4. THE BUSINESS ENVIRONMENT AND THE SUPPLY CHAIN

Leading industries worldwide are placing increasing emphasis on integrating, optimising, and managing their entire supply chain from component sourcing, through production, inventory management, and distribution to final customer delivery. Over the last few decades, business environments have been changing from mass-production to customisation, and from technology and product-driven to market and customer-driven. Providing distinctive customer value has become one of the main business drivers for companies. However, a single company often cannot satisfy all customer requirements, including fast-developing technologies, a variety of product and service requirements, and shortened product life-cycles. Such developing new business environments have made companies look to the supply chain as an 'extended enterprise', to meet the expectations of end-customers. Participants within the extended enterprise will cooperate and collaborate with each other to achieve common goals, hence gaining competitive advantages. The efficiency of the supply chain, and its interaction with the company's own logistics concept may determine the performance of an individual company within the extended enterprise. In many cases, the performance of a company will be highly dependent upon its upstream suppliers.

Since the 1980s, aero-engine and component manufacturers have faced increasing competition from all over the world. The product introduction life-cycle is becoming shorter and market requirements more diversified, while there is pressure to cut costs and product lead-times.

Performance, quality and price used to be key factors for competitive advantage, but service is increasingly becoming a differentiation factor. Companies can no longer maintain profitability and competitive advantage simply with good quality products and technologies in the traditional ways [Christopher, 1998]. Alternative approaches now being explored feature a *combined product and service offering* in which the boundaries between manufacturer, vendor and support provider are eroded. Within the aero industry, current product-service concepts include 'Total Care' and 'Power-by-the-Hour'.

Often, a single company can no longer compete effectively in the modern aero-engine market, so interest in the extended enterprise has grown. Companies have benefited from collaborative partnerships [Lummus and Vokurka, 1999] and risk-and-revenue sharing arrangements. Because of the high initial costs associated with aero-engine development and manufacture, it is particularly important that efficient supply chain operations allow income streams to be secured throughout the product lifecycle.

The creation of distinctive customer value requires the provision of a differentiated offering including short lead-times linked to high flexibility in the volume and variety of products and associated services. These requirements are frequently too demanding for a company to accommodate entirely using only its own resources. Traditional vertical integration is no longer the solution because it would not be flexible enough to accommodate the variety of requirements. Therefore, companies may need to deliver customer value in new ways, obtaining and retaining vital business contracts. Companies have tended to focus on their own core business and competencies, outsourcing other areas into the extended enterprise [Lehtinen, 1999].

Christopher [1998] argued that real competition in the marketplace now exists between supply chains, not between companies. This implies that an organisation can no longer act as an isolated and independent entity in competition, but the fully-integrated supply chain can provide competitive advantages in the market.

4.1. SUPPLY CHAIN DEFINITION

A number of definitions of the supply chain have been proposed. Christopher [1998] defined it as, “a network of connected and interdependent organisations mutually and co-operatively working together to control, manage and improve the flow of material and information from suppliers to end users”. According to Johansson [2002], one of the most common perceptions of the supply chain is, “A system whose constituent parts include material suppliers, production facilities, distribution services and customer linked together via the feed-forward flow of materials and the feedback flow of information”.

It is commonly accepted that there are three main flows in the supply chain: material flow, information flow, and cash flow. The activities involved in the material flow are to deliver to the end-user via procurement of raw materials, manufacturing, distribution and customer service. All these activities must be managed using suitable information flows. (Cash flows within the supply chain do not fall within the scope of WP2.5.) Figure 1 shows the forward flow of materials from upstream to downstream, the bidirectional flow of information, and the movement of money from downstream to upstream.

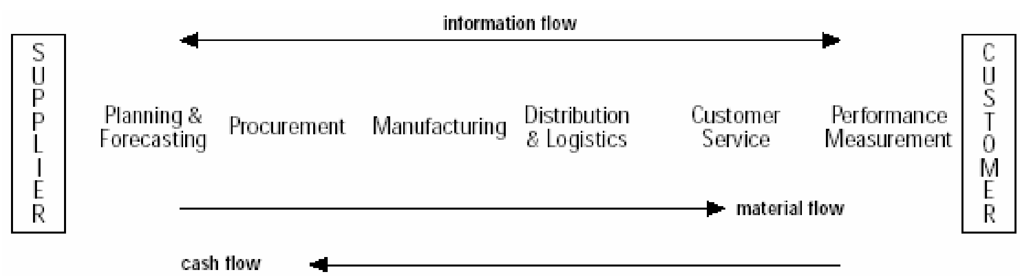

Figure 1: Flows in the supply chain (from Spekman et al [1998])

4.2. BEHAVIOUR OF THE SUPPLY CHAIN

Supply chains do not always behave as expected or desired. Excessive demand variability – due to information distortion in the supply chain, between one member and the next – can become a serious problem, and this led to some of the early studies of supply chain behaviour.

Forrester [1961] initiated the analysis of demand variability amplification and pointed out that it is a consequence of industrial dynamics; the time-varying behaviours of industrial organizations. Demand variability can be amplified as one moves up the supply chain, and small changes downstream can result in large variations upstream. As a result, the whole supply chain can be distorted by very large demand swings; as each company within the supply chain tries to solve the problem within their own perspective. This distortion is known as the Bullwhip or Forrester effect (Lee, et al [1997], Metters [1997], Fransoo & Wouters, [2000]) and has been observed across most industries (Figure 2).

