Design and Realisation of An Integrated Methodology for the Analytical Design of Complex Supply Chains

By

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Abstract:

Supply chain systems are inherently complex and are dynamically changing webs of relationships. Wider product variety, smaller production lot sizes, more tiers and different actors involved in coordinated supply chains also cause supply chain complexity and presents major challenges to production managers. This context has led modern organizations to implement new supply chain paradigms and adopt new techniques to support rapid design, analysis and implementation of the new paradigms.

The present research focuses to develop an integrated methodology which can support the analytical design of complex supply chains. Capabilities are identified in response to this research context which needs to be built into such an integrated methodology. The capabilities are; i) graphical representation and explicit description of key characteristic properties of complex supply chains, ii) analytical exploration of dynamic properties of complex supply chains, to provide analytic means of reasoning about impacts of uncertainty in complex supply chains, such as those introduced due to changes in demand, supply, make, delivery and return processes, iii) prediction of possible future behaviours of complex supply chains when uncertainties arise, and iv) to quantify and predict relative performances of alternative complex supply chain configurations subjected to uncertainties or risks. State of the art modelling techniques like enterprise modelling (EM), causal loop diagramming (CLD), simulation modelling (SM) and product classification are studied and analysed. As yet EM, CLD and SM have not been used in a coherent fashion to support the lifecycle engineering of complex supply chains. Particularly though there appears to be potential to do so by developing and testing the use of an 'integrated model driven method of lifecycle engineering complex supply chains'. The purpose of such a method is to enable better, faster and most cost effective engineering of complex supply chains, than was feasible prior to the conception of this new method.

This research proposes an integrated methodology for the analytical design of complex supply chains. The integrated methodology uses EM, CLD, SM and product classification techniques together in a unified way to address analytical design issues related to complex supply chains. To test the usefulness of the integrated methodology, two case studies were conducted. One case study is related to a parking and valeting company in which issues of information shortfall and training short fall are suitably analysed using the integrated methodology. The second case study is related to a point of purchase (POP) equipment manufacturing company in which issues of 'product change over' and 'components availability' at assembly cells are usefully investigated using the integrated methodology. Some suggestions are deduced for supply chain improvement in the case companies. The application of the methodology proved useful in both case study organizations.

Key words: Complex supply chains, analytical design, enterprise modelling (EM), causal loop diagramming (CLD), simulation modelling (SM), product classification.

Glossary

Analytical Design

The term 'Analytical design' is used to imply 'a systematic approach which leads to quantifiable results'.

Complex Supply Chain

The term 'Complex supply chain' is used to imply 'a supply chain which is required to process multiple product types'.

Model

The term 'model' is used to imply 'a representation of some aspect of an entity under study which can be used to facilitate visualisation, analysis, design, etc'.

Modelling Technique

It is a way to carryout a particular modelling task. For example, in this thesis some of the modelling techniques presented are enterprise modelling (EM), causal loop diagramming (CLD) and simulation modelling (SM).

Modelling Tool

It is a device used to support carrying out a particular modelling task as per requirement of related modelling technique. For example, Simul8 is a computer simulation modelling tool which can be used to perform simulation modelling.

Supply Chain

The term 'supply chain' is used to imply 'a process network used to deliver products and services from raw materials and purchased components to customers through an engineered flow of information, physical distribution, and cash'.

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Chapter 1: Introduction

1.1 Research context and focus

1.1.1 Complex supply chains[1] and research context

Supply chain systems are inherently complex (Beamon, 1998). Complexity is the amount of variety at and across processes (Kambil, 2008). Supply networks are becoming more complex and are dynamically changing webs of relationships (Harland et. al., 1999). Complexity in the supply chain can be viewed as a threat and something that needs to be avoided and/or reduced but achieving these objectives may be difficult in practice (Wilding, 1998). Wider product variety, smaller production lot sizes, more tiers and different actors involved in coordinated supply chains also cause supply chain complexity (Perona and Miragliota, 2004). Today's market environment is characterised by diverse customer tastes and preferences, rapid developments in technology, and the management of globalization (Hsu and Wang, 2004). These factors have resulted in the need for a variety of products, which presents major challenges to production managers. The emphasis is on redesigning products and processes so that the negative impact of product variety due to product proliferation can be overcome (Lee and Tang, 1997). This context has led modern organizations to implement new supply chain paradigms and adopt new techniques to support rapid design, analysis and implementation of the new paradigms.

1.1.2 Analytical design of complex supply chains and focus of research

A most important core competence of an organization is the capability to design its supply chain (Fine, 1998). Supply chain management (SCM) can be drawn from a collection, customization and implementation of tools to fit the environment (Plenert, 2007). Knowledge of business processes that define real supply chains, and information technology, collectively constitute a powerful and compelling decision technology base for reengineering, integrating, planning, and optimizing supply chains (Bhaskaran and Leung, 1997). Supply chains are dynamic and involve the constant flow of information, product and funds between different stages and it is important to visualise information, funds and product flow along both directions of this chain (Chopra and Meindl, 2004). Simulation of systems and non-linear dynamic analysis of key outputs should be a mandatory part of any supply chain re-engineering proposal (Wilding, 1998). Simulation easily incorporates effects of uncertainty (Harrison et al., 2003). Due to the inherently complex supply chain systems, thus the models and methods used to accurately study these systems are, expectedly, also complex (Beamon, 1998). The future supply chains include existing leading practices, applications to example supply chains and new ways to calculate the impact on the supply chains (GCI, 2008). Therefore, the focus of this research is to develop an integrated methodology which can support the analytical design of complex supply chains.

