sites and the modification of the product to use standards processes as a means to mitigate against disruptions at production facilities.

Focusing on security is yet another way of enhancing supply chain resilience. This can be through the technique of layering where various levels of protection exist before a system can fail. Other options for security include ongoing assessments of supplier resilience, establishing emergency operating centres, establishing or improving on supplier relationships along with having a thorough knowledge of trading partners. Developing a secure system also entails backing up all knowledge, information and processes such as communication protocols and decision making procedures; business relationships and the cross training of employees.

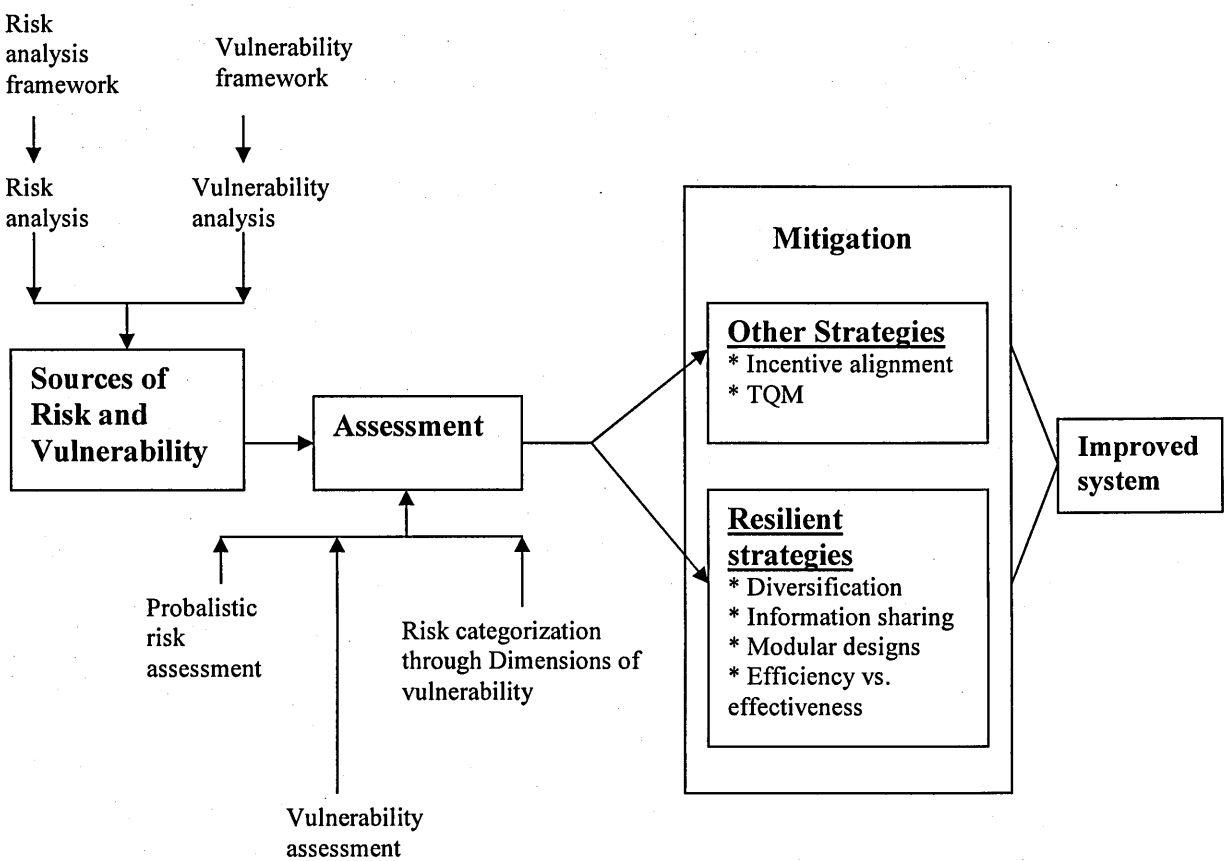
6.6 Disruption Risk Management

The author considers disruption risk management and resilience to be two separate strategies that use similar mitigation techniques (Figure 20). Essentially, resilience seeks to create a system that can 'bounce back' from a disruption, returning to its natural state or maybe even improved state whereas, DRM follows very much along the lines of risk management and thus seeks to identify, assess and mitigate against disruptive events.

The sources of risk are categorized into natural hazards, accidents and intentional disruptions including terrorist attacks and political instability. Determining the causes of risk are opened to the traditional risk analysis framework and the categorization of disruptions and the determining the drivers of supply chain vulnerability as mentioned in sections 5.3 of this report.

The assessment uses the probabilistic risk assessment, vulnerability assessment and the risk categorization through the dimensions of vulnerability into low & high impact/low & high probability framework as mentioned in section 5.3.5 of the report.

Figure 20: Diagrammatic Representation of Disruption Risk Management



Source: The Author 2006

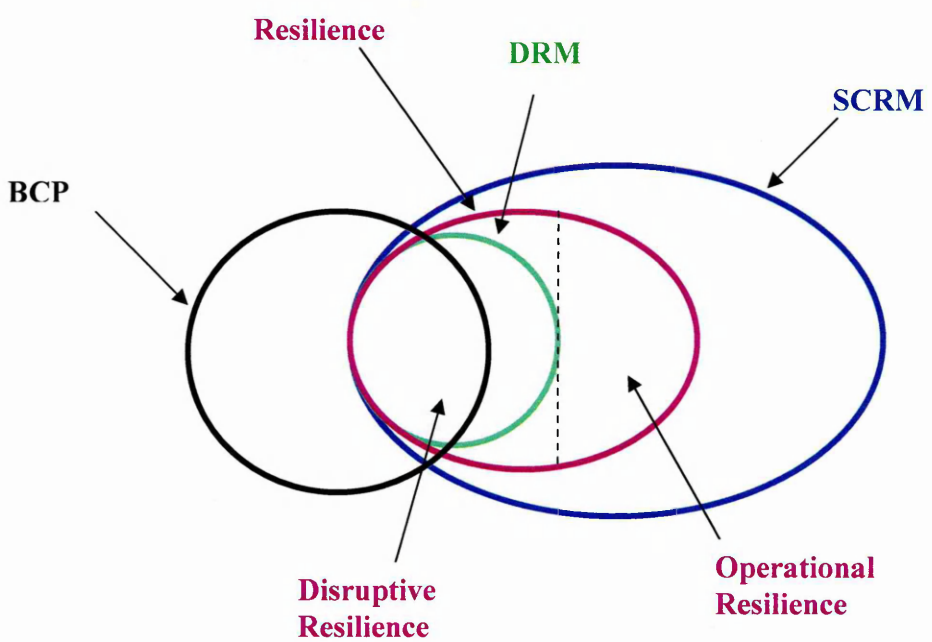
The analysis then moves to the mitigation stage. The principles suggested by Kleindorfer and Saad (2005) to introduce this framework into the organisation are very similar to the strategies that exist, and have been discussed to increase supply chain resilience. The main additions to the mitigation strategy are the use of incentive alignment where new suppliers are encouraged with and present suppliers are provided with incentives to align their business to the focal organisation and the use of Total Quality Management principles of prevention rather than inspection as a strategy to increase resilience.

6.7 Conceptualising the Relationship between Resilience, SCRM, DRM and BCP

The literature has shown that developing a robust, resilient supply chain is not solely hinged on resilient strategies but also includes business continuity strategies, supply chain risk management, supply chain security, failure mode analysis and disruption risk management. Thus this is reflective of what Peck said in 2005, that 'Supply chain vulnerability and resilience is wider in scope than integrated supply chain management and business continuity planning and commercial corporate risk management or an amalgamation of all of these disciplines' (Peck 2005).

Figure 22, the mind map summarizes the Resilient, SCRM, DRM and BCP strategies. The author now envisages supply chain risk management to be the umbrella under which disruption risk management, resilience and some aspects of business continuity are contained (Figure 21).