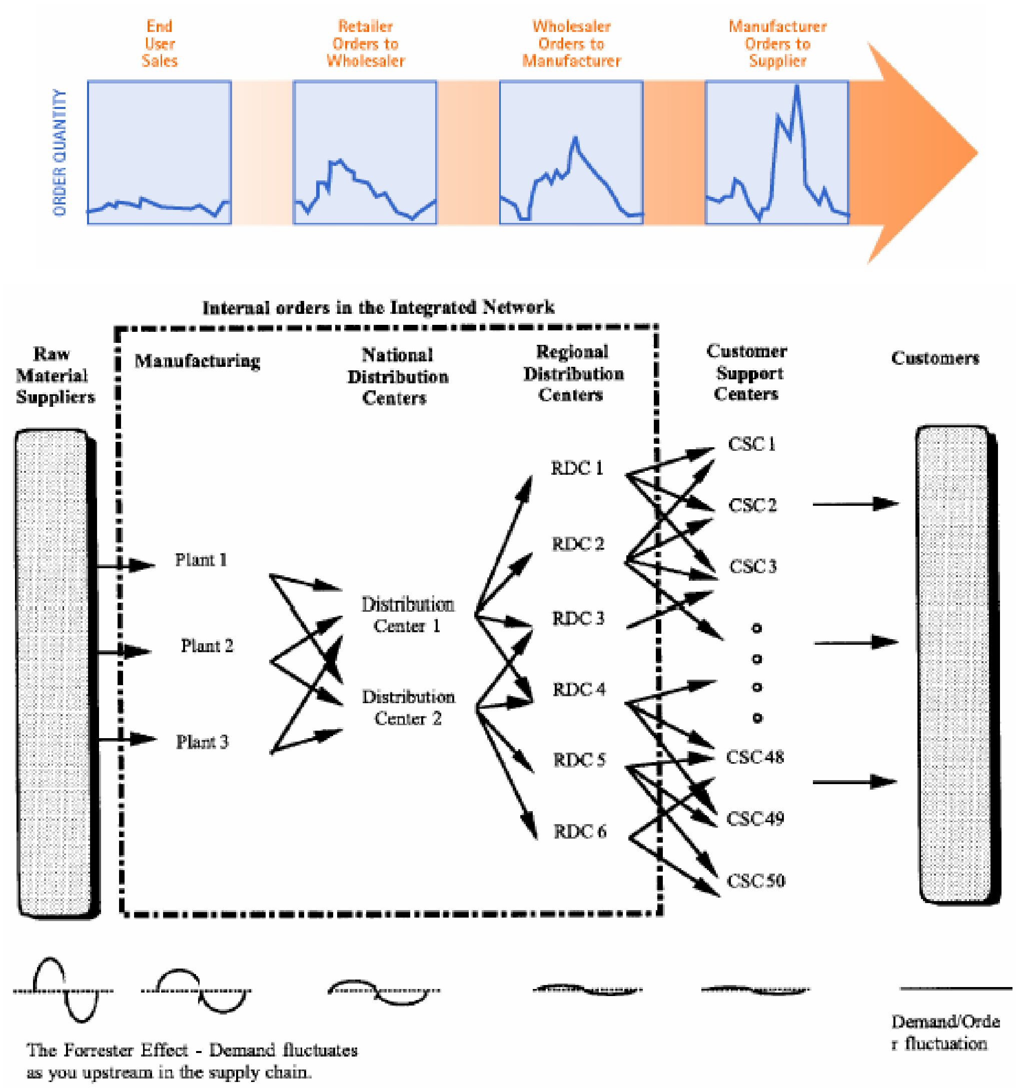

Figure 2: Distortion and the Bullwhip Effect (Davis and O'Sullivan [1999])

The consequences are significant; piles of stock, frequent stock-outs and unpredictable demands, and therefore bottlenecks in delivery. Lee et al [1997] identified four major causes of the Bullwhip effect:

- Quality of the forecast and its update frequency
- Reorder frequency and the reorder batch size
- Price fluctuation
- Policy for expectation of shortage and level of safety stocks

In general, the solutions to the bullwhip effect should be in line with the causes. Lee et al [1997] developed a framework for supply chain co-ordination initiatives to deal with bullwhip effect. The framework includes three general counteracts proposed by the authors:

information sharing, channel alignment, and operational efficiency. In relation to operational efficiency, for example, a company can reduce the bullwhip effect by mitigating price fluctuation with an initiative called every day low price. By this initiative, the manufacturer can reduce the incentives for retailers forward buying. On the other hand, to obtain better demand transparency from the end customers, the manufacturer may have to initiate the use of point-of-sale (POS) data or other means of transferring data such as web-based technology or electronic data interchange (EDI). Machuca & Barajas [2004] studied the impact of EDI on reducing bullwhip effect and supply chain costs. They concluded that the comprehensive use of EDI results in substantial reduction of the bullwhip effect and associated supply chain costs.

In addition to demand variability and information distortion, other main issues in supply chain management relate to the uncertainties within the supply chain system. There are many sources of uncertainties in a supply chain. Davis [1993] identifies three sources of uncertainties:

- Supplier uncertainty measured in terms of suppliers' on-time performance, average lateness and degree of inconsistency;
- Manufacturing uncertainty that arises due to process performance, machine breakdown etc;
- Demand or customer uncertainty arising from forecasting errors, irregular orders etc.

Lee and Billington [1992] claim that one of the potential pitfalls in managing supply chains is failing to understand the likelihood and the magnitude of impact of these uncertainties. Reiner and Trcka [2004] argue that the main objective of problem-solving methods in SCM is to reduce uncertainties. Fisher [1997] proposes that the supply chain strategy has to match the level of demand uncertainty of the product. Lee [2002] extends Fisher's framework to include supply uncertainties in developing the right supply chain strategy.

4.3. SUPPLY CHAIN MANAGEMENT

The term supply chain management was introduced in the early 1980s by Oliver and Webber [1982] where they discuss the potential benefits of integrating purchasing, manufacturing, sales and distribution. Houlihan [1987] repeats the term to describe the management of materials across organisational borders. Since then, many researchers have worked on establishing the theoretical and operational bases for supply chain management concepts including Giannakis and Groom [2004], Lee and Billington [1992], Ellram and Cooper [1993], Schary and Skjott-Larsen [1995], Fisher [1997], Lambert et al [1998], and Lee [2002].

Definitions of Supply Chain Management (SCM) have been supplied by several authors. Ellram and Cooper [1993] described it as "an integrating philosophy to manage the total flow of a distribution channel from supplier to ultimate customer". Christopher [1998] defined SCM as '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". From these definitions, SCM should integrate all the activities within the supply chain into a seamless process. In other words, it links all the involved organisations including internal departments, external partners and vendors, and third party companies, which means that the whole set of processes and their activities must be viewed as one system.

According to Schary and Skjott-Larsen [1995], the full strategy in supply chain management has three points of focus: structure, organisation and process. The interrelationships between the three focuses are depicted in Figure 3. At a strategic level, supply strategy concerns the supply structure and organisations. Structure of the supply chain deals with the issue of location of facilities and processes by stages within the supply chain. In addition, Lambert et al [1998] describe supply chain structure as the group of members, the structural dimensions of the group (horizontal and vertical structure and the focal firm's position in the horizontal structure) and the links between members of the supply chain.

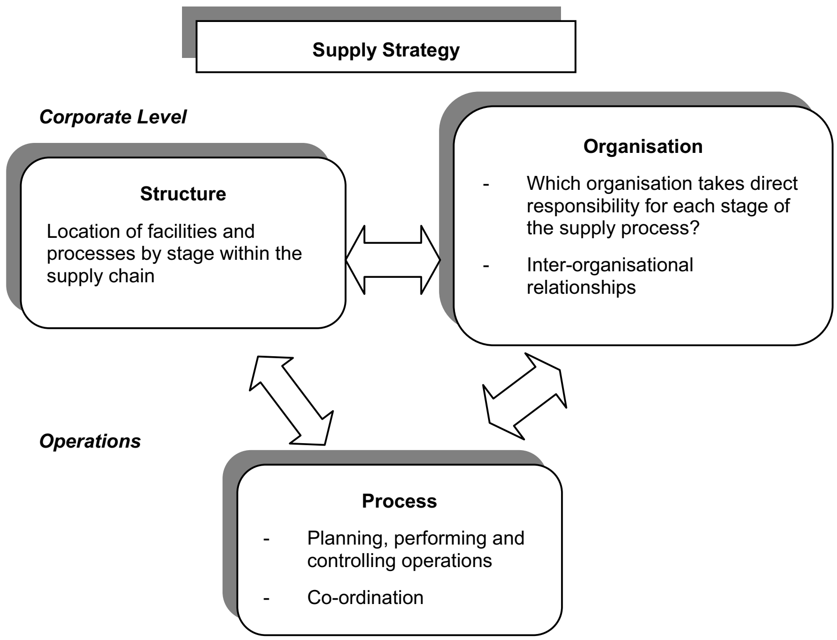

Figure 3: Supply Strategy (adapted from Schary and Skjott-Larsen, [1995])

The second focus of supply strategy proposed by Schary and Skjott-Larsen [1995] covers the issues of organisations and their boundaries. The organisations of supply chains include: 1) determining which organisation is responsible for each stage of supply process and 2) inter-organisational relationships. The first point concerns with how much of the supply chain a company should own. The issue of conducting activities in-house or buying from outside organisations has been widely addressed in the literature (Fine and Whitney [1996], Slack and Lewis [2002], Wisner et al [2004], pp 43). Equally, the issue of inter-organisational relationships has also received a lot of attention in supply chain management literature (Harland [1996], Peck and Juttner [2002]). According to Slack et al. [2004], the type of inter-firm contact can be categorised based on:

- The structure of the market relationships in terms of the number of supply relationships used by an operation.
- The closeness of the relationships, ranging from transactional or 'arm-length' relationships at one extreme to close relationships or 'partnerships' at the other extreme.