1.2 State of the art solution techniques for analytical design of complex supply chains and lack of provision

Different state of the art solutions have been reviewed with potential to support analytical design of complex supply chains. Some of the techniques are supply chain mapping (Christopher, 2005), Supply Chain Operations Reference (SCOR) model (SCC, 2008), Customer Chain Operation Reference (CCOR) model, and Design Chain Operation reference (DCOR) model (Bolstorff and Rosenbaum, 2007), optimisation, simulation and heuristics (Harrison, et. al., 2003). These techniques are supporting supply chain analysis either by modelling some structural aspects of the supply chain or by analyzing behavioural aspects of the supply chain. A general review for need of this research in light of the context of this research, current state of the art solution techniques, limitations of current state of the art techniques, and some potential technologies are presented in figure 1.1.

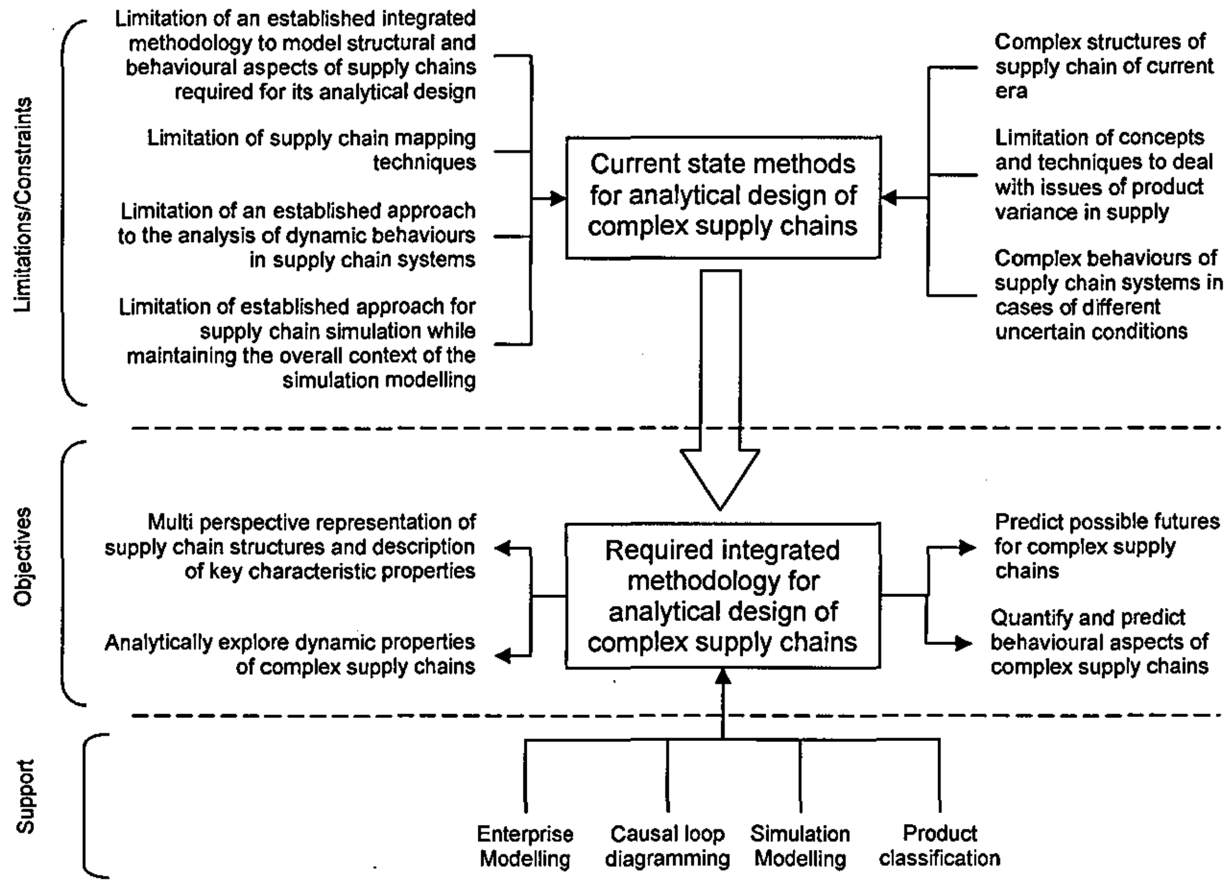

Figure 1.1 General review of the research need.

Some modelling techniques like enterprise modelling (EM) (Vernadat, 1996), causal loop diagramming (CLD) (Sterman, 2000), simulation modelling (SM) (Rahimifared and Weston, 2005), and unified use of EM, CLD and SM (Weston et,. al., (2007), Rashid et. al., (2009)) have been used across the world in general and particularly in MSI research institute at Loughborough university to provide an analytical basis for underpinning organization design and change (OD&C). However, there is a need to case test the application use of unified modelling concepts in many different business-wide contexts, and in respect of various industry sectors. This is an area of ongoing research in MSI Research Institute (Chatha and Weston, 2006). The research reported in this thesis contributes to that initiative. As yet EM, CLD and SM have not been used in a coherent fashion to support the lifecycle engineering of complex supply chains. Particularly therefore this research will develop and test the use of an 'integrated model driven methodology of lifecycle engineering complex supply chains'.