Figure 21: Conceptualising Resilience, SCRM, DRM and BCP



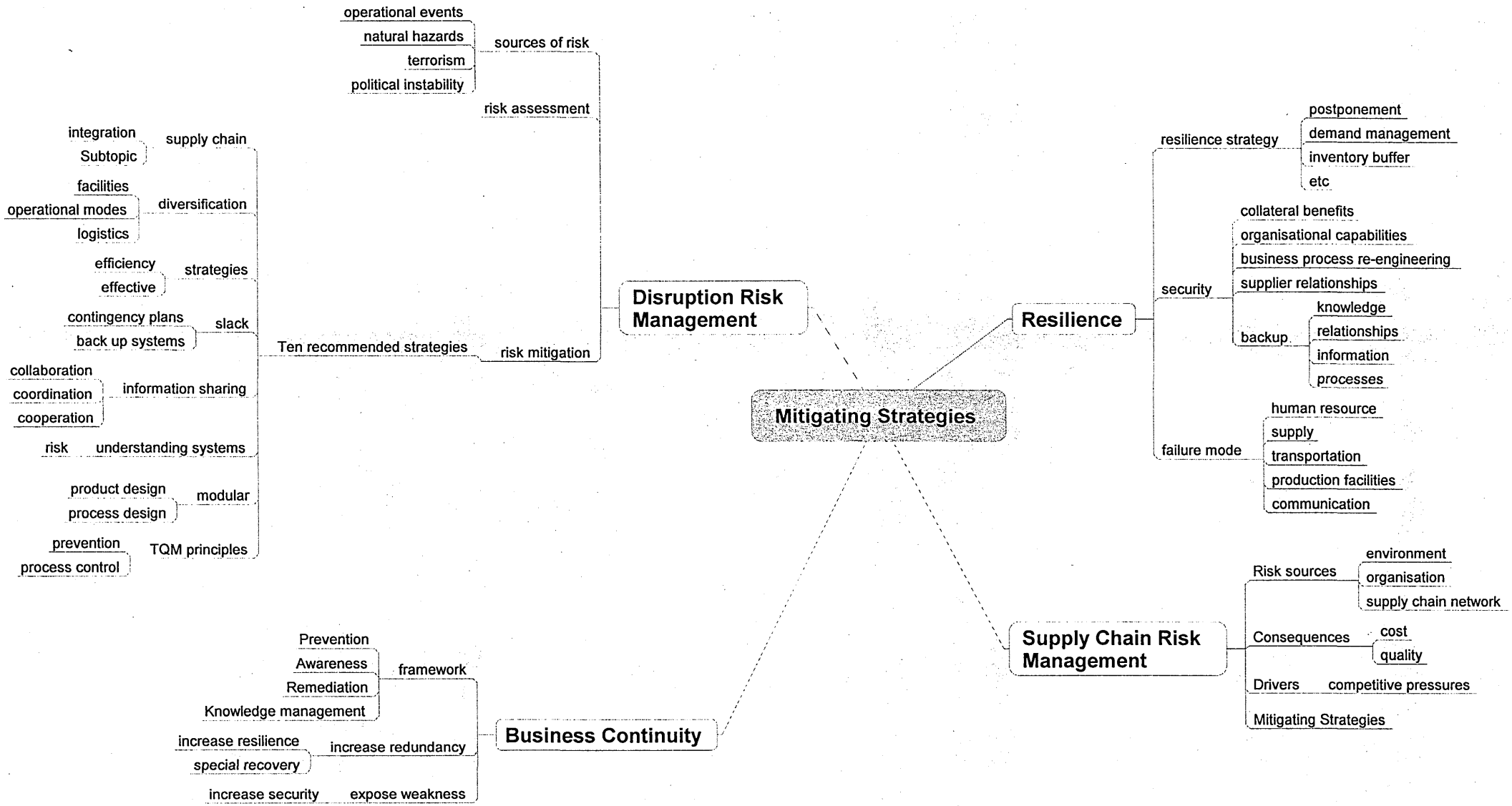
Source: The Author 2006

Supply Chain Risk is all encompassing as it considers any risk in the supply chain that can occur between the original supplier and the end user. This can include operational risk, risk due to competition, changing customer demand, environmental variability and any disruptive event. However, disruption risk management, which draws on the traditional risk management process and supply chain management, is specific to disruptive events attributed to natural disasters, accidents and terrorist attacks and so is merely a subset of SCRM as shown in the diagram above.

The author suggests that two distinct categories of resilience exist, Operational Resilience and Disruptive Resilience. It is suggested that Operational Resilience deals with disruptions on the micro level, due to events internal to the supply chain such as problems in operations. Disruptive resilience is concerned with major disruptive events on the macro level. This is the focal point of disruptive risk management and the resilient strategies proposed have been the central theme of this systematic review. This resilience is closely linked with business continuity planning.

However, the author suggests that for the moment developing a robust, resilient supply chain should focus around supply chain resilience, disruption risk management, supply chain risk management and business continuity (Figure 22).

Figure 22: Mind Map of the Influential Mitigating Strategies



6.8 Research Opportunities

This section is a compilation of the possible areas of research found to be identified by various researchers and authors through the systematic review process. The list is not intended to be exhaustive, but certainly highlights the potential for research in the future (Table 29).

Table 29: Research Opportunities

Research Opportunity	Source
Research on inter-organisation dependency and a more cohesive industry-wide approach to 'business continuity' in the study of the supply chain	Christopher & Peck 2004
Research that supports the importance of resilience of a company's supply chain as part of the overall approach to risk and business continuity management	Christopher & Peck 2004
The implications of anti-terrorism measures implemented by the US authorities and their impact on domestic business and international trade.	Christopher & Peck 2004
Modern supply chains are at greater risk than many managers recognize and it is not clear that the risk from within the demand/supply network is always apparent. There is generally the lack of understanding of the wider supply/demand network amongst managers.	Christopher & Peck 2004
Few grounded studies of supply chain risk/vulnerability have been published	Peck 2005
The need for individual business entities to understand the extent of the network of which they are a part of, and opportunity to systematically explore the network identifying its vulnerabilities.	Christopher & Peck 2004
The need for formalized procedures for supply chain risk management within and between organizations	Christopher & Peck 2004
The construct of vulnerability has principally been explored quantitatively (Svensson 2000, 2002a, b). As such, further research is required into the qualitative features of the construct of vulnerability	Svensson 2004
The research on the constructs of corporate vulnerability in the upstream and downstream supply chains, based on qualitative data suggest that the findings should not be generalised beyond the automotive industry where the research was performed (Svensson 2004). Thus there should be further research into corporate vulnerability in other supply chains	Svensson 2004
The impact of the visibility line (i.e. the degree of transparency or obscurity) on corporate vulnerability in supply chains needs to be further explored	Svensson 2004
Further empirical testing and evaluations have to be performed in order to test the validity, the reliability and the universal applicability of the developed conceptual framework of vulnerability	Svensson 2000
The conceptualisation of the construct of vulnerability in firms' inbound and outbound logistics flow was done in the Swedish automotive industry and thus the findings may not be generalisable beyond this industry and it may also not be transferable to other countries	Svensson 2002
A focus on how the upstream vulnerability in a specific supply chain affects the existence, or the occurrence of downstream vulnerability in the same supply chain and vice versa	Svensson 2002
The impact of JIT and other lean manufacturing principles in inbound and outbound logistics on vulnerability in the supply chains.	Svensson 2002
Several frameworks have been proposed to guide purchasing organisations in their assessment of the risk that exists with inbound supply, however, few studies exist that explore the key constructs necessary for assessing supply risk	Zsidisin *et al* 2004
Developing and conducting a survey of supply risk assessment techniques to triangulate the initial case study research findings	Zsidisin *et al* 2004
The need to discover the cost-effective opportunity for risk mitigation while	Kleindorfer

simultaneously providing the means to share the investment and insurance costs that must be in place to finance ex ante and ex post relief from the consequences of disruptions	and Saad (2005)
The methods and tools to assess risk of terrorism is lacking	Rice 2003
There are a few ways then that supply chain flexibility is perceived. Much of the practitioner literature emphasises the importance of supply chain flexibility for successful operation in the global environment, however, little research has been done to define what constitutes supply chain flexibility	(Duclos *et al* 2003).
The relationship between corporate strategy, risk and implications for supply chain management are poorly understood	Juttner et al 2003
A better understanding of the source of various sources of supply chain risk and vulnerability, particularly from a supply network perspective	Juttner et al 2003
A method or framework for determining how risk implications can be anticipated at an earlier stage.	Juttner et al 2003
Observations of past supply chain disruptions such as Kobe, earthquake, 1995; Quebec ice storm, 1998; major strikes and disasters etc to determine and to give insight into the variety of prevention and response mechanisms. This can be applied to dealing with any type of disruption	Rice & Caniato 2003
Further development of tools to adequately assess risk of their specific network	Rice & Caniato 2003
The development of an analytical model for the dual supply arrangements suggested by Sheffi to increase resilience	Bundschuh et al 2003
The analytical formulation for the integration of strategic emergency stock in the supply chain as suggested by Sheffi	Bundschuh et al 2003
An investigation of the uncertainty over oil prices and the future cost effectiveness of the global supply chain (due in part the military action in the Middle East)	Peck 2005
The need to conduct an in-depth multi-tiered case study on each of the sectors used to validate the findings of the aerospace case study. The aerospace study highlighted the absence of any understanding of the scope and dynamic nature of the sources and drivers of vulnerability	Peck 2005
Further work on the integration of supply chain risk and conventional risk management concepts and taxonomies.	Peck 2005
A need for more conceptual and empirical research on disaster planning for logistics managers and supply chain managers	Hale & Moberg 2005
To determine the extent to which supply chains are able to cope with uncertainty and emergencies	Lee 2004
The study of BCP from a solely empirical perspective to a theory oriented perspective	Zsidisin *et al* 2004

Source: The Author 2006

6.9 Conclusion

This chapter is a synthesis of the information presented in the previous chapters. Models for supply chain vulnerability, resilience and the approaches to resilience were presented. The author also presented a conceptual framework of resilience and a conceptual diagram representing Resilience, DRM, SCRM and BCP. Possibilities for further research as explicitly identified in the literature have been presented.