In the new paradigm, the number of suppliers is likely to be reduced (Chen and Paulraj [2004], Slack et al [2004]), but the quality of interaction – the level of information sharing - with the remaining companies is increased. Supplier efficiency is considered through a reconciliation of cost and quality throughout the whole supply chain, rather than simply as direct suppliers offering the lowest price. Likewise, the relationships with downstream players, such as distributors, are tightened. Sharing point of sales (POS) data is an example of how information sharing is enhanced from downstream players of a supply chain.

The third focus of supply strategy proposed by Schary and Skjott-Larsen [1995] is on process, which cover the issues of planning, performing and controlling operations. Processes need to be co-ordinated in order to ensure their continuity and their ability to respond as an integral unit in order to achieve the overall objectives of the system. Lambert et al. [1998] propose a process-based framework for managing a supply chain. As depicted in Figure 4, they view supply chain management as an integrated approach of delivering values to the end customers, which involve key processes such as customer relationship management, demand management, order fulfilment, procurement, etc. These processes are facilitated by information technology solutions such as Enterprise Resource Planning (ERP), distribution requirements planning, electronic commerce, Product Data Management (PDM), collaborative engineering, etc. [Aberdeen Group, 1996]. Duplicated and non-value-adding activities must be eliminated within the supply chain to improve the efficiency of the whole extended enterprise.

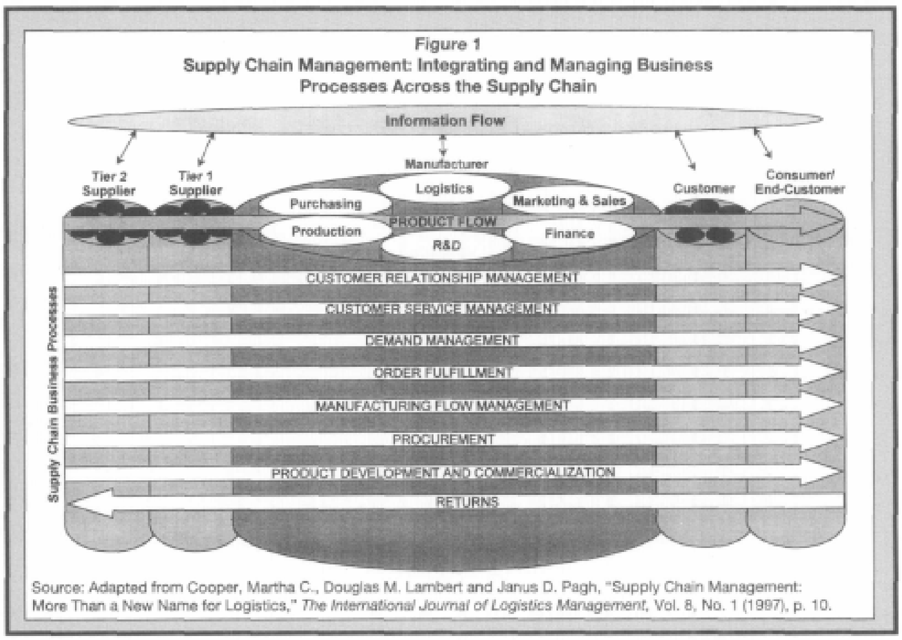

Figure 4: Key supply chain business processes [Lambert et al, 1988]

4.4. SUPPLY CHAIN RISK, ROBUSTNESS AND RESILIENCE

The notion of risk is receiving greater attention in research on supply chain management by academics and practitioners alike [Spekman and Davis, 2004]. Not only are there risks inherent in supply chain flows, but also there are risks associated with security, opportunistic behavior, corporate social responsibility, etc.

It is thus very important for organizations and supply chains to have the abilities to be responsive to risks to achieve supply chain robustness and resilience.

4.4.1. Types of supply chain risk

Risk is an inherent feature of all operations [Slack and Lewis, 2002]. Supply chain risk management has recently gained much greater attention as a result of natural disasters and terrorist attacks, as well as the greater complexity and globalization of supply chains.

First supply chains are subject to disruption type of risks caused by natural or environmental disasters. Norrman and Jansson [2004] cite a few examples of these:

- Hurricane Floyd flooded a Daimler-Chrysler plant producing suspension parts in Greenville, North Carolina (USA). As a result, seven of the company's other plants across North America had to be shut down for seven days.
- The foot-and-mouth disease in the UK in 2001 affected the agriculture industry more than its last outbreak 25 years ago. The reason for this was that former local and regional supply networks had become national and international, and the industry was much more consolidated. But other industries were also affected: luxury car manufacturers like Volvo and Jaguar had to stop deliveries due to lack of quality leather supply.
- Toyota was forced to shut down 18 plants for almost two weeks following a fire in February 1997 at its brake-fluid proportioning valve supplier. Costs caused by the disruption were estimated to be $195 million and sales loss was estimated to 70,000 vehicles ($325 million) [Converium, 2001]. This emphasized the problems of single sourcing and partnerships for the supply of critical parts.

Norrman and Jansson [2004]

Peck and Juttner [2002] added a few more man-made problems: Y2K-related IT problems, the fuel price protests of September 2000, recent transportation infrastructure failures – for example, rail disruptions, terrorist attacks of 11th September 2001.

Today's business world also faces challenges and pressures on an unprecedented scale from customer demand and competition. According to Christopher and Peck [2004], Christopher [2003], Haywood and Peck [2003], Peck [2004] many of these obstacles have the potential to severely affect the continuity of a commercial enterprise, in particular, through disruption to the wider supply chain.

A further reason for this increased risk has come, paradoxically, from the focus on efficiency and cost reduction. Examples include the move to offshore sourcing and manufacturing in pursuit of lower labour costs; the widespread adoption of 'lean' practices, particularly through inventory and capacity reduction; and the continuing trend towards outsourcing and single sourcing. All these strategies can lead to beneficial business outcomes, but can also radically change the risk profile of the supply chain.

Second there are delay type risks on a more continuous and smaller scale [Chopra and Sodhi, 2004]. Delays in material flows often occur when a supplier, through high utilization or another cause of inflexibility, cannot respond to changes in demand. Other culprits include poor-quality output at supplier plants (or at their suppliers' plants), high levels of handling or inspections during border crossings and changing transportation modes during shipping.

A third type of risks is the Forecast Risk. Forecast risk results from a mismatch between a company's projections and actual demand. If forecasts are too low, products might not be available to sell. Forecasts that are too high result in excess inventories and, inevitably, price markdowns. Long lead times, seasonal demand, high product variety and smaller product life cycles all increase forecast error.