The purpose of so doing is to enable better, faster and more cost effective engineering of complex supply chains, than was feasible prior to the conception of this new methodology.

1.3 Research objectives

This research was initiated from a general observation that industry at large requires an improved analytical basis for designing and changing complex supply chains. An extensive literature survey is conducted in this regard to study supply chains and different issues associated with supply chains and to study state of the art techniques to support decision making about complex supply chains. Analysis of the surveyed literature showed that there are some techniques which can analyse some aspects of supply chain (for details, see chapter 2). However, to analyse several important aspects of a complex supply chains, there is a need for an integrated methodology to do so (for details, see chapter 3, section 3.2). Therefore the overall aim of this research is "to develop and test use of an integrated modelling methodology to support decision making about complex supply chains". To fulfil this aim, the following objectives were defined.

Objective 1. To study state of the art modelling techniques that have potential for the analytical design of complex supply chains.

Objective 2. To develop an integrated modelling methodology for the analytical design of complex supply chains.

Objective 3. To case test and update the integrated modelling methodology for the analytical design of complex supply chains.

The capabilities envisaged for the integrated modelling methodology for the analytical design of complex supply chains were as follows:

- graphically represent and explicitly describe key characteristic properties of complex supply chains.

- analytically explore dynamic properties of complex supply chains, via the provision of analytic means of reasoning about impacts of uncertainty in complex supply chains, such as those introduced due to changes in demand, supply, make, delivery and return processes.
- predict possible futures of complex supply chains when certain types of uncertainties that may arise.
- quantify and predict behavioural aspects of complex supply chains when they are subjected to observed uncertainties or risks (potential uncertainties).

1.4 Research approach

The general research approach and general research methodology developed is presented below in table 1.1.

Table 1-1 General research approach

General Research Steps Taken	Description	Thesis Chapters
Step 1: Define the research project	• Make sense of research • Define general research need and problem • Define research approach	Chapter 1
Step 2: Literature Survey	• General review of supply chain management • Supply chain paradigm review • Current supply chain issues review • Current supply chain modelling techniques review	Chapter 2
Step 3: Gap Analysis	Define important supply chain issues and identify lack of provision of a suitable methodology for the analytical design of complex supply chains	Chapter 3
Step 4: Selection of Research Objectives	Develop research aim and objectives in support to the research gap, bearing in mind the time and resources available. The research aim and objectives were; Research Aim: "to develop and test use of an integrated modelling methodology to support decision making about complex supply chains". Objective 1. To study and analyse state of the art modelling techniques that have potential for the analytical design of complex supply chains. Objective 2. To develop an integrated modelling methodology for the analytical design of complex	

General Research Steps Taken	Description	Thesis Chapters
	supply chains. Objective 3. To case test and update the integrated modelling methodology for the analytical design of complex supply chains.	
Step 5: Design of the integrated modelling methodology	To meet the objective 1 & 2, design the required integrated methodology for the analytical design of complex supply chains. Also describe the implementation description for the use of the modelling methodology in case study enterprises.	Chapter 4
Step 6: Use of the integrated modelling methodology (M1)	To meet objective 3, use and test the usefulness of the integrated modelling methodology for the analytical design of complex supply chains in a case service enterprise.	Chapter 5
Step 7: Analyse and update the integrated modelling methodology (M1)	To meet objective 3, analyse and update the integrated modelling methodology for the analytical design of complex supply chains.	Chapter 6
Step 8: Use of the updated integrated modelling methodology (M2)	To meet objective 3, use and test the usefulness of the integrated modelling methodology for the analytical design of complex supply chains in a case service enterprise.	Chapter 7 & 8
Step 9: Discuss usefulness of M1 and M2, suggest improvements and some future work	Discuss novelty and usefulness of M1 and M2 and describe some future potentials related to the research done.	Chapter 9

1.5 Thesis structure

The thesis is decomposed and organised in nine chapters. Brief contents of each chapter are given below.

In chapter 1, the research problem is described and in relation to the research aims and objectives the research approach is expressed.

In chapter 2, literature related to supply chain paradigms and supply chain issues is surveyed and analysed. Also current state of the art modelling techniques are analysed in support of the analytical design of complex supply chains.

In chapter 3, the research gap is analysed and the research objectives are described. Also general research methods and data collection methods are reviewed and suitable ones are selected for this research. Furthermore, the general research approach is described.

In chapter 4, the required integrated methodology for the analytical design of complex supply chains (referred to in the thesis as M1) is designed. How to use the M1, some designed benefits of M1 and some aspects of M1 for which impacts as new knowledge are also presented.

In chapter 5, M1 is used and tested for a case parking and valeting company and its supply chain. The usefulness of M1 is also analysed and presented.

In chapter 6, M1 is enhanced to address a new issue of high product variance in complex supply chains which is required by the second case study company manufacturing customised point of purchase (POP) equipment. M1 is enhanced by developing and integrating it with a new technique for product classification. The resultant enhanced integrated methodology for analytical design of complex supply chains is referred to in the thesis as M2.

In chapter 7, M2 is used and tested in the case customised POP equipment manufacturing company. In this chapter only the enterprise modelling (EM) technique of the M2 is used and tested for its usefulness in the case company.