The following chapter describes some elements of the author's journey through this learning process.

CHAPTER 7

7. LEARNING EXPERIENCE

7.1 Introduction

Before the author concludes the report, it was thought useful or helpful to share the feelings, perceptions, concerns and triumphs through the journey of discovery[36]. To this end, this is what this chapter is set to do.

7.2 Reflections

The review and methodological process at times seemed more suited to fields such as medicine that, once the techniques are adequately applied, should yield similar results. Essentially, in the social sciences this process, and thus the results, seems very much subject to the researchers' biases and limitations. So though this process is transparent, I hesitate to say that it is replicable though it does minimize bias and errors.

Carrying out the systematic review required two main types of knowledge, one, of the field that is being researched and two, of the techniques and tools required to complete the process. Firstly, knowledge of the field guards from doing repetitious work, which at times I felt I was doing, thus not necessarily contributing anything new at the moment. It felt like a big data gathering exercise to say things that have already been said. A more adequate knowledge of the field would have prevented the 'repeat' work. While this is part of the learning process, it seemed to be somewhat 'time-wasting', which was crucial when time was a limited resource. Secondly, the process of carrying out the systematic review, searching, finding, recording, selecting and synthesising the data still had to be learned.

The key is in generating the appropriate keywords and search strings. This is a crucial element of the research and is probably one of the areas that I found very challenging, i.e. to develop the search strings that will uncover the precise papers that provide the information on which to 'hang' the report. The panel members Ms. Heather Woodfield and Dr. Paul Chapman were very helpful at this point. Additionally, Ms Woodfield and Dr. Denyer were extremely instrumental in identifying more suitable boundaries for the scoping study and the systematic review.

In addition to generating the search strings the inclusion and exclusion criteria were also considered critical, but I did not experience too much difficulty here as there is not much literature in this area, and thus I did not experience a challenge in determining the boundary conditions for the research.

The papers that passed the inclusion and exclusion analysis stage were then quality assessed. There is room for subjectivity when applying the quality assessment criteria as it is opened to the biases, experience and perceptions of the researcher. Some papers that

[36] This was seen in a previous report and thought to be a good idea. – From Luis Coehlo (2005)

were originally accepted needed to be reassessed as they were later found to be lacking in information or new contribution to the research. It was then thought prudent to recheck some of the papers that were originally rejected. Papers were not accepted but were used as a reference source. The process in itself was not complete and should not stand on its own. This is where the experience of the panel and cross-referencing came into play and were thus very important. I was then able to get papers and new ideas that I would not have had, had I relied solely on using the search strings and databases, working papers and citation databases.

Initially, I could not conceptualise how to synthesise and present the information, but discussions with my supervisor, Professor Wilding, did bring some ideas and clarity which were very helpful, greatly appreciated and well used.

At times it did seem that I was doing two, or three projects, one, enhancing the scoping study, two, focussing on the key findings and developing that area, and three, ensuring a transparent, replicable and auditable process to be written up as the methodology. This, I found distracting, as just as much or even more time was spent recording the data as was spent analysing and synthesising it to produce a sensible and creditable piece of work. At times, the process seemed too structured as in recording all the figures, actions and decisions, some potential 'leads' for papers were unexplored due to the immensity of the project. I did however, try to capture the evolution of thought, concepts and questions in the methodological diary (refer to the appendix). This was recommended in a previous review and thought to be a good idea (Lupson 2004).

7.3 Conclusion

In this chapter the thoughts and perceptions and feelings when carrying out this systematic review process were discussed.

Though the systematic review process may be a tedious one, I do believe that there is a lot of merit and good that comes out of it. It allows for focus and guidance, particularly if one enjoys processes. This was then a 'mixed bag' as I think it is good, but very tedious and requires persistent, meticulous and constant work to successfully complete the process. The development and reference to the consultation panel is very useful. The use of the databases and learning about data gathering from other sources of information are an invaluable skill, and thus a good head start into the academic career. Limitations, such as the researchers' bias and inexperience and the inability of the technique itself to uncover all the sources of information, are mitigated through the assistance of the expert panel. I am in agreement that, though sometimes too structured, it does give a more sound output than the traditional review process.

The following section provides the conclusion to the report where I revisit the objective and the research question to determine where all the elements or questions previously presented have been answered and, if not, then some explanation is presented. I also try to develop opportunities or ideas for further research that can be taken to the stage of the PhD.

CHAPTER 8

8. CONCLUSION

8.1 Introduction

There are three main aims to this chapter.

The first aim is to revisit the research question and supporting questions to discuss whether the report has indeed fulfilled its original aims and objectives, and the extent to which these have been fulfilled. This section highlights ambiguities and concerns that have evolved from the research.

The second aim of the research is to identify the limitations of this research piece. This acknowledges that there are things that could have been done better. It also signals to others that there are varying perspectives that could have been taken to complete the report.

One of the key aims of this research piece is establish further research questions on which to build the PhD. To this end, this report sought to provide the foundation for further PhD research by discussing relevant bodies of literature that will influence that work and through the descriptive and thematic analysis, establish gaps in the literature on which to build the PhD research. To this end, the third and final section presents various ideas, questions and research opportunities that can be taken to the PhD stage.

8.2 Discussion

A lot of work and research findings have been presented through the course of the report, but the task at the end of it all, is to determine if and how well the aims and objectives have been met. For this we revisit the research question:

Disruptive Risk Management: What makes supply chains resilient to low probability/high impact disruptions to the inbound and outbound aspects of the supply chain?

The supporting questions included:

4. How are vulnerability and resilience related in the supply chain context?
    a. What are the definitions of a resilient supply chain and the global resilient supply chains?
    b. How do you create resilient supply chains?
    c. Is there a framework for resilient supply chains?
    d. Are resilient strategies the key approach to managing disruptions?
    e. How do you define vulnerability?
    f. Have the supply chain strategies such as single sourcing and lean manufacture truly made the supply chain more vulnerable to the types of

risk under discussion? Are there other factors that cause systems to be vulnerable (besides lean strategies)?

g. How were risk and vulnerability managed before the emergence of lean strategies and such other strategies?

5. What are resilience considerations for the inbound and outbound aspects of the supply chain?
6. How are Business Continuity and Supply Chain resilience related?

8.2.1 Defining resilience and creating a resilient supply chain

In 5.4 a definition of supply chain resilience was presented, however, specific reference was not made to the global resilient supply chain. This was due on part to the fact that the literature did not make specific reference to the global supply chain and it was taken that the supply chains that are most affected by the described disruptions or disruptive events are the extended or global ones.

This section then proceeded to present the various perspectives of resilience as presented by various authors. Many authors presented frameworks, or concepts by which to create a resilient supply chain, the most recommended methods included the postponement of decisions and operations to as late a stage as possible; increased redundancy through increased inventory, buffer stock and multiple suppliers; better communication through the free and quicker flow of information with customers and suppliers; corporate culture and strategy alignment with respect to the procurement, production and distribution strategy for example.

8.2.2 Are resilient strategies the key approach to managing disruptions?

Resilience strategies are a key approach to managing disruptions. However other approaches such as Business Continuity, Supply Chain Risk Management and Disruption Risk Management have also been identified in managing disruptions.

Supply Chain Risk Management seems to provide the broad perspective of risk in the supply chain, incorporating operational and disruptive events, while disruption risk management seems to focus mainly on disruptive events. Additionally, there is no clear distinction between business continuity and resilience. However, chapter five and figures 12 and 22 show there is a significant overlap in the strategies used to mitigate against these risks. Therefore, as the literature has suggested, these core fields are yet to be clearly understood and thus integrated in a coherent way.

In addition to the strategies mentioned above, there is the failure mode analysis which seeks to plan and manage disruptions through looking at the things that can fail a system. Consequently, these are other areas or ways in which companies can plan for disruptions. The fact is that companies may need to combine strategies to ensure a robust network.

8.2.3 How is vulnerability defined?

Section 5.3 seeks to focus on the concept of vulnerability. Vulnerability has been defined as an exposure to serious disturbance arising from risk within the supply chain as risks internal to the supply chain (Christopher & Peck 2003). The present stage of vulnerability analysis has been defined and discussed. Two methods of determining the sources of risk and vulnerability have been presented. The first method considered the sources of vulnerability as presented by Peck and associates. This considered the origins of risk and vulnerability on the four levels of the value/ stream product or process, the asset and infrastructure dependencies, the organisation and inter-organisational networks and the environment. The second, which was presented by Svensson, considered the construct of vulnerability through four different conceptual frameworks. Once the source of the disturbance has been understood the dimension of the disturbance, i.e. its disruption probability and consequence then needed to b determined.