Forecast inaccuracies can also result from information distortion within the supply chain. Christopher and Lee [2004] describe this type of risk caused by, for example, the attitudes and perceptions of the users and members of the supply chain. A manager running a supply chain with these risks may lack confidence in the following:

- order cycle time
- order current status
- demand forecasts given
- suppliers' capability to deliver
- manufacturing capacity
- quality of the products
- transportation reliability
- services delivered

The intangible lack of confidence in a supply chain leads to actions and interventions by supply chain managers throughout the supply chain, which collectively, could increase the risk exposure. The "bullwhip" effect (see Section 4.2), which describes increasing fluctuations of order patterns from downstream to upstream supply chains, is such an example, partially caused by the rational actions of managers aiming to reduce exposure to supply chain risk.

Other types of risk include inventory, capacity, systems, intellectual property, procurement and receivables risks.

4.4.2. Definition of robustness and resilience

The ability to be respond to the risks listed in the previous system determines supply chain robustness and resilience. Some authors distinguish between robustness and resilience. Christopher and Rutherford [2004] define robustness as meaning "strong, and sturdy: constitutionally healthy". Thus a robust supply chain might reasonably be expected to produce consistent results with very little variation in output; However, Resilience is "the ability of a system to return to its original (or desired) state after being disturbed". A resilient supply chain must also be adaptable, as the desired state may be different from the original. The key difference between the two is in their ability to respond to variations in input. A robust supply chain can deal with reasonable variability in input whilst maintaining good control over output variability. A resilient supply chain is certainly robust, but it offers much more; as well as being responsive to predictable input variability it is also able to respond to a sudden and unexpected shift in the level and variability of input.

Other authors tend to use robustness and resilience interchangeably. Conboy and Fitzgerald [2004] refer to Robustness or resilience as the ability to *endure* all transitions caused by change, or the degree of change tolerated before deterioration in performance occurs *without* any corrective action. The RLSN Project Team of Altarum [2003], working on the Robust Lean Supply Networks (RLSN) project, develop knowledge and capabilities that will allow defence suppliers to be more responsive to *demand surges* and *supply disruptions* anywhere in their supply chains (this by Christopher's definition will be resilience).

In the context of this review, we will not intentionally distinguish the two as the strategies, approaches and techniques described below could apply to both types of variation.

4.4.3. Strategies to achieve supply chain robustness and resilience

To achieve robustness and resilience, supply chain risk mitigation strategies should be created at the top level. Christopher [2003] outlines a set of principles that underpin the creation of a more resilient supply chain:

- **Supply chain understanding:** One fundamental prerequisite for improved supply chain resilience is an understanding of the network that connects the business to its suppliers and their suppliers, and to its downstream customers and their customers. Mapping tools can help in the identification of 'pinch points' and 'critical paths'.
- **Supplier base strategy:** While there has been a move towards a reduction of the supplier base in many companies, there could be limits to what might be pursued. Where a firm has multiple sites, it may be possible to have a single source for an item or service into each location, thus gaining some of the advantages of single sourcing without the downside risk.
- **Supply chain collaboration:** It will be apparent that since supply chain vulnerability is a network wide concept, management of risk has to be network-wide too. A high level of collaborative working across supply chains can help mitigate risk. The challenge is to create conditions in which collaborative working becomes possible.
- **Agility:** One of the most powerful ways of achieving resilience in the supply chain is to create networks which are capable of rapid response to changed conditions. This is the idea of agility whereby the time required to respond to new circumstances is dramatically reduced. Time compression is at the heart of 'Agile' strategies Agility is founded on two key principles – velocity and visibility.
- **Creating a supply chain risk management culture:** It can also be argued that supply chain risk assessment should be a formal part of the decision-making process at every level. As in every case of cultural change within organisations, nothing is possible without leadership.

[Christopher, 2003]

4.4.4. Qualitative approaches to supply chain robustness and resilience

On the tactical level, improvement approaches and techniques have been widely used in operations management [Slack at al, 2001]. These can apply to the supply chain as well.

There are two types of improvement approaches: breakthrough and continuous. Business process re-engineering is an example of a breakthrough improvement approach while TQM incorporates a process-oriented continuous improvement process. The TQM improvement process typically employs many types of improvement techniques, for example, statistical process control, failure mode and effect analysis, flow charts, scatter diagrams, cause-effect diagrams, Pareto diagrams and Why-why analysis, which can be of use in supply chains as well as internal business processes.

From a supply chain point of view, the newly emerging field of supply chain event management [Stiles, 2002] holds some promise. The idea behind event management is that partners in a supply chain collaborate to identify the critical nodes and links through which material flows across the network. At these nodes and links, control limits are agreed within which fluctuations in levels of activities are acceptable, e.g. shipments from an off-shore manufacturing source. If for whatever reason the level of activity goes outside the control limit, then an alert is automatically generated to enable corrective action to be taken

4.4.5. Quantitative techniques to supply chain robustness and resilience

Although the number of supply chain variables is huge, and there are many complicatedly intertwined supply chains affecting each enterprise, quantitative techniques offer the opportunity to improve and even optimise supply chain robustness and resilience both on the strategic and tactical levels.

There are three main types of quantitative techniques for supply chain robustness and resilience analysis; analytical methods, simulation methods and combined approaches. (See Chapter 7 for more information on simulation approaches). The main analytical approaches are sensitivity analysis, scenario analysis, multi-dimensional dynamic programming, stochastic programming, robust optimisation and real options. A short description of the methods now in favour is given here.

- **Scenario analysis:** Scenario analysis has been in use for decades. By generating scenarios with associated probabilities and effects, robust decisions can be made to minimise downside risks (the risk of not meeting certain targets) and disasters. A good example of its use is task 2.1.1.
- **Stochastic programming:** Stochastic programming with recourse was first introduced by Dantzig in 1995. Since then, there has been significant development. The most common stochastic programming problem is the two-stage stochastic linear programming problem. Infanger [1994] describes a two stage stochastic linear programming problem as consisting of a first-stage master problem involving structure decision variables, and a number of second-stage problems involving operational decisions variables. The objective is to optimise the expected values (cost or profit) of all scenarios.

  Santoso et al [2003] proposed a stochastic programming model and solution algorithm for solving supply chain network design problems of a realistic scale. Their solution methodology integrates a recently-proposed sampling strategy, the Sample Average Approximation scheme, with an accelerated Benders decomposition algorithm to quickly compute high quality solutions to large-scale stochastic supply chain design problems with a huge (potentially infinite) number of scenarios.

- **Robust Optimisation:** Robust optimization tries to achieve a balanced or optimal solution for all scenario realizations by minimizing either expected regret (e.g. downside risk) or absolute variation. Bertsimas and Thiele [2003] propose a general methodology based on robust optimization to address the problem of optimally controlling a supply chain subject to stochastic demand in discrete time. This model incorporates a wide variety of phenomena, including demands that are not identically distributed over time and capacity on the echelons and links. When the parameters are chosen appropriately, the proposed approach preserves performance while protecting against uncertainty.
- **Real Options:** Real options is an approach which is used more and more for investment planning. This is due to some of the drawbacks of the traditional discounted cash flow approach.