In chapter 8, the causal loop diagramming (CLD), simulation modelling (SM) and product classification techniques of M2 are used and tested for their usefulness in the case POP equipment manufacturing company.

Chapter 9 summaries and concludes the research conducted and reviews the results and new knowledge achieved in different chapters of the thesis. It also presents future research potential of this research.

Chapter 2: Literature survey

The purpose of this chapter is to review literature on supply chains and other related topics and to describe in detail the literature which is most relevant to the scope and focus of the thesis. The literature review is presented in two broad sections namely part A which is associated with the concepts and problems in supply chain and part B covers literature survey associated with some candidate techniques which can support supply chain engineering in different ways. Each of the two parts of this chapter concludes with an analysis of the literature and a gap analysis for further research.

Part A – Supply chain paradigms and issues

2.1 Supply chain introduction

The field of supply chain management was conceived to manage the flow of information, products and services across a network of customers, enterprises and supply chain partners (Russell and Taylor, 2009). The term supply chain management was first used in its popular sense by Oliver and Weber (1982) and related ideas were developed by Houlihan in a series of articles (Houlihan 1884, 1985, 1988) that describe the management of material flows across organizational boundaries (Giannakis et al., 2004). Interest in the concept of supply chain management has steadily increased when companies saw the benefits of collaborative relationships within and beyond their own organization (Lummus and Vokurka, 1999). Since then several researchers have investigated the concept of supply chain management (Ellram, 1991; Christopher, 1992; Harland, 1994; Lamming, 1996; Handfield and Nichols, 1999) establishing the theoretical and practical basis we know today (Giannakis et al., 2004). The influence of supply chain thought on organizational strategy has also been significant, reflecting, as Christopher (1992) and Macbeth and Ferguson (1994) and other authors have claimed that competition takes place between supply chains rather than between individual organizations (Giannakis et al., 2004). In the last decade of 20th century, purchasing and supply perspectives on supply chain management (Tan et al., 1999, 1998b) and transportation and logistics perspectives of supply chain management evolved from previous understandings about purchasing and logistics functions of an enterprise; which were typically considered to be support functions. These two traditional supporting functions of corporate strategy evolved along separate paths and eventually merged into a holistic and strategic approach to operations, materials and logistics management, commonly referred to as supply chain management (SCM) (Tan, 2001). The concept of supply chain is about managing coordinated information and material flows, plant operations, and logistics. Supply chain flexibility and agility should be enabled to respond to consumer demand shifts without cost overlays in resource utilization (Chandra and Kumar, 2001). The future supply chain should be engineered by applying leading practices, in example related supply chains coupled to new ways of calculating impacts on the supply chain (GCI, 2008). A most important core competence of an organization is the capability to design its supply chain (Fine, 1998). (Walker, 2005) has proposed a shift from using a functional cost-driven view of supply chains towards a network throughput-driven view of supply chains.

Apparently though there is no agreed consensus on the meaning of supply chain management (Giannakis et al., 2004). Different terms have been used instead of, or interchangeably with, supply chain; like value chain and demand chain (Russell and Taylor, 2009). A profusion of different terminologies can be found referring to: supply network (Nishiguchi, 1994), Lean chain approach (New and Ramsay, 1995), supplier integration (Dyer, Cho and Chu, 1998), buyer-supplier partnership (Lammming, 1993), integrated purchasing strategy (Burt, 1984), supply base management, integrated supplier alliances (Lewis, Naim, and Towil, 1999), supply chain synchronisation (Tan, Kannan, and Handfield, 1998) , network supply chain (Nassimbeni, 1998), (Walker, 2005), value added chain (Lee and Billington, 1992), supply pipeline management (Farmer and van Amstel, 1991) (Christopher and Peck, 2004), value stream (Jones, 1994), value chain (Porter, 1985) and demand chain (Frohlich and Westbrook, 2002, Giannakis et al., 2004, Russell and Taylor, 2009). These definitions typically have different meanings or different emphasis but they all share one common theme – they all share phenomenon related to the management of operations across organizational boundaries (Giannakis et al., 2004).

The APICS dictionary, 10th edition defines supply chain as "the global network used to deliver products and services from raw materials to end-customers through an engineered flow of information, physical distribution, and cash". The supply chain network provides a continuous path from dirt to the paying end-customer and operates through the integration of its three flows namely information, physical distribution and cash (Giannakis et al., 2004). Each basic supply chain is a "chain" of source, make, deliver, and return execution processes (SCOR, 2008). Each interaction of two execution processes (source-make-deliver) is a "link" in the supply chain. Planning sits on top of these links and manages them (Huan et al., 2004). Supply chain contains all the activities involved in delivering a product from raw material through to the customer including sourcing raw materials and parts, manufacturing and assembly, warehousing and inventory tracking, order entry and order management, distribution across all channels, delivery to the customer, and the information systems necessary to monitor all of these activities (Lummus and Vokurka, 1999). Supply chain consists of all parties involved, directly or indirectly, in fulfilling a customer request. Supply chain is dynamic and involves the constant flow of information, product and funds between different stages and it is important to visualise information, funds and product flow along both directions of this chain (Chopra and Meindl, 2004). Realistic supply chains have multiple end products with shared components, facilities and capacities. The flow of materials is not always along an arborescent network, various modes of transportation may be considered, and the bill of materials for the end items may be both deep and large (Ganeshan and Harrison, 1995). From the physical distribution perspective, a typical supply chain network looks like a tree turned on its side with many branches, a thick trunk, and many roots. Because a product BOM has parallel paths, the upstream portion of a network will have many roots. Because a business serves many customers, the downstream portion of a network will have many branches (Walker, 2005). SCM desires the optimised movement of resources from supplier to customer (Plenert, 2007).