8.2.4 Have the supply chain strategies made the supply chain more vulnerable to the types of risk under discussion?

Though not explicitly defined or discussed in this report, the literature has clearly identified that globalisation and supply chain strategies such as single sourcing, and 'lean' manufacture have increased supply chain risk, thus making them a lot more vulnerable to disruptions.

Additionally, if one considers that vulnerabilities cause disruptions, then one is open to think of other ways in which supply chains are vulnerable to disruptions. This can be through new product innovations, operation or process problems, or increased competition. However, the focus and thrust of this dissertation has been towards what has been coined 'disruptive events' due to low probability/high impact events, where events such as operational problems and new product innovations may not be easily categorised.

8.2.5 How were risk and vulnerability managed before the emergence of lean strategies and such other strategies?

In retrospect, this is a very 'weighty' question as it does not distinguish between risks internal and external to the organisation and risks internal or external to the supply chain. Of course, the issue of the supply chain would not have been as relevant before as this area is relatively new with increasing emphasis over the last 20 years. However, there are two elements which exist when considering the question.

Firstly, the area of risk and operational risk, though not defined in this report has a well established history and thus, these were the techniques applied to managing risk previous to this era. This has led many authors to comment that the traditional risk management framework and models were no longer applicable in dealing with the evolving supply chain risk (refer to section 2.5.3). Additionally, as identified in section 2.4, Crisis Management, Contingency Planning and Disaster Preparedness techniques were used to manage risks that were external to the organisation.

Secondly, the original question of 'How were risk and vulnerability managed before the emergence of lean strategies and such other strategies?' seems to imply that lean manufacture in a sense solely brought about this new type of risk and vulnerability. This is not entirely correct. The way the world does business has significantly changed, with globalisation, increased networked organisations and, yes, supply chain strategies as well. Thus disruptive events will have more of a profound effect now than they would have had in the past, since more organisations are networked. But two things have also changed. Firstly, the threat of natural disasters has increased due to changing weather patterns (Herbane et al 2004) and the changing landscape of the world. Secondly, there has been an increase in terrorist activity, especially in places such as the US and the UK. To compound the issue, in the event of such threats, governments impose restrictions on air travel and the like, which then severely cripples the movement of goods. All of these issues together make managing supply chain risk and vulnerability much more difficult in this era and thus cannot be compared with previous eras.

8.2.6 What are resilience considerations for the inbound and outbound aspects of the supply chain?

A clear distinction between the various effects of disruptions to the inbound and outbound aspects of the supply chain was not established. The review process has highlighted that no clear distinction exists between supply chain inbound and outbound resilience strategies. Section 5.4 however, does mention that Tomlin recommended some mitigation and contingency tactics for the supply side while Tang provided two major classifications of the supply management issues of supplier selection and relationships, supply planning, transportation and logistics and the demand management issues which included demand planning, product line planning, promotion planning etc. However, following this, the nine suggested robust strategies suggested by Tang did not differentiate between the inbound and outbound aspect of the supply chain.

8.3 Research Reflections

No project would be complete without a critique of the process and an identification of what could have been done differently were this to be redone. This is what this section sets out to identify, limitations and thus potential areas of improvement in the report.

With respect to the process there are some specific areas that needed augmenting:

- Though the well known databases such as Proquest and EBSCO were used it would have been good to include a search of other databases such as Scopus.
- With respect to working papers it would may have been beneficial to be able to refer to other databases such as that provided by the Judge Business School Library which source working papers from academic institutions around the world.
- It was unfortunate that it was not possibly to liaise with practitioners as had originally been intended. It is believed that their comments would have most certainly enhanced the outcomes of the report.

- In the case of the descriptive analysis it would have been good to be able to provide a thematic representation of the papers chosen as the key papers to show which themes took precedence in which year.

With increased understanding there are various aspects that are now better understood and could be further pursued:

- I would specifically try to distinguish between demand side and supply side resilient strategies. Tang (2006) and to a lesser extent Tomlin (2006) did attempt to do this
- I think great scope exist for trying to understand supply chain risk management which was not fully understood and appreciated in the outset of this review and were this paper to be redone, this would take a more central place in the analysis
- The author is of the opinion that disruption risk management still needs more definition. Other themes that emanated from the research included terrorism and security, business continuity, disruption risk management and supply chain risk management. The author now considers these as overlapping areas, but yet distinct areas of research and thus, it was felt that justice was not done to these areas through the course of the review. Only one paper makes specific reference to the term Kleindorfer and Saad (2005) and thus it is believed that this area requires more synthesis and understanding.
- The author has identified some ambiguity in her own understanding of vulnerability. Though this is considered important in understanding resilience it is felt that more could have been done to integrate vulnerability in the synthesis of the review.

8.4 Further Research

This area is rich with possibilities that can either generate several interesting PhDs or opportunities for further research. It is a shame to have to take only one idea further. However, the ideas and questions that the author considers interesting and hence would like to take forward to the next stage of the PhD are presented below.

1. How to create a business case to implement a supply chain resilient strategy in an organisation?: the strategic and business template for supply chain resilience.
   The possibility exist to do achieve this through the case study approach

2. How do companies decide on which strategies will provide them with a flexible supply chain? To what extent does the company apply flexible and agile strategies to ensure the resilience of the organisation and the supply chain? What are the tensions in resource allocations towards establishing and implementing a resilient strategy?
   A framework for determining the best flexible strategies to be implemented in the organisation can be developed.
   This question lends itself to a one or three case study analysis approach

3. A comparative study: What were the response mechanisms that helped companies and supply chains through disastrous effects such as the Kobe earthquake (1995), the Quebec storm (1998) or SARS (2003)? How can the knowledge gained be used to plan for supply chain disruptions such as further natural disasters or other pandemics?
   A combined methodological approach can be used by the way of the case study analysis and a quantitative analysis approach.

4. Are there levels of resilience, i.e. is there a micro or operational level resilience or a macro, environmental level of resilience (disruptive resilience)? If this does exist how can they be defined and applied to organisations? Can a company be micro level resilient and not macro level resilient and vice versa? If there is a macro level or disruptive resilience how fundamentally different is this from business continuity planning?
   Again this lends to the single case study approach. The findings or conceptual framework that would be developed can then be applied and tested across other companies to determine its validity.

5. What are the most effective demand side disruption management and resilient strategies? An empirical study.
   Given the information and understanding thus far of supply chain resilience a conceptual framework can be developed and tested quantitatively to determine the best demand side disruption management and resilient strategies.

6. Is resilience measurable? How is resilience measured? Is resilience static or changing? Can a company move in and out of being resilient?
   The preference would be to perform a quantitative method of data gathering and analysis.

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APPENDICES

Appendix 1: Pre-Crisis Planning Process

Pre-Crisis Planning Process developed by Perry and Lindell (2003). Taken from McConnell & Drennan (2006).

The Process should:

1. Be based on accurate knowledge of threats and likely human responses
2. Encourage appropriate action by crisis managers
3. Encourage flexibility in responses
4. Promote inter-organisational coordination
5. Integrate plan for each hazard into a multi-hazard approach
6. Involve the training of relevant personnel
7. Provide for testing through drills and exercise
8. Be adaptable through an ongoing process adjustment to new circumstances
9. Be a strong advocate in the face of inevitable resistance to resources commitments for low probability events
10. Recognise the differences between crisis planning (preparedness) and crisis management (implementation and performance)

Appendix 2: Break down of search results

These tables give the details of the search over various databases. Duplicates have not been accounted for, and thus the numbers do represent papers that have been duplicated.