  The main idea about real options is that options can be created with a cost. With more and better information available in the future from acquiring the option, a decision maker can significantly avoid risks and improved expected returns on investment.
- **Simulation:** Siprelle etc. [2003] describe the benefits of using a supply chain simulation tool to study inventory allocation. Simulation was used for answers to the following questions:
  - What is the relationship between inventory policies and the resulting inventory levels, customer service levels, and redeployment of stock?
  - Does the location of inventory storage for different classes of product have an effect on total inventory levels and redeployment of stock?
  - Would better forecasting methods reduce the amount of inventory in the system and the redeployment of stock?
- **Combined approaches:** Truong and Azadivar [2003] describe a hybrid optimization approach to address the Supply Chain Configuration Design problem. The new approach combines simulation, mixed integer programming and genetic algorithms. The genetic algorithms provide a mechanism to optimize qualitative and policy variables. The mixed integer programming model reduces computing efforts by manipulating quantitative variables. Finally simulation is used to evaluate performance of each supply chain configuration with non-linear, complex relationships and under more realistic assumptions.

4.4.6. IT infrastructure and decision support systems

Christopher and Lee [2004] identified the two main elements of the supply chain that can reduce the lack of confidence – visibility and control. Two things that have happened in the last few years have improved both supply chain visibility and control significantly. The first of these is the availability of technology and software to enable the capture and sharing of information across a supply chain, achieved mainly through IT infrastructure, extranets and decision support systems including ERP, supply chain management software, and the collaborative hub concept of WP 3.6. The second, even more fundamental change, is the increasing willingness of members of the supply chain to put aside the traditional arms-length relationship with each other and in its place move towards a closer, partnership-type arrangements.

4.4.7. Supply chain risk management

Risk management is the process whereby decisions are made to accept a known or assessed risk and/or the implementation of actions to reduce the consequences or probability of occurrence. Typical risk management aims are to avoid, reduce, transfer, share or even take the risk. To avoid is to eliminate the types of event that could trigger the risk. To reduce risk applies both to reduction of probability and consequences. Examples of how to reduce the impact could be to have an extra inventory, multiple sources, back-up sites/resources identified, sprinklers in buildings, having risk managers and emergency teams appointed, parallel systems or to diversify. Probability could be reduced by improving risky operational processes, both internally and in cooperation with suppliers, and to improve related processes, e.g. supplier selection. Risk could also be transferred to insurance companies – or to supply chain partners by moving inventory liability, changing delivery times of suppliers (just-in-time deliveries), to customers (via make-to-order manufacturing), or by outsourcing activities. Furthermore, contracts can be used to transfer commercial risks. Finally, risks could be shared, both by contractual mechanisms and by improved collaboration.

Norrman and Jansson [2004] describe supply chain risk management as comprising two elements: the risk management process and Business Continuity Management (BCM). The risk management process is focused on understanding the risks and minimizing their impact by addressing, for example, probability and direct impact. The stages of the risk management process discussed can vary from risk identification/analysis to different forms of risk management.

There are many methods for risk identification and analysis. One important tool is risk mapping, i.e. using a structured approach and mapping risk sources and thereby understanding their potential consequences.

After the risk analysis, it is important to assess and prioritize risks to be able to choose management actions appropriate to the situation. One common method is to compare events by assessing their probabilities and consequences and locating them in a risk map/matrix.

BCM is defined 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" [Hiles and Barnes, 2001]. BCM includes crisis management (overall processes to manage the incident), disaster recovery (recovery of critical systems, applications, data and networks), business recovery (recovery of critical business processes) and contingency planning (recovery from impact external to the organization). Developing action plans is important in BCM, and business continuity planning (BCP) is a term often used.

Sinha et al [2004] develop a generic methodology for mitigating risks in the aerospace supply chain with a view to consistency across supply chains.

To aid the development of the methodology, IDEF0 (integrated definition) method is employed. The methodology consists of 5 main tasks: identify risks, assess risks, plan and implement solutions, conduct failure modes and effects analysis, continuously improve.

4.5. THE EVOLUTION OF THE MANUFACTURING BUSINESS

In addition to radical changes in the ways businesses interact, their internal operations have also been subject to change during the past few decades, moving beyond the mass production approach that had been predominant for most of the twentieth century. The main benefit from mass production was to minimise unit production cost with a high level of repetitive production bringing about a reduction in the proportion of fixed cost per unit. This approach was very cost-effective, but allowed little flexibility in product or process. Due to the high level of investment required, product life cycles were very long and there were few product varieties. Buffer stocks were used to accommodate unpredictable demands, and to cope with variability within the manufacturing system. Many companies had vertically-integrated structures to secure supplies of critical materials, and to achieve cost-effectiveness through economies of scale. Relations with external companies were neither close nor cooperative because sharing information was considered as risky, as expertise and technologies might be revealed to competitors. As a result, interactions with vendors were often adversarial, win-lose relations.

In the 1970s, the introduction of computerised Material Requirements Planning (MRP) systems had a great impact on material management methods, in terms of cost, lead-time and level of work-in-progress (WIP), etc., whilst facilitating greater complexity and flexibility of manufacturing operations.

Competition intensified during the 1980s, with continuing downward pressure upon cost joined by requirements for a broad range of reliable, high quality products. Significant changes during this period were the widespread adoption of Just-in-Time (JIT) work scheduling and quality initiatives such as Total Quality Management (TQM). The JIT approach stressed that stocks should not be kept in advance, either for forecast or unpredictable demands. These concepts brought companies to a realisation of the potential benefits of integration of functions, as well as the importance of strategic alliances between customers and suppliers. The concepts of SCM emerged as manufacturers experimented with strategic partnerships with their immediate suppliers and customers.

Further responses aimed at increasing competitiveness included Concurrent Engineering (also known as Simultaneous Engineering, Design for ‘X’, etc.; Boeing simply call it ‘working together’). This involves information being shared between departments, and also up and down the supply chain with suppliers and customers playing a part in a multi-functional team. (The application of Concurrent Engineering methodologies is at the heart of VIVACE Task 2.5.4, with which UNOTT has some involvement.)

Agile Manufacture is another route to increased competitiveness, gearing manufacturing facilities to respond to changes in products or their demand patterns, while Lean Manufacturing is a (sometimes abused) term describing a range of techniques meant to eliminate the ‘seven wastes’, or ‘Muda’ in the original Japanese [Ohno, 1988]:

- Overproduction
- Waiting
- Transportation
- Inventory
- Motion
- Over-processing
- Defects

Some sources now include an eighth waste, underutilisation of employees, though there is clearly a danger that in pursuing high utilisation – of people or machines – overproduction will result. What is required is a balance where a certain level of inventory is permitted to collect where it will smooth fluctuations or improve delivery reliability. Similarly, spare capacity may be tolerated where it increases responsiveness and manufacturing system robustness. In recognition of the need for a post-lean approach, some companies are now using a new methodology that acknowledges the need for some of the 'fat' that is normally eliminated by the Lean Manufacturing methodologies. This alternative is called Just Enough Desirable Inventory, or JEDI.

Any approach meant to eliminate waste requires collaboration within the supply chain, since inventory can only be reduced safely once delivery performance is assured. Whether an entire supply chain can be made lean is open to question; often a prime's desire to become lean forces its suppliers to deliver small quantities of products at irregular intervals, frustrating that business' efforts reduce inventory.

4.6. CONTEMPORARY TRENDS IN SUPPLY CHAIN MANAGEMENT

Thus far, this chapter has presented the economic case for a collaborative supply chain, and has described its behaviour and means of control. Changes to the way manufacturing businesses within the supply chain operate have also been explored. Contemporary trends for the supply chain as a whole are discussed in the subsections that follow. The key issues are competition, collaboration, the extended enterprise and the virtual enterprise.