From the view point of market and product characteristics, supply chain can be classified in two main classes namely physical and operational, and relational. Physical and operational is further sub divided into structural, product strategy and process strategy (Dani, 2005) (see Figure 2.1).

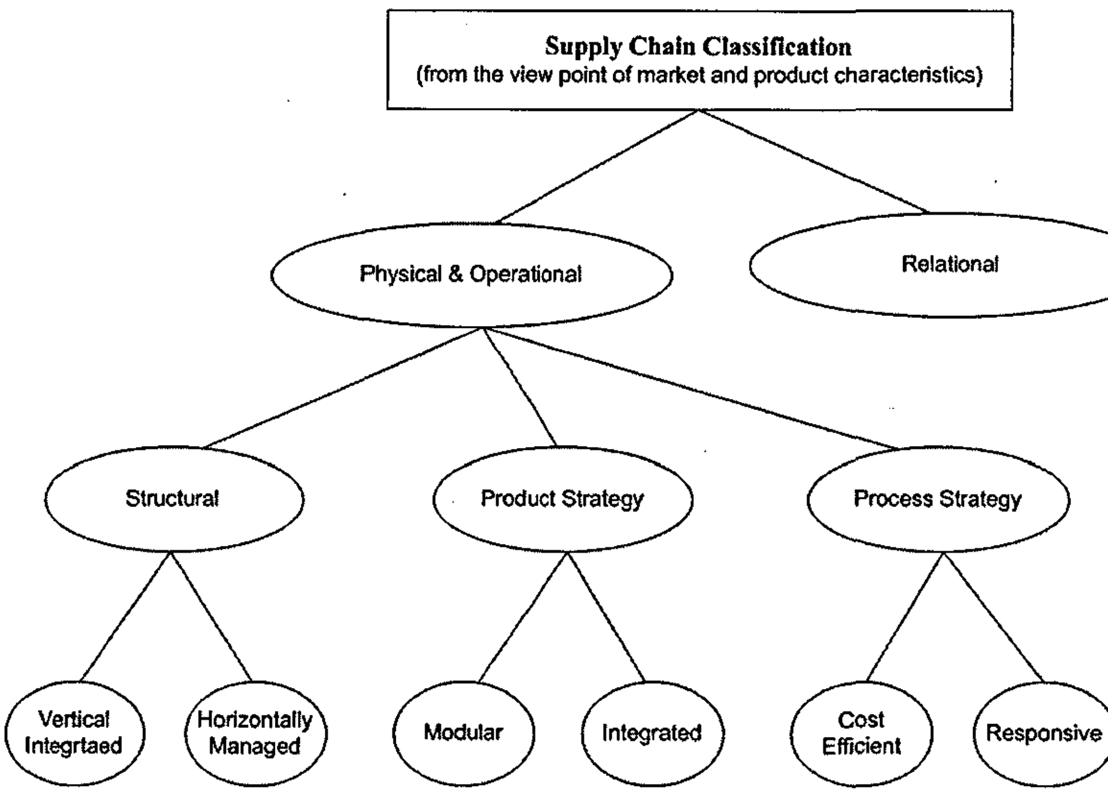

Figure 2.1 Supply chain classification from view point of market and product characteristics (Dani, 2005).

A typical supply chain structure is shown in figure 2-1 (Dani, 2005). This will normally be vertically integrated (hierarchical integration within an enterprise) and/or horizontally managed (cross functional management). Product strategy is either centred on modular products or an integrated product. Process strategy can be cost efficient (for functional products) or responsive (for innovative products) (Dani, 2005).

A focus on cash flow creates differences in the study of supply chain management from that of logistics and lean manufacturing (Walker, 2005). Supply chain management (SCM) can be drawn from a collection of tools, and when SCM is implemented, the tools are selectively chosen and customised to fit the environment (Plenert, 2007).

Harland, (1996) identified four main uses of the term supply chain management; 1) management of internal supply chain that integrates business functions involved in the flow of material and information from inbound to out bound ends of the business, 2) management of dyadic or two party relationship with the immediate suppliers, 3) management of a chain of businesses including a supplier, a supplier's supplier, a customer and a customer's customer, and 4) management of a network of interconnected businesses involved in the ultimate provision of products/services required by the end customer.

2.2 Supply chain management views

Literature on supply chain includes different views for decomposing supply chains. The view is presented as follows.

2.2.1 Process views of supply chain management

According to SCOR, each basic supply chain include five standard processes, namely: planning, source, make, deliver, and return (SCOR, 2008). SCOR chains can span from the supplier's supplier to the customer's customer (Stewart, 1997). The Supply Chain Operation Reference (SCOR) model is shown in Figure 2.2.