Resilience

1. ((Supply OR demand OR Logistics OR Distribution OR Production) AND (Chain or network)) and ((Resili* OR robust OR reliable OR (ultra reliable) OR flexib*))

Database	Initial Search	Rejected	Accepted	Acceptance Rate (%)
ProQuest	1026	1007	19	1.85
EBSCO	1401	1366	41	2.9
Science Direct	571	550	21	3.67
Google Scholar	14	13	1	7.14

2. ((Supply OR demand OR Logistics OR Distribution OR Production) AND (Chain or network)) AND ((Lean AND (thinking OR manufactur* OR produc*)) OR (just-in-time OR JIT) OR (Toyota production system OR TPS) AND (Resili* OR robust OR reliable) OR (ultra reliable) OR flexib*)

Database	Initial Search	Rejected	Accepted	Acceptance Rate (%)
ProQuest	41	35	6	14.63
EBSCO	47	44	3	6.38
Science Direct	729	710	19	2.60
Google Scholar	2	2	0	0

3. ((Supply OR demand OR Logistics OR Distribution OR Production) AND (Chain or network)) AND ((single AND (sourc* OR supply)) AND (Resili* OR robust OR reliable OR (ultra reliable) OR flexib*))

Database	Initial Search	Rejected	Accepted	Acceptance Rate (%)
ProQuest	34	32	2	5.88
EBSCO	53	52	1	1.88
Science Direct	3731	3700	31	0.83
Google Scholar	7	6	1	14.29

Vulnerability

4. ((Supply OR demand OR Logistics OR Distribution OR Production)) AND (Chain or network) AND (Vulnerab* OR risk OR exposure OR uncertain*)

Database	Initial Search	Rejected	Accepted	Acceptance Rate (%)
ProQuest	922	895	27	2.93
EBSCO	1485	1402	83	5.59
Science Direct	1502**	1467	35	2.33
Google Scholar	22	22	0	0

** Search done on titles only as the advanced search produced over 50 000 articles and the title, abstract and keyword search produced over 10 000 hits

5. ((Supply OR demand OR Logistics OR Distribution OR Production) AND (Chain or network)) AND ((Lean AND (thinking OR manufactur* OR produc*)) OR (just-in-time OR JIT) OR (Toyota production system OR TPS)) AND ((Vulnerab* OR risk OR exposure OR uncertain*))

Database	Initial Search	Rejected	Accepted	Acceptance Rate (%)
ProQuest	8	7	1	12.50
EBSCO	34	28	6	17.64
Science Direct	5*	3	2	40.00
Google Scholar	0	0	0	0

* Search done on titles, abstracts and keywords as the advanced search produced approximately 5 000 articles

6. (Supply OR demand OR Logistics OR Distribution OR Production) AND (Chain or network) AND (single AND (sourc* OR supply)) AND (Vulnerab* OR risk OR exposure OR uncertain*)

Database	Initial Search	Rejected	Accepted	Acceptance Rate (%)
ProQuest	52	49	3	5.77
EBSCO	50	43	7	14.00
Science Direct	27 ***	22	5	18.52
Google Scholar	21	20	1	4.76

*** Search done on titles, abstracts and keywords as the advanced search produced approximately 10 000 articles

Disaster Management

7. ((Supply OR demand OR Logistics OR Distribution OR Production) AND (Chain or network)) AND ((Disaster OR crisis OR event OR catastrophe OR emergency)) AND (preparedness OR management OR planning OR study)

Database	Initial Search	Rejected	Accepted	Acceptance Rate (%)
ProQuest	300	283	17	5.67
EBSCO	425	408	17	4.00
Science Direct	424 ***	416	8	1.92
Google Scholar	101, 000	-	8	-

*** Search done on titles, abstracts and keywords as the advanced search produced approximately 10 000 articles

Contingency Planning

8. ((Supply OR demand OR Logistics OR Distribution OR Production) AND (Chain or network)) AND (Contingency planning) OR (risk AND (mitigation OR avoidance OR removal))

Database	Initial Search	Rejected	Accepted	Acceptance Rate (%)
ProQuest	39	20	19	48.71
EBSCO	499	453	46	9.21
Science Direct	15***	13	2	13.33
Google Scholar	7060	-	12	-

*** Search done on titles, abstracts and keywords as the advanced search produced over 10 000 articles

Appendix 3: Summary of Core Papers

Author & Title	Journal	Country	Service Context	Research Category	Sample Size	Summary Findings
Chopra, Sunil & Sodhi, ManMohan (2004), Managing Risk To Avoid Supply-Chain Breakdown	MIT Sloan Management Review	US	General	Theoretical	N/A	Presented the 'universe' of risk categories. Risks are interconnected and managing one can exacerbate another for example, lean supply, which decreased the impact of overforecasting demand, increases the impact of supply chain disruption. Table of mitigation strategy that greatly increases or decreases risk presented.
Juttner, U, Peck, H & Christopher, M (2003), Supply Chain Risk Management: Outlining an Agenda for Future Research	International Journal of Logistics	UK	Industrial, consumer and service industries	Empirical	Not specified	Clarifying, supply chain risk management. Supply chain concept and basic construct. Supply chain risk sources and risk consequences presented. Also identifies framework for directing future research in Supply Chain Risk Management.
Christopher, M (2004), Creating Resilient Supply Chains	www.exel.com	UK	General	Theoretical	N/A	Presents basic principles underpinning the creation of more resilient supply chains, e.g. supply chain understanding, supply strategy, collaboration, agility and culture
Sheffi, Y & Rice Jr, J (2005), A Supply Chain View of the Resilient Enterprise	MIT Sloan Management Review	US	General	Theoretical	N/A	Presents the disruption profile, i.e. stages of a disruption, the vulnerability framework and ways of building resilience in the supply chain
Christopher, M & Peck, H (2004), Building the Resilient Supply Chain	The International Journal of Logistics Management	UK	General	Theoretical	N/A	Includes risk categorisation and sources of risk in SC. Looks at ways in increase supply chain resilience through supply chain reengineering, supply chain collaboration, agility, and creating a risk management culture
Sheffi, Y (2001), Supply Chain Management under the Threat of International Terrorism	The International Journal of Logistics Management	US	General	Theoretical	N/A	Looks at preparing to deal with the aftermath of a terrorist attack and operating under heightened security. Analysing through supplier relationships, inventory management and knowledge and process back-up. Also looks at the importance of improved visibility, collaboration and risk pooling
Rice, Jr J (2003), Supply Chain Response to Terrorism: Creating Resilient and Secure Supply Chain'	MIT Center for Transporation and Logistics	US	General	Theoretical	N/A	How Terrorism and its threat are affecting supply chains. Considered disruptions to supply, transportation, facilities, communications and human resources which are core to the continuity of the firm. Looks as responding or preparing for a disruption through the failure mode

Kleindorfer, P. & Saad, G (2005), Managing Disruption Risks in Supply Chains	Production and Operations Management	US	General	Theoretical	N/A	Introduces the theory of disruption risk management, Source, Assessment and Mitigation (SAM). Conceptual framework for risk management and mitigation presented.
Foster, S & Dye, K (2005), Building continuity into strategy	Journal of Corporate Real Estate	US	Corporate Real Estate and Workplace Resources, Energy, Financial Services, Technology, Telecom	Empirical	Twelve	Paper on the gives the evolution of business continuity planning. Highlights the important aspects of BCP which include culture, programme governance, the degree of formalised policies and procedures, BCP offices were small but highly leveraged into the organisation
Sheffi, Y (2005), Building a culture of flexibility	World Trade	US	General	Theoretical		The importance of culture to ensuring supply chain flexibility. This can include teamwork communication, informal networks based on personal relationships, continuous communication among informed employees, passion for job and distributed power
Christopher, M (2000), The Agile Supply Chain: Competing in Volatile Markets	Industrial Marketing Management	UK	General	Theoretical		The use of agility to create flexible systems. The routes to agility include market sensitivity, use of information technology, shared information between supply chain partners. Also looks at the need to reduce complexity to enhance agility.
Duclos et al (2003), A Conceptual model of supply chain flexibility	Industrial Management & Data Systems	US	General	Theoretical		Forms a conceptual model of supply chain flexibility. Gives some historical background to it and looks at how flexibility was treated in the literature. Looks at Supply chain flexibility in the supply chain
Prater et al (2001), International supply chain agility: Tradeoffs between flexibility and uncertainty	International Journal of Operations & Production Management	US	Computer	Case study & theoretical	Five	Defines supply chain agility that the organisation is broken down into three basic segments of sourcing, manufacturing and delivering and focuses on the external vulnerability of the supply chain. Graphically represents the supply chain trade-off between supply chain agility and complexity
Bundschuh et al, 2003, Modelling Robust and Reliable Supply Chains	Unpublished paper	US	General	Empirical		Traditionally designed supply chains cannot deal with the disruptions due to unanticipated events. Have suggested postponement and redundant techniques to build a reliable and robust supply chain. Model to create a robust and reliable inbound supply chain taking into account disruptive events.