4.6.1. The changing nature of competition

From the final customer's perspective it is satisfaction, based on the overall value of the product (or product/service bundle) that is vital, regardless of what happens earlier in the supply chain. Although the operations of an individual company within the supply chain may be focused on its core business and highly efficient, it may not create the desired value for the customer unless the whole supply chain is also effectively organised and coordinated. No single company can ensure that the entire offering is optimal because inefficiency, delays and waste (i.e. non-value adding activities) may be found elsewhere within the supply chain. There is also the very real possibility that a set of locally optimised solutions do not equal optimal performance for the system as a whole. This can affect the competitiveness (and hence financial situation) of all the collaborators.

By the nature of the modern aerospace industry, competition must coexist with collaboration [ACARE, 2002]. The development of the extended enterprise concept facilitates effective collaboration. Hence, competition is less evident between companies, but appears more strongly between supply chains or extended enterprises. Only an effectively integrated supply chain can create full end-customer value, with companies working together as partners.

Collaborative partnerships with the companies that are found upstream and downstream in the supply chain are a vital prerequisite to achieve a highly competitive posture for the extended enterprise. Through collaboration, companies can enhance information and technology as well as sharing the risks and costs, taking an equitable share in the profits created. They will be motivated to help each other to improve operational efficiency and eliminate waste, so that the whole chain will be optimised and integrated as a single system. As a company faces this new era of competition, the winners will be those companies that can collaborate and work with their partners, in a supply chain committed to better, faster and closer relationships with their final customers [Christopher, 1998].

4.6.2. Collaboration

As efficient management of the supply chain becomes critical to achieving high performance, the intensity of company partnerships must also increase. Cooperation has always involved sharing information and involvement of suppliers and customers in the long term, but this arms-length approach may not be sufficient for the extended enterprise.

Spekman et al [1998] state that the next level of intensity is coordination and collaboration, as shown in Figure 5. According to these authors, in co-ordination relations, trading partners can cooperate and coordinate to develop seamlessly linked activities between and among trading partners, through JIT systems and other mechanisms. They consider that this is not sufficient for total supply chain management, so companies are required to move from coordination to collaboration.

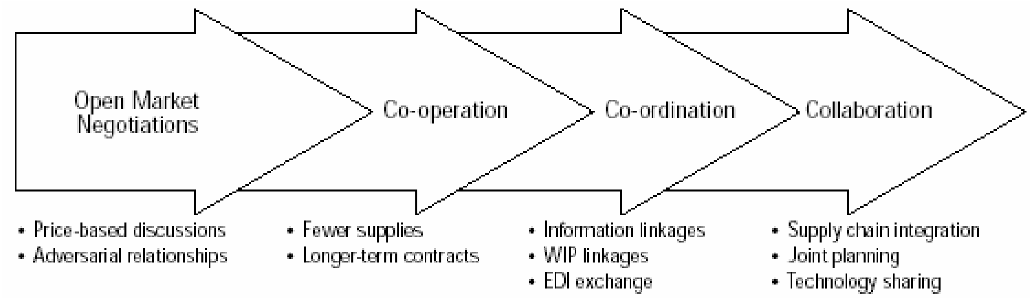

Figure 5: Key transition to collaboration in the supply chain (Spekman et al [1998])

True collaboration partnerships are based on high levels of trust, commitment and information sharing among the partners [Slack et al [2004]). Partners throughout the supply chain must be integrated into others' processes. Staff need to accept that a company, although perhaps playing a comparatively minor role in the supply chain, has relations with many partners, and that its business decisions can have a significant impact on their own performance as well as that of the whole supply chain. Close collaboration relationships with partners; including manufactures, suppliers, distributors, transporters and end-customers are the key to success. Therefore, companies must collaborate with partners towards common goals and mutual benefit, as well as for the benefit of the individual company. Failing to collaborate would result in the distortion of information, which, in turn, can lead to inefficiencies, excess stock, slow response and lost profits [Lee et al, 1997]. Collaboration also enables partners to gain a better joint understanding of future product demand, and to implement more realistic programmes to satisfy that demand, so that successful collaboration yields major benefits: increased market share, stock reductions, reduction in cost and lead-time, improved quality and shorter product development cycles [Corbett et al, 1999].

These changing environments have created the new concepts of enterprise, referred to as the extended enterprise and the virtual enterprise. In addition, the concept of the 'Adaptive Supply Chain' has been developed [SAP, 2002] to refer to a supply chain able to have visibility of requirements and capabilities, and automatically manage variation in these issues in real time, with greater 'velocity' of both information and physical assets within their networks.

4.6.3. The extended enterprise

Current business environments have changed, as discussed above, so that the traditional view of business organisation is no longer valid. The concept of the extended enterprise has recently been developed as a new paradigm to reflect the high level of collaboration between partners. A company's operations and processes are not confined to the company, but cross enterprise boundaries. Integration of the operations of independent companies into the operations of their partners produces an extended enterprise. The extended enterprise can be regarded as a kind of enterprise where companies are integrated collaboratively in the design, development, manufacturing and delivery of a product to end user (Browne et al [1995], Browne et al [1996]).

According to Spekman and Davis [2004], "the notion of the extended enterprise takes supply chain management to the next level and focuses on those factors and characteristics that link supply chain members by far more than just workflow and logistics". They emphasise that in an extended enterprise, firms are linked as learning organisations where knowledge becomes "the currency of exchange". Key suppliers and partners become virtually a part of the principal company and its information infrastructure, with frequent exchange of status information [Jagdev and Thoben, 2001]. Jagdev and Browne [1998] defined the extended enterprise as the formation of close co-ordination across design, development, costing and the co-ordination of the respective manufacturing schedules, for co-operating independent manufacturing enterprises and related suppliers. The extended enterprise is responsible for all operations related to the product, from procurement of raw material to end customer, plus maintenance, customer service and final disposal of the product.

All activities for movement of materials and information should be operated through collaboration with partners in a synchronised and coordinated way. Figure 6 shows a typical example of an extended enterprise in the manufacturing and distribution supply chain.

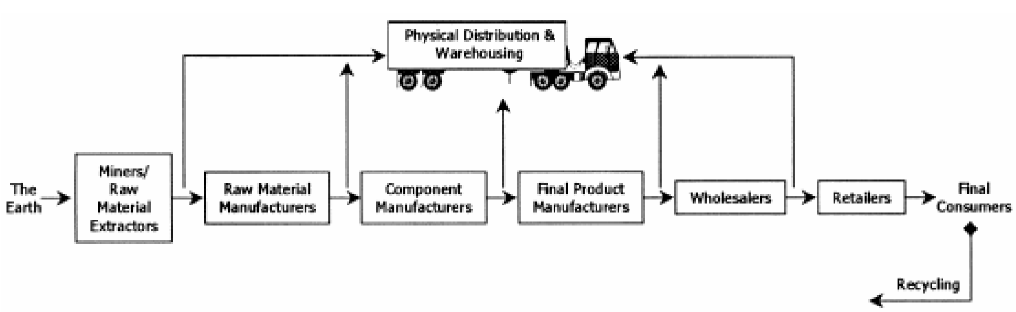

Figure 6: An example of the extended enterprise [Tan, 2001]

4.6.4. The virtual enterprise

Like the extended enterprise, the concept of virtual enterprise has emerged as a form of collaboration, but it has particularly emerged to respond efficiently to the reduced time-to-market, fast-changing customer requirements for complex products in the digital age. A new virtual entity can be organised by selecting business resources from different organisations and integrating them into a single business entity. This is due to the fact that a single company cannot have all the necessary skills and competencies to respond to the market requirements. Many different resources within the joint entity collaborate with each other to perform specific, allocated business operations. The whole joint entity should behave as if it were a single company committed to a particular project. After the project finishes, the joined resources can be split apart, to perform other projects - possibly joining again in different configurations to tackle new projects. This concept of virtual enterprise is made possible by sophisticated information technology and telecommunication systems.