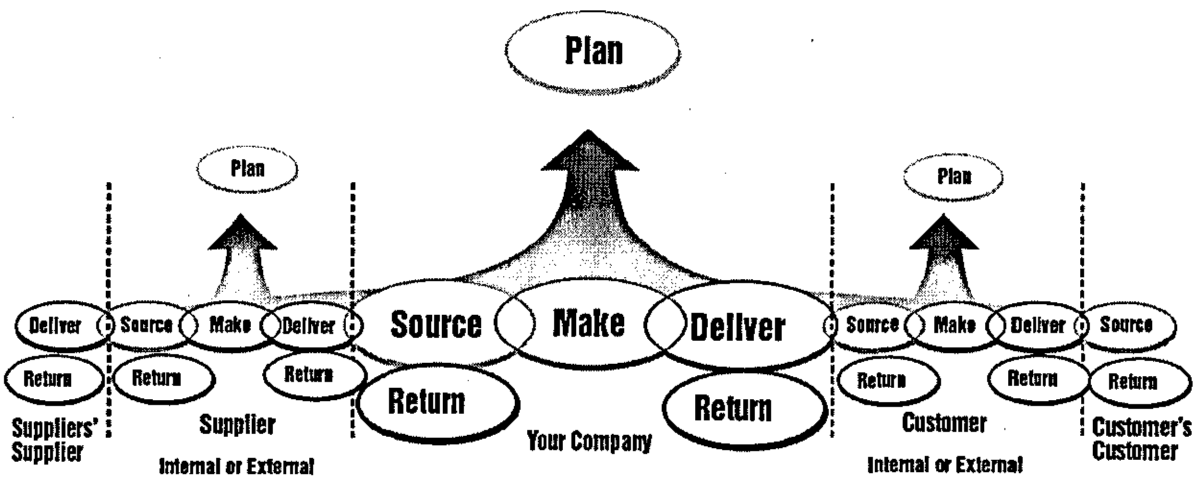

Figure 2.2 SCOR model showing supply chain management processes (SCOR, 2008).

Supply chains can also be broken down into five processing areas. This will involve flows and processes of the chain both inside and outside the focal company; namely transport/distribution, manufacturing, order cycle, warehousing, and procurement (Gaudenzi and Borghesi, 2006).

Another process view of supply chains is presented by Chopra and Meindl (2007). They defined supply chain as a sequence of processes and flows that take place within and between different stages that combine to fill a customer need for a product. Two different ways are presented to view supply chain processes.

i) Cyclic view of supply chain management: The processes in a supply chain are divided in to a series of cycles, each performed at the interface between two successive stages of a supply chain. All supply chain processes can be broken down into four process cycles namely, customer order cycle, replenishment cycle, manufacturing cycle, and procurement cycle (see figure 2.3).

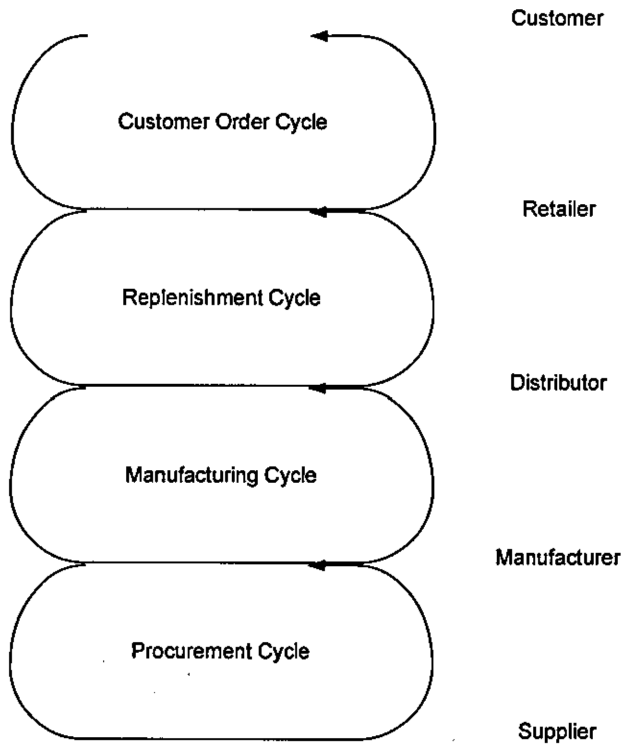

Figure 2.3 Cyclic view of supply chain management (Chopra and Meindl, 2007).

ii) Push/Pull view of supply chain management: The processes in a supply chain are divided into two categories depending on whether they are executed in response to a customer order (Pull) or in anticipation by a customer order (Push). This view is shown in Figure 2.4.