Sheffi, Y (2005), Manage Risk Through Resilience	Chief Executive	US	General	Theoretical		Discusses how resilience is achieved, i.e., through redundancy and flexibility, i.e., the ability to move the product between plants, using concurrent processes, postponement and aligning the procurement with supplier relationships
Christopher, M (2005), Coping with complexity and chaos: Enterprise Supply Chains must be both responsive and resilient	Financial Times	UK	General	Theoretical	N/A	Itemises why supply chains have become vulnerable to disruption risks, i.e., the focus on efficiency rather than effectiveness, the globalisation of supply chains, focussed factories and centralised distribution, reduction of supplier base. It suggests how to achieve supply chain resilience.
Ferris, G (2002), Response and recovery at Morgan Stanley	Risk Management	US	Financial	Case study & theoretical	One	Gives a good case study of how Morgan Stanley developed its Business Continuity and Crisis Management Plans, hence being able to respond positively to the attacks of 9/ 11.
Peck, H (2005), Drivers of Supply Chain Vulnerability: an integrated framework	International Journal of Physical Distribution & Logistics Management	UK	Aerospace	**Case study & theoretical**	One	Indicates that few grounded studies of risk and vulnerability exist. There is also a lack of understanding of vulnerability and the sources and consequences of the risk that supply chains face in the global environment. Developed a framework (with four levels) for the sources and drivers of supply chain risk
Svensson , G (2000), A conceptual framework for the analysis of vulnerability in supply chains	International Journal of Physical Distribution & Logistics Management	Sweden	Automotive	**Case study & theoretical**	One	Develops the conceptual framework to analyse vulnerability. This framework consists of two dimensions, categories of disturbance (qualitative and quantitative disturbances) and sources of disturbance (atomistic and holistic disturbances)
Svensson , G (2002), A Conceptual framework of vulnerability in firms' inbound and outbound logistics flow	International Journal of Physical Distribution & Logistics Management	Sweden	Automotive	Case study & theoretical	One	This considers that time and functional dependencies cause vulnerability. Has conceptualised the construct of vulnerability in a firm's inbound and outbound logistics flow
Svensson , G (2004), Key area, causes and contingency planning of corporate vulnerability in supply chains: a qualitative approach	International Journal of Physical Distribution & Logistics Management	Sweden	Automotive	Empirical	229	Examines companies' perceptions of corporate vulnerability in supply chains. The perception of the key areas and causes of corporate vulnerability are limited

Svensson , G (2002), A typology of vulnerability scenarios toward suppliers and customers in supply chain, based upon perceived time and relationship dependencies	International Journal of Physical Distribution & Logistics Management	Sweden	Automotive	Empirical	Two Hundred & Twenty nine	This looks at the time and relationship dependencies in the supply chain and develops a typology of vulnerability scenarios (applied to both suppliers and customers).
Norrman, A & Janssonm U (2004), Ericsson's proactive supply chain risk management approach after a serious sub-supplier accident	International Journal of Physical Distribution & Logistics Management	Finland	Electronics	Case study & theoretical	One	How Ericsson, after having its supply chain interrupted has implemented new processes and tools for Supply Chain Risk Management.
Hale, T & Moberg, C (2005), Improving supply chain disaster preparedness: A decision process for secure site location	International Journal of Physical Distribution & Logistics Management	US	General	Theoretical	N/A	Gives a view of the disaster planning literature. It establishes a site location decision process for important documents, supplies and equipment
King, J (1993), Contingency Plans and Business Recovery	Information Systems Management	US	General	Theoretical	N/A	This outlines things that must be in place to ensure the continuity of the business in the event that a disaster occurs. It covers practical topics including people, communication and other issues
De Tura, N et al (2004), Disaster Recovery Preparedness Through Continuous Process Optimization	Bell Labs Technical Journal	US	Telecommunication	Case study & theoretical	One	Describes the three elements, planning, execution and feedback, of a disaster recovery plan.
Zsidisin, G et al (2005), An Institutional theory perspective of business continuity planning for purchasing and supply management	International Journal of Production Research	US	Varying	Case study & theoretical	Three	Discusses how managers create business continuity plans to manage disruptive risks
Tomlin, B (2006), On the Value of Mitigation and Contingency Strategies for Managing Supply Chain Disruption Risks	Management Science	US	General	Theoretical	N/A	Focussed on supply chain tactics of sourcing mitigation, inventory mitigation and contingent routing as disruption management techniques

Finch, P (2004), Supply chain risk Management	Supply Chain Management: An International Journal	UK	General	Case study & theoretical	Two Thousand	Large company exposure *to risk increased by in an extended or inter-organisational network. Discussed various types of risk including data/ information security risk*
Peck, H (2006), Reconciling supply vulnerability, risk and supply chain management	International Journal of Logistics	UK	General	Theoretical	N/A	Supply chain risk is a concern for many other disciplines and as such, should not be used for supply chains alone. Covers risk in many areas such as corporate risk and business strategy, risk in strategic networks, security and civil contingencies
Wu, T et al (2005), A model for inbound supply risk analysis	Computers in Industry	US	Varying	Case study & theoretical	Four	Presents methodology for classifying, managing and assessing inbound supply risk proposed
Martha, J & Subbakrishna (2002), Targeting Just-in-Case Supply Chain for the Inevitable Next Disaster	Supply Chain Management Review	US	General	Theoretical	N/A	Gives methodology for preparing for a disaster - Just- in- case
Rice Jr., J & Caniato, F (2003), Building a Secure and Resilient Supply Network	Supply Chain Management Review	US	All Industries	Theoretical	Not specified	Examines and describes how to have a secure and resilient network design.
Cranfield CLSM (2003), Creating Resilient Supply Chains: A practical guide	Report produced by the CLSM for department of transport	UK	Aerospace and other industries	Case study & theoretical	Not specified	Examines supply chain risk, vulnerability and develops a framework for creating a resilient supply chain
Lee, H (2004), The Triple A-Supply Chain	Harvard Business Review	General	General	Theoretical	N/A	Introduces the concept that supply chains need to be agile, adaptable and aligned to increase supply chain resilience
Tan, W & Enderwick, P (2006), Managing Threats in the Global Era: The Impact and Response of SARS	Thunderbird International Business Review	Australia	Health, Tourism, others	Theoretical	N/A	Speaks of the impact and implication of SARS for Asian countries. Has suggested ways in which to increase resilience through quicker access to information, decentralisation, diversifying the supplier base
Drickhamer, D (2005), House of Cards	Industry Week	US	General	Theoretical	N/A	Insurance premiums' through redundancies are now becoming as important part or at least suggestion for increasing SC resilience. Also adds a varying perspective to Sheffi's view on redundancy
Mason-Jones, R et al (2000), Engineering the leagile supply chain	International Journal of Agile Management Systems	UK	General	Theoretical	N/A	Identifies that the need for agility &/ or leanness is dependent on the supply chain strategy

van Hoek, R (2000), The thesis of leagility revisited	International Journal of Agile Management Systems	UK	N/A	Theoretical	N/A	Describes how leagile chains/ systems work through postponement and information decoupling
Lummus, R et al (2005), Delphi study on supply chain flexibility	International Journal of Production Research	US	General	Empirical	One Hundred	A Delphi study to improve supply chain flexibility
Carpenter, et al (2001), From Metaphor to Measurement: Resilience of What to What?	Ecosystems	US	Not specified	Case study & theoretical	Not specified	Have presented the operational indicators of resilience
Juttner, U, (2005), Supply Chain Risk Management: Understanding the business requirements from a practitioner perspective	The International Journal of Logistics Management	UK	Varying	Empirical	One Hundred and Thirty seven	The concept of SCRM is still in its infancy. Describes the key components of SCRM and presents opportunities for further research.
Tang, C (2006), Robust strategies for mitigating supply chain disruptions	International Journal of Logistics	US	Varying	Case study & theoretical	Three	Presented nine strategies on which to develop a robust supply chain which included postponement, demand management, strategic stock, flexible supply base, flexible transportation, revenue management and silent product roll over

Appendix 4: Methodological Diary

7th July 2006

I have just printed some sample dissertations to guide me through this process. I have also formulated some mind maps on what the key processes are to complete the systematic review and what the key components of the report are.

From reading the dissertations I realise that it is important that I record all that is done throughout the process, so all the finds and hits need to be recorded. The methodology has been emphasised as being key to producing a good quality review.

I have also decided to do the methodological diary to record the stages of the research and the progress of thinking and ideas.

8th July 2006

I have just completed the mind map of the timeframe to complete the dissertation project.

I need to revisit the keywords and search strings that were developed at the MRes stage. I still am not satisfied with them and thus will refine them even further. However, I have used some of the keywords and have identified an overwhelming number of articles. I then need to redefine the keywords to find a manageable number of articles that are precise and insightful.

10th July 2006

I met with my supervisor Professor Richard Wilding. I did not have anything to report at the moment except that I have started the process.

I have decided that the Scoping aspects of the research should include:

- Foundation elements or antecedents of business continuity
- A discussion on disruptions categories, i.e. whether they are internal, accidents, disasters OR low probability/high impact grouping/framework OR disruption types or impact (failure mode). I intend to choose an angle to describe the 'best' way to consider a disruption
- What the main risks or vulnerabilities for the inbound, outbound and internal aspects of the company are

For the Systematic Review aspect I want to present/discuss

- The definition of resilient supply chain, global supply chain and vulnerability
- How to create a resilient SC
- The framework for resilience
- Supply chain strategies – e.g. single sourcing etc, and the effect they have on increasing supply chain vulnerability

I have categorised key words into what I consider to belong/contribute to the Scoping Study and the Systematic Review

13th July 2006
I have just revisited the search strings, have tested them and am using them to perform the search on ProQuest, EBSCO and other sites

18th July 2006
I have completed the elimination of approximately 100+ articles based on:

- Being in e-business,
- Being focussed on regular or traditional SC problems
- Describing SC frameworks and their application which is not the focus of my research
- Emphasising buyer-supplier relationship

However, the readings have emphasised the importance of agility in creating a flexible supply chain. Flexibility lends to resilience.