Some authors define the virtual enterprise as a temporary network of independent companies engaged in providing a product or service. Forbairt [1996] stated that the virtual enterprise may have no physical facilities, very few full-time workers and exist as a combination of resources with specific skills, expertise and competences from different companies. Scholz [1997] pointed out that a characteristic of the virtual enterprise is the absence of specific physical attributes and features such as a common administration or a common legal status. Nevertheless, collaboration can be achieved through the application of sophisticated information and communication infrastructure and mutual confidence. Figure 7 shows a typical virtual enterprise. The coordinating agent specialises in the coordination of the activities of other independent companies including suppliers, subcontractors, manufactures and distributors.

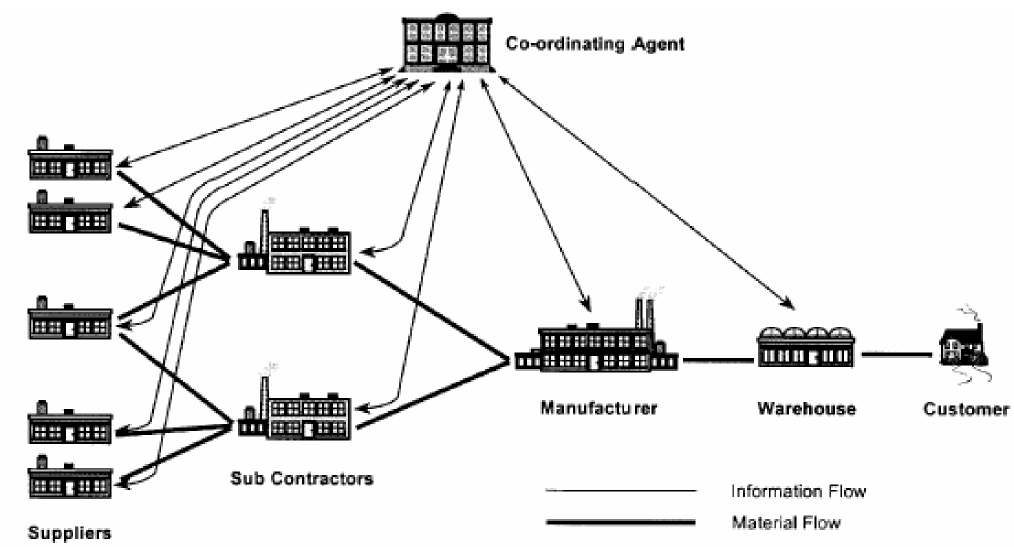

Figure 7: A typical virtual enterprise [Jagdev and Browne, 1998]

4.7. Enterprise Integration

Enterprise Integration (EI) has emerged as a technique to bring together the various elements that constitute an enterprise, whether extended or virtual. EI is an holistic approach that can provide key definition, frameworks and methodologies. EI has largely been focussed on IT system design to date, and many EI concepts are incorporated into the VIVACE project in WP3.6 (Collaboration Hub for Heterogeneous Enterprises). Miller and Berger [2001] describe a concept of the Totally Integrated Enterprise (TIE), with a reference architecture with four dominant perspectives or reference planes. Miller and Berger propose a hierarchical concept of the component-based extended enterprise, taking into consideration the entire customer/product life-cycle.

5. SUPPLY CHAIN MODELLING BEST PRACTICE

As described in Chapter 4, a supply chain encompasses the integrated processes by which raw materials are converted into finished products and delivered to end-users, perhaps to be further maintained and serviced throughout the product lifecycle. These processes, including procurement, production, and distribution, interact with each other and require collaboration between partners in order to produce an integrated offering. Because of differences in business environments and market requirements, the supply chain must be configured to meet specific performance goals. Therefore, the appropriate design and management of the supply chain are vital.

Modelling can assist in the design and implementation of a new supply chain. According to Vernadat [1996], there are two basic aspects in supply chain modelling: first, the supply chain should be modelled in order to manage it properly; second, the processes to be integrated and coordinated need to be modelled. Therefore, the model should be able to capture the complexities of the supply chain and facilitate supply chain integration. Li et al [2002] summarised the main motivations for supply chain modelling:

- Capturing supply chain complexities by better understanding and uniform representation of the supply chain
- Designing the supply chain management process to manage supply chain interdependencies
- Establishing the vision to be shared by supply chain partners, and provide the basis for internet-enabled supply chain coordination and integration
- Reducing supply chain dynamics at supply chain design phases

5.1. CLASSIFICATION OF SUPPLY CHAIN MODELLING METHODS

There are a number of supply chain modelling methods that have been proposed. Beamon [1998] classified multi-stage models for supply chain design analysis into four categories by analytical and mathematical approaches. The classifications are:

- Deterministic analytical models,
- Stochastic analytical models,
- Economic models, and
- Simulation models.

Deterministic models assume that all the variables are known and can be specified with certainty, whilst stochastic models have at least one variable that is unknown and assumed to follow a particular probability distribution.

Min and Zhou [2002] added more categories of supply chain modelling; hybrid models and IT-driven models (Figure 8). They also classified deterministic models and stochastic models in more detail. Deterministic models are divided into single-objective and multiple-objective models, to tune conflicting objectives of different supply chain partners, and stochastic models are sub-classified into optimal control theoretic and dynamic programming models.

Hybrid models have characteristics of both deterministic and stochastic models. These models include inventory-theoretic and simulation models and can manage both deterministic and stochastic variables. IT-driven models reflect the proliferation of IT applications for supply chain modelling through rapid developments in Information Technology. These models target integration and coordination of various activities based on real-time application throughout the supply chain, including a variety of different systems and system modules, such as warehousing management systems (WMS), enterprise resource planning (ERP), geographic information systems (GIS), and aspects of various forecasting, distribution and transportation systems.

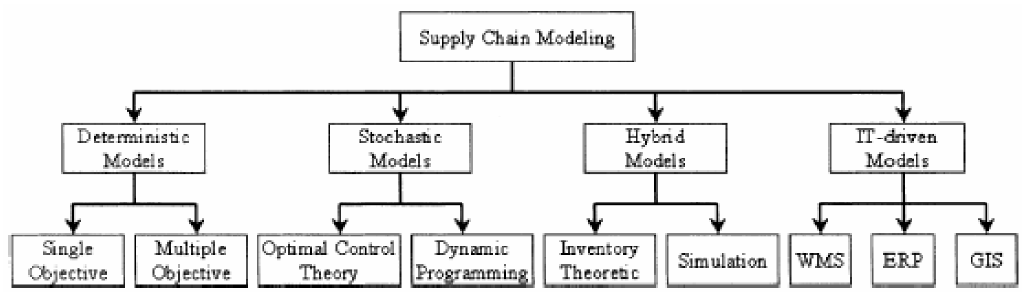

Figure 8: Taxonomy of supply chain models [Min and Zhou, 2002]

In addition to classifications based on mathematical structure, Min and Zhou [2002] classified supply chain models with regard to the problem scope and application area (Figure 9). They confined the model problem scope to problems that cut across supply chains. This is due to the fact that only these models can cover the different functions of the supply chain. These models are involved with multi-functional issues such as location/routing, production/distribution, location/inventory control, inventory control/ transportation, and supplier selection/inventory control.