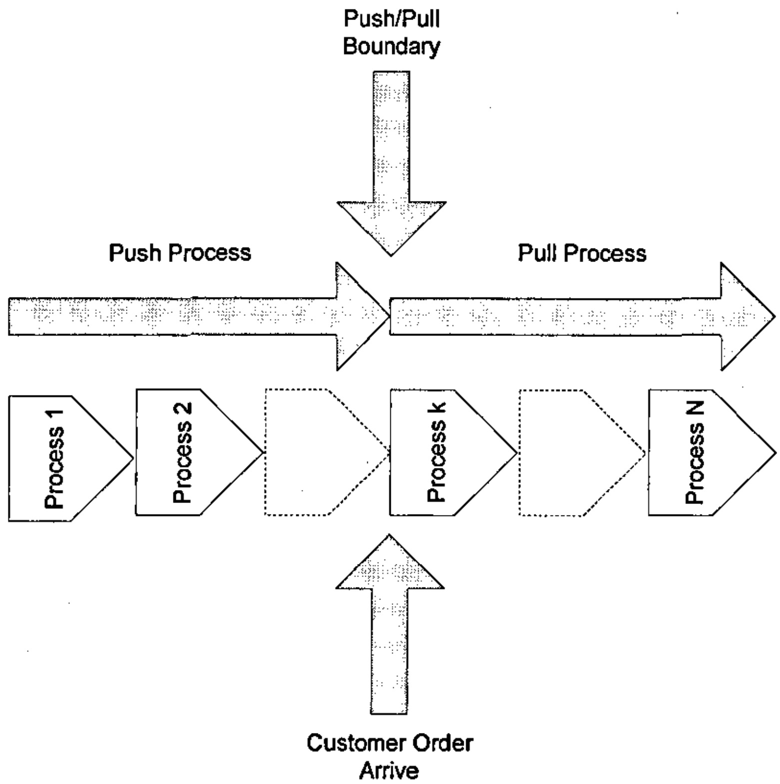

Figure 2.4 Push/Pull view of supply chain management (Chopra and Meindl, 2007).

2.2.2 Network view of supply chain management

Four zones provide an easy framework for describing an organization's position within a supply chain network. The rectangles in figure 2.5, identify four zones namely: upstream, mid-stream, downstream, and reverse-stream zones (Walker, 2005). Inventory locations define the boundaries of each zone. Component inventory locations establish the upstream edge of midstream zone while finished-goods inventory locations establish the downstream edge of the midstream zone (Walker, 2005).

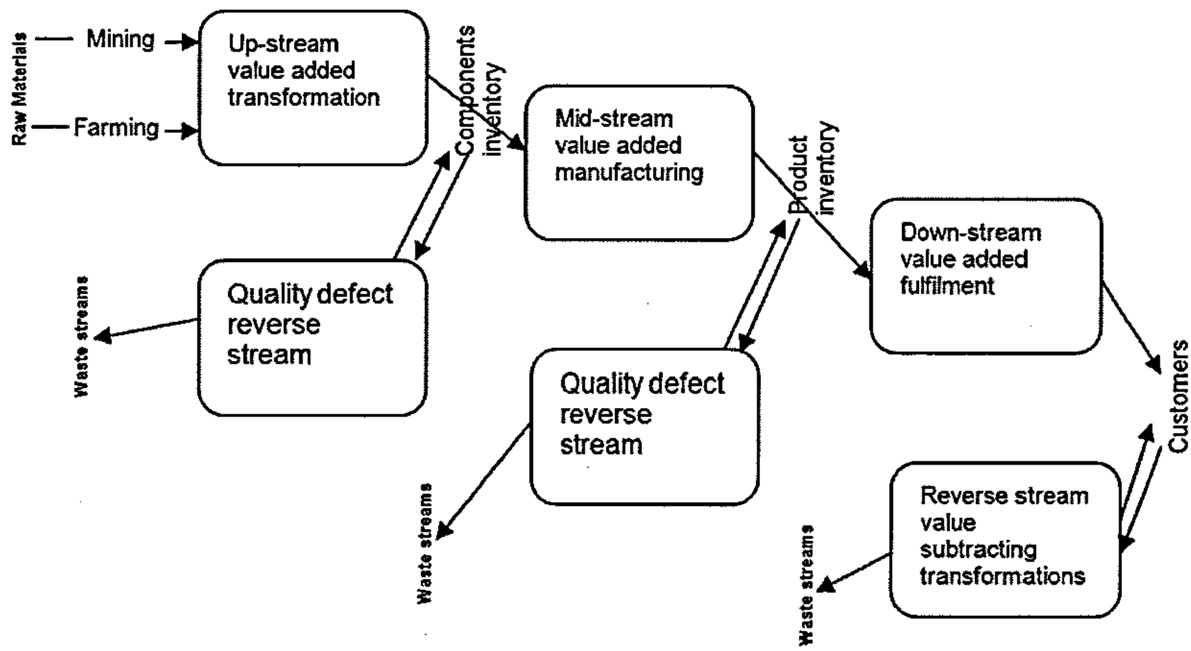

Figure 2.5 The four supply chain network zones (Walker, 2005).

The midstream zone must be competitive in the following core manufacturing competencies: logistics, import/export, manufacturing processes, production engineering, capacity management, inventory management, planning and forecasting, material handling, lot tracking, procurement, materials engineering, quality management, information systems and product development (Walker, 2005).

Reverse stream zones can have six common organizational functions namely defective-item return, product return, repair and recalibration, recall, remanufacture, and recycle (Walker, 2005).

Criss-crossed networks are very common among supply chain networks where one or more organizations in a network, may buy and sell out-of-network as part of other, totally unrelated networks. For example, a machine screw supplier in a network also sell hardware components to different auto, aero and durable goods manufacturers which are part of different network (Walker, 2005).

2.2.3 Functional view of supply chain management

Chopra and Meindl (2007), described a variety of stages/functions in a supply chain namely, suppliers, manufacturers, distributors, retailers and customers. All such functions need to interact with each other presenting, a functional view of a supply chain network (see figure 2.6).