The second elimination phase to begin where I will be applying (lightly) the quality criteria

20th – 22nd July 2006
From the readings it seems that supply chain flexibility is also achieved through focussing on SC agility.

Given the present climate there are a few articles on security and terrorism. I am yet to decide if I will include this in the report since they may include looking at supply chain security, which, in itself, is a huge topic.

24th July 2006
Have applied the quality criteria to 100+ articles and have identified 47 as being core to the research.

25th July 2006
I have completed the key article searches and compiled the core list, reference list and rejected list. I have sent the core list to the panel members and am awaiting feedback.

26th July 2006

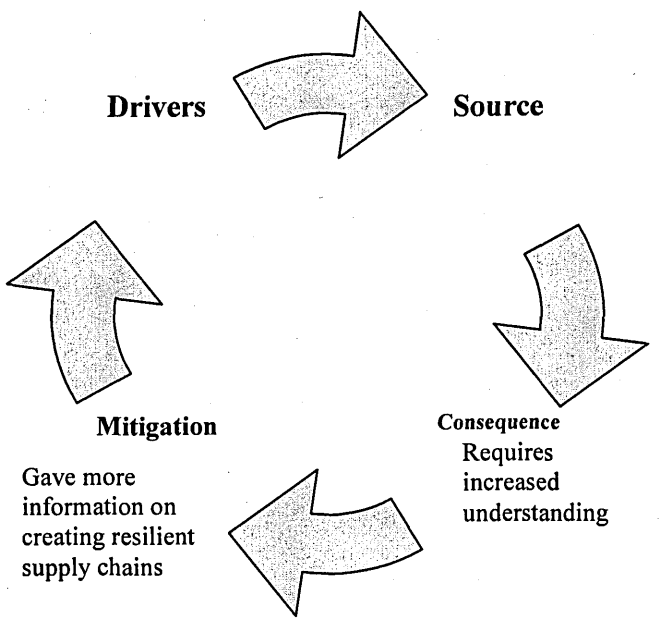
I have started reading the literature and have realised, or rather, further appreciated, that external events can be divided into four categories to include non-terrorist activities such as strikes

Resilience can be referred to as effective emergency response strategies which to react and recover from inevitable supply chain disruptions (Hale, & Moberg 2005)
I have not considered the use of sites to store documents and equipment in case of a disruption, though, thinking about it, this was part of the risk management strategy used by my employing company in Trinidad.

There has been insufficient work in Logistics and hence in supply chains, about business continuity and resilience, therefore the focus of the research has to encompass disaster preparedness.

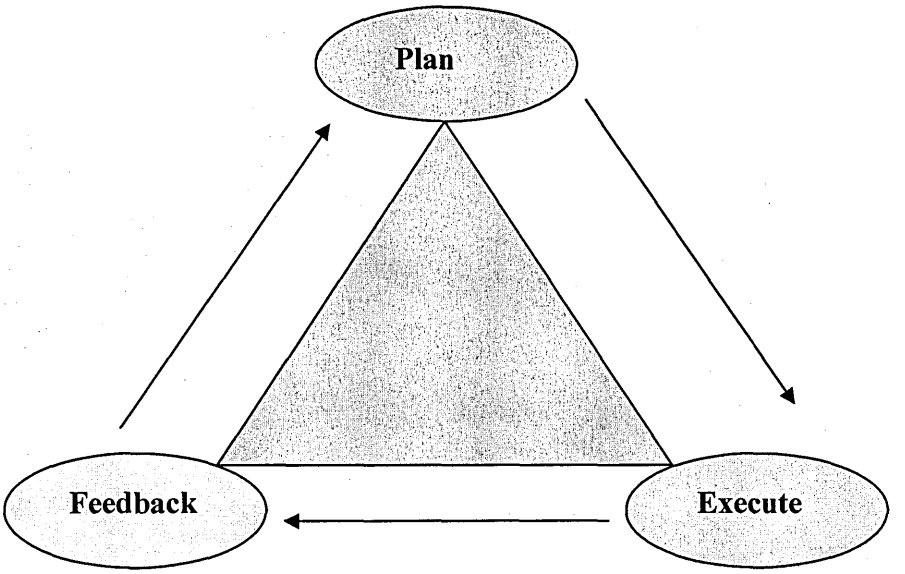
The disruption profile can be used to understand how to plan for resilience (Sheffi, & Rice Jr, 2005). Companies need to understand *how* they are vulnerable and *why* they are vulnerable.

Supply Chain Risk Management should contain these four elements (Cavinato 2004) - 4



Source: Cavinato 2004

The disaster recovery process can include:



Adapted from de Tura *et al* 2004

I have read that:

- The passive acceptance of disruptions is sometimes appropriate, as mitigation and contingency strategies are not free (Tomlin 2006)!
- The effect of the risk varies between SMEs and large companies due to their size and resource capability (Milgate 2000)
- That Finch (Milgate 2000) has categorised the possibility of risk to the
    - Application level – floods etc
    - The organisational level – intellectual property
    - Inter-organisational level – strategic alliances
- That resilience and security are not the same thing though there may be responses to address the both, (Rice & Caniato 2003) e.g.
    - Business continuity planning
    - Designing systems to 'fail smartly'
    - Using layers to provide backups
    - Aggressively training people
- Risk operates at many different levels (Cranfield CLSM 2003)
- Risk management & risk management in supply chains are two different things (Cranfield CLSM 2003)
- There is a general upsurge in interest in risk management, public policy management, corporate governance, business continuity, emergency planning and national security which are influencing or affecting the drive for supply chain resilience (Peck 2006)

28th July 2006
This seems to come to me as 'new' revelations although I have said this numerous times. To answer the question 'What makes supply chains resilient?' you not only need to consider flexibility and agility, but you also need to consider and understand what are the risks involved and what makes the supply chain vulnerable.

30th July 2006
I have started the task of writing the Findings part of the report.

I have also decided to include Supply Chain Security in the research, given the importance of it in today's environment.

31st July 2006
I think that a key point is identifying or defining what is a 'disruption'. I had considered that disruptions were due to natural disasters, acts of terrorism or accidents. However, disruptions can also be due to New Product Innovations, Operational Issues, Change in Demand and Competition. Thus, disruptive events can be anything that leads to the supply chain not being able to produce the product on time, to specification and quality to fulfill customer demand. I then need to specify the type of disruption, i.e. whether they are low probability, high impact events etc, that I am interested in.

Rice (2003) has suggested that it may be wise to focus strategy on the type of failure mode. This now makes sense given the extent of disruptions that the supply chain is opened to.

I have been reading Hallikas et al and Sheffi and Rice and think that whether within a risk framework (Hallikas et al 2004) or vulnerability framework (Sheffi & Rice 2005), the idea then is to take the risks identified, and place each in the framework. This can then be used to form the vulnerability in map (Sheffi & Rice 2005) or a risk map (Hallikas et al 2004) to understand the company's risk profile.

I have been reading Sheffi and Rice and now think that in understanding the risk profile you can then use the vulnerability map that categorises the relative likelihood of potential threats to an organisation and a company's relative resilience to these disruptions. This helps in the prioritising and planning. (Sheffi & Rice 2005)

NVivo would have come in very handy here to synthesise the information being found. However, it is late to start coding papers now. Therefore, I have decided to use mind maps to synthesize the information and build a picture/framework of thoughts, definitions, findings etc., and to develop my own understanding and conclusions as I work.

I have started working with the concept of what makes a resilient supply chain. I have identified some differences in perspective between that held by Sheffi and Christopher &

Peck., e.g. with respect to redundancy. Culture has been identified as being critical to all perspectives on building resilience. Most of the work thus far though has been from these two represented institutions and thus I am anxious to find what others are saying.

I have started forming a master mind-map to capture the varying perspectives on creating a resilient supply chain.

1st August 2006

I have started compiling the flexibility mind-map and comparing and analysing the findings.

With regards to the flexibility perspective I am yet to find someone who says something different to Christopher and Sheffi. However, there are various frameworks that can be used to obtain flexibility. The best suited thus far is the one recommended by Duclos et al (2001, 2003) as they encompass most of the components as described by Sheffi and Christopher and Peck.

2nd August 2006

I have decided not to go in depth into terrorism and security in the supply chain as this will be very much involved and beyond the scope of this paper. However, according to MIT there exists an overlap in the techniques used to produce a resilient and a secure supply chain. This information I will discuss.

I have made countless mind-maps to this date! I have also started making the Master mind-map for vulnerability. Once this information has been assimilated and written up, I will do one to help me understand the many dimensions, meanings and evolutions in risk management and supply chain risk management.