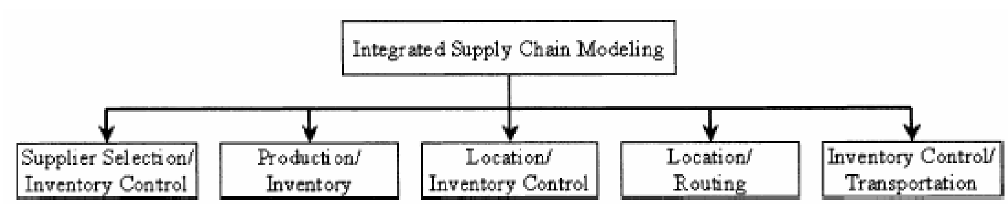

Figure 9: Types of integrated supply chain models [Min and Zhou, 2002]

5.2. TECHNIQUES FOR SUPPLY CHAIN MODELLING

Four techniques are commonly used to model the supply chain for problem-solving; linear programming, integer/mixed-integer programming, network models and simulation modelling. Each of these is described in the sub-sections that follow.

5.2.1. Linear programming.

Linear programming can be used to model various situations, and identifies optimal problem solutions using linear mathematical equations. Only the relationships between decision variables and impact on objective functions are considered. Therefore, there are no qualitative aspects, but only quantitative ones, which means that only problems that can be expressed mathematically can be solved. The technique is available with computer support for more complex problems, and is useful for a variety of situations, where a wide range of constraints can be modelled. Although linear programming helps to find optimum solutions, it may not be realistic because of the dynamic and non-linear behaviour of many variables.

5.2.2. Mixed-integer programming

Integer programming is similar to the linear programming, but all the variables must be integers. Linear mathematical equations can still be used for developing solutions in this approach. On the other hand, Mixed-integer programming (MIP) can use a mixture of integer and real variables, to cover a wider variety of supply-chain modelling scenarios. Typically, the real variables relate to materials flow, while integer or binary types are used for model configuration variables.

Arntzen et al [1995] describes a mixed-integer programming model, called Global Supply Chain Model (GSCM) that incorporates a global, multi-product bill of materials for supply chains with arbitrary echelon structure and a comprehensive model of integrated global manufacturing and distribution decisions. Melachrinoudis and Min [2000] used a dynamic, multiple objective, mixed-integer programming model for assessing the viability of a proposed facility site from multi-echelon supply chain perspectives and determining the optimal timing of relocation and phase-out in multiple planning horizons. Models of the supply chain under uncertainty generate large mixed-integer programming problems, which can make searching for solutions based on the standard MIP solution algorithms very time-consuming [Goetschalckx, 2004].

5.2.3. Network models

Network models represent a supply chain graphically as shown in Figure 10. The network is represented with nodes and connections. Nodes generally represent plants, distribution centres, suppliers or customers, while connection represents transportation lanes. The network can be translated into mathematical representations such as linear, integer and mixed-integer programming [Hicks, 1997]. A typical example is to find a solution to minimise the transportation costs from factories to distribution centres with certain production output from each factory [Johansson, 2002]. The transportation cost could be minimised by determining the shipping quantity of the product from each plant to each distribution centre.

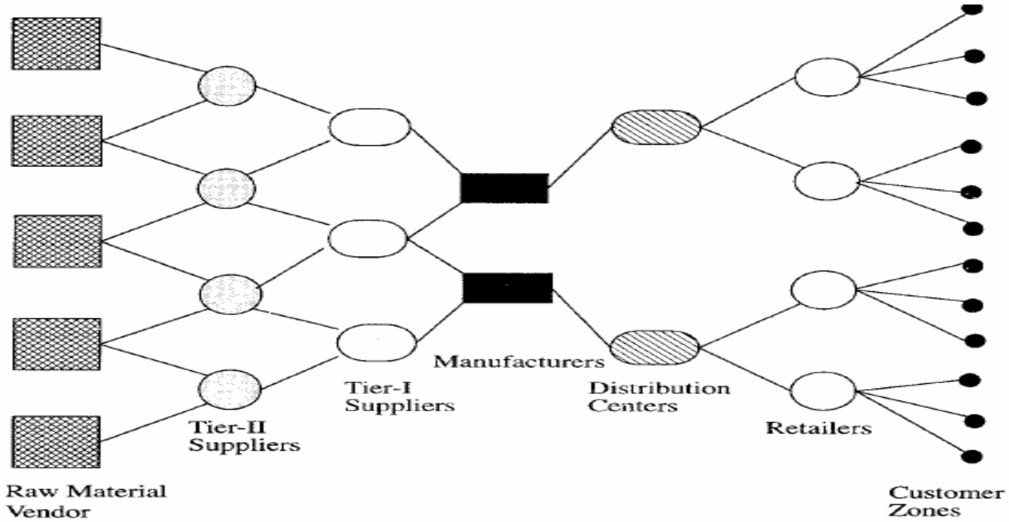

Figure 10: Sample supply chain network [Swaminathan et al, 1998]

Due to the complexity of representing entire supply chains with networks of this kind, analyses are often conducted with respect to a single *focal company*, together with its suppliers and customers for a limited number of steps up and down the supply chain. Key issues to be represented in such a model might typically include:

- Identifying which suppliers can offer a given material or component
- The manufacturing lead time for each item, including degree of variation
- The time required to transport materials or components, including degree of variation
- Constraints such as minimum order sizing
- The cost of a material or components, from each source, including transportation cost
- The level of finished goods stock that is typically held at each node within the model
- The time required to raise an order

Equipped with information of this kind, the responsiveness of a virtual enterprise may be assessed, together with the cost of achieving that level of performance.

5.2.4. Simulation modelling

The main problem with most analytical models is that numerous additional issues and constraints have to be considered before the results can be applied in practice. Many analytical models are highly simplified, and consider only a few variables, such as inventory and the cost of running out of stock, ignoring other costs such as order processing and transportation. In short, mathematical approaches often require too many simplifications to model realistic supply chain problems, although they may be valuable for gaining an understanding of general supply chain principles and effects.

Simulation is the process of designing and creating a model of a real or proposed system, using abstract objects in an effort to replicate the behaviour of their real-world equivalents.

The parameters of the model are dynamic, and change over a period of time to show the behaviour of the system under given conditions.

Simulation is considered as one of the most powerful techniques to apply within a supply chain environment [Terzi and Cavalieri, 2004]. Wyland et al [2000] argue that the increasing popularity of simulation as a tool in supply chain management is due to its strength in evaluating system variation and interdependencies. This enables a decision-maker to assess changes in part of the supply chain and visualise the impact of those changes on the other parts of the system, and ultimately on the performance of the entire supply chain. Simulation has been used to model supply chains in various industrial sectors including mobile communication systems [Persson and Olhager, 2002], food [Reiner and Trcka, 2004], apparel [Al-Zubaidi and Tyler, 2004], and the aerospace industry [Bilczo et al, 2003].

This approach is judged to have particular merit for the experiments to be conducted within Tasks 2.5.1 and 2.5.3, and is therefore described in detail Chapter 7.