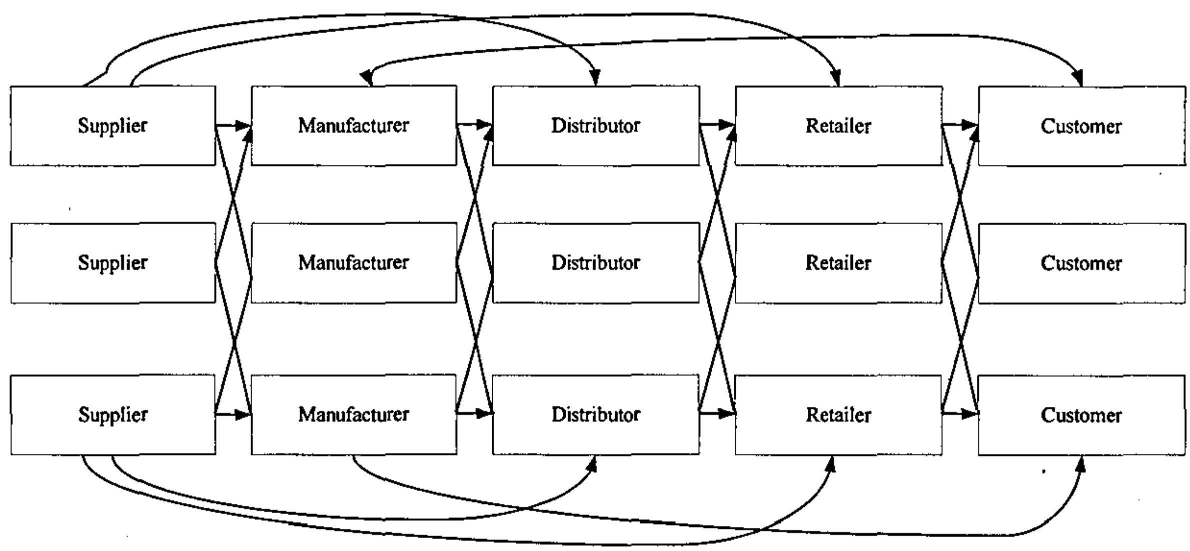

Figure 2.6 Supply chain stages (Chopra and Meindl, 2007).

2.2.4 Operation management view of supply chain management

(Russell and Taylor, 2009) presented the operation management view of supply chain management. According to this view, supply chains are composed of input, transformation and output processes. Transformation processes are depicted as operations which are systems that transform inputs into outputs of higher value. Supply chain management concentrates on the input and output sides of transformation processes. Increasingly, however, as the transformation process is performed by the suppliers who may be located around the world, the supply chain is also concerned with the timeliness, quality, and legalities of the supplier's operations. This view is presented in figure

2.7.

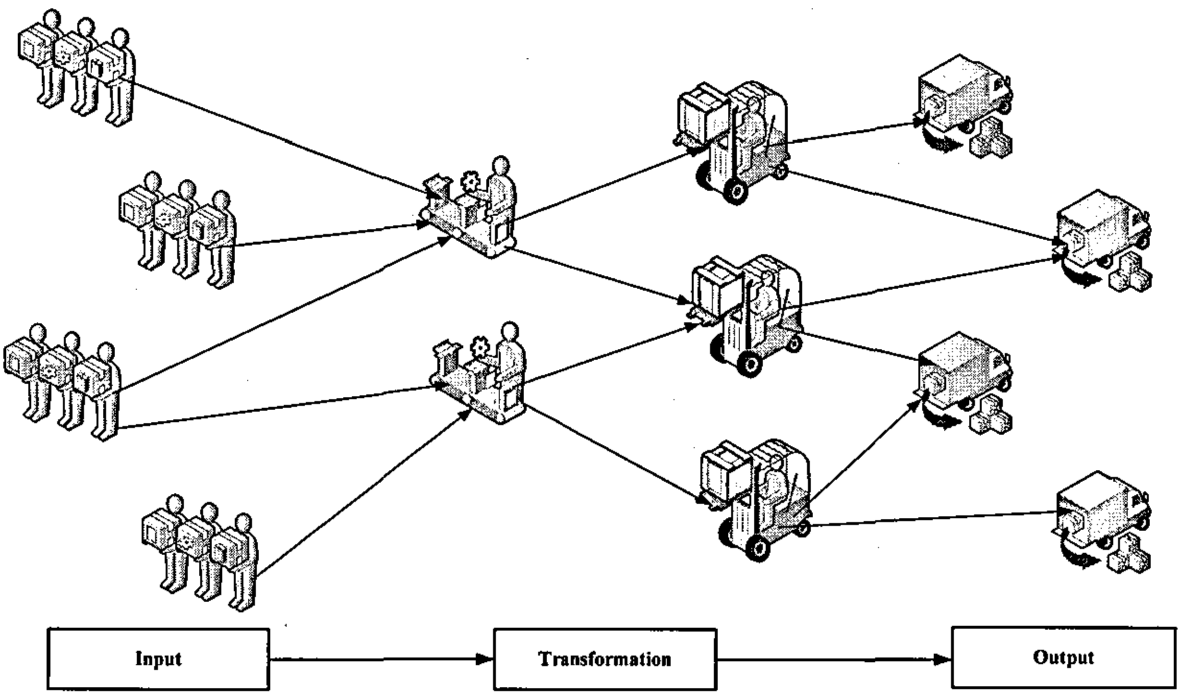

Figure 2.7 Operation management view of supply chain management ((