3rd August 2006

It is very difficult to decide whether this report should include a full aspect on terrorism or not, however, if we are examining how to make supply chains resilient in the face of disruptive events, then we must include how to make them resilient in the face of terrorist attacks because they can and will occur at some point in the future and companies have had to change the way they do business due to this fact.

The fact is that businesses have to continue to live in the aftermath of terrorist attacks which however, have led them to work in a heightened state of security.

5th – 7th August 2006
I have just completed reading some new information that will form the basis for the Scoping study which I expect to include as description of the problem and areas of risk management, crisis management, business continuity and supply chain management.

7th August 2006
I have a problem defining or distinguishing between developing a resilient supply chain through implementing agile and flexible systems .... Or rather, understanding if this is indeed business continuity!

I was unsure as to whether agility leads to flexibility or flexibility leads to agility, but I have since concluded that agility leads to flexibility. Can the theory or perspective of lean & agile or leagile systems be used in creating a resilient supply chains as agility leads to flexibility?

Business Continuity Planning is at the heart of making supply chains resilient and flexible?! Then how is BCP linked with DRM?!

What is supply risk management?

8th August 2006
Leagile Systems may not in themselves be used to increase supply chain resilience because, as described earlier, the supply chain is concerned with two types of agility, agility on the customer side and agility due to disruptions. However, some of the concepts, such as postponement, can be used to help or prepare a company to bounce back from a disruption.

I think that further investigation of leagile systems needed to look at how it can be used to increase supply chain resilience in the event of disruptive events.

Additionally, what has been identified as being necessary to develop a resilient system such as people leadership, team work, communication, training, making problems visible were at least partly encapsulated in the 'complete' and true Toyota Production/lean System (Likert & Morgan 2006) So is it that people wrongly or incompletely used TPS, only focusing on JIT processes?

9th August 2006
I met with Professor Martin Christopher. An idea for further research was the area of business continuity and its link to supply chain resilience, and another was looking at the inhibitors and enablers to a resilient system.

9th and 10th August 2006

I am now working on the methodology and the Descriptive Findings chapters of the report. The Descriptive Findings have highlighted that the main source of information is the International Journal of Physical Distribution & Logistics Management. A distant second is the Supply Chain Management Review which was one of the journals recommended by Professor Christopher. Since the research is still very much in a fluid stage it is felt that the Descriptive Findings should be one of the last aspects of the report to be concluded where the findings will be a true representation of the papers found and used to inform the research.

11th to 12th August 2006

I have started the full edit of the report. Not a process that fills my heart with joy!!!

13th August 2006

The focus is on the Scoping Study. I am not sure that the report is saying what I want it to say at the moment. I have decided to speak on supply chain and supply chain management and how the lack of definition of the topic has led to an inability to define and therefore mitigate against vulnerabilities. The areas of disaster management, crisis management and contingency planning have been discussed, but I am not satisfied with them at this moment. I believe that they should be more descriptive, i.e. tell more about the development of the fields and how they relate and lead to supply chain management, supply chain risk management, supply chain vulnerability and, by extension, resilience.

I now need to work on the area of identifying risk and vulnerabilities in the supply chain.

15th August 2006

I met with my supervisor, Professor Richard Wilding, who recommended a few key points that I want to immediately take on board:

- To read the paper on writing a dissertation or PhD thesis by Chad Perry
- To try and create models to synthesise the information that has been found
- The ability to convert the mind-maps into meaningful narrative

16th August 2006

I have started creating the models to represent the work. I thought that I would synthesise resilience and vulnerability through this process. I may consider resilience with a core (being culture) with three key dimensions of flexibility, communication, ... and one other from strategy or redundancy, or I may have to think of another model. I also want to represent the different ways or dimensions of thinking of supply chain vulnerability, i.e. whether as a construct, contributors, dimensions etc. This is still to be developed.

18th August 2006
I have started editing the Introduction and Executive Summary again. They are all still too wordy, so I have to figure a way around that.

They may all be 'risks', but they may not all be sources of vulnerability! Vulnerability is such that it will actually disrupt the business. I had seen this earlier, but I am a little more convinced of this now.

19th August 2006
I have started synthesizing the information. I have actually used a flow that I previously created to represent DRM. I think I will use this as a springboard to discuss the vulnerability and flexibility models. Still want to include one on agility and leagile systems.

I have also gone through the aims and objectives of the research to determine if I have achieved, or rather, to what extent I have achieved the aims of this research. This is discussed in the conclusion. I have also started describing further research that can come out of this dissertation.

21st August 2006
I have realised that the main principles or benefits of leagile systems are postponement and information decoupling, as well as general decoupling. This is covered in the things raised by Christopher, Peck and others, i.e. postponement and visibility or the free flow of information to increase resilience.

I now think that to develop a safe system you need to have three elements: resilience, business continuity and DRM.

Previously I had not considered DRM to be separate and distinct from creating resilience but I now believe that it is. I understand resilience to or as making a system 'bounce back' from a disruption, while DRM looks at ways of mitigating against disruptions. But I think that there is overlap and a company may explore elements of more than one concept.

Also, I think that there is a circular relationship with vulnerability, flexibility and agility all of which impact on resilience.

23rd – 24th August 2006
I somewhat changed the model on understanding vulnerability to include the stages of a disruption, the sources of vulnerability, the categories of vulnerability and the dimensions of vulnerability.

I continue to edit the document (including this section).

25th August 2006
First draft sent to Supervisor via e-mail as a preparation for the meeting on 31st August.

31st August 2006
Met with my Supervisor where we discussed or agreed that more work needed to be done on the models generated. We also discussed the need to have the report poised in such a way that a PhD topic can be developed beyond this stage.

31st August – 1st September 2006
This time was spent pulling together the references for the report.

2nd September 2006
Spent the time developing the future areas of research which can be found in the conclusion of the report. I also continued editing the report.

3rd September 2006
Have continued working on the thematic finds and synthesis of the report.

6th September 2006
The concept of SCRM has taken precedence. I am trying to establish or clarify the link between DRM, SCRM, BC & Resilience. I now believe that SCRM is the umbrella under which DRM and Resilience are contained.

8th – 9th September 2006
I have drawn the three mind maps using the mind mapping programme.

10th – 12th September 2006
Continue to synthesise information and work on the conclusion of the report. I have included the limitations of the report in this chapter.

I am also working with explicitly and succinctly stating the links and ambiguity with the areas of SCRM, DRM, BC and Resilience.

13th – 14th September 2006
I have been developing new conceptual models for resilience and for the relationship between DRM, Resilience, SCRM and BCP. I have also reworked the questions for further research at the PhD stage.

15th September 2006
Mres dissertation was submitted to the Registry.

Appendix 5: The Scoring System Explained

All the papers were not necessarily rated out of thirty (30). It was preferred that papers did include limitations and opportunities for further research, however, if they didn't this did not necessarily work against them. Empirical papers with limitations and future research were rated out of thirty, with the decision rule to accept being above 22 points. Papers with a score less than 12 were rejected. Empirical papers that did not have limitations or future research were rate out of 25. The decision point to accept these papers was at 18. Papers below 11 were rejected. Theoretical and conceptual papers were not judged for research methodology. Theoretical and conceptual papers with limitations or future research were rated out of 25, with the decision point to accept being 18. Papers that received a rating below 11 were rejected. Theoretical and conceptual papers without the limitations and future research were rated out of 20 with the acceptance decision point being 14. Papers with less than 7 points were rejected. The table below describes how the various scores on the scale were defined

Appraisal tool for the Systematic Review

Elements to consider	1 - Poor	3 - Medium	5 - High
Relevance the work has to the field on enquiry	Little relevance to field of enquiry	Moderate to field of enquiry	Significant relevance to field of enquiry
Theoretical and conceptual contributions	Inadequate literature review and rationale for theoretical and conceptual contributions poorly established	Adequate review of the literature and good discussion of theoretical and conceptual contributions	Good review of literature and excellent discussion of theoretical and conceptual contributions
The research methodology used	Paper does not provide sufficient information on research methodology	Adequate information of research design provided	Full discussion on information for research design provided
The data analysis process	Sufficient information on analysis process not provided	Some information on the data sample and method and rationale for analysis provided	Adequate information on the data sample and method and rationale for analysis provided
Limitation and future research.	Paper does not provide sufficient information in either of these areas	Paper mentions limitations but does not explain relevance to understand results. Paper mentions further research but does not provide sufficient links to present research or possible impact of future research	Paper clearly states limitations and implications. Future research is well defined and links to paper and possible impact of future research identified
Contribution, originality, appropriateness and significance	Does not make a significant contribution to current knowledge.	Contribution to knowledge exist, but limited in importance, originality and significance	Significant contribution to current knowledge

Adapted from Marcos (2000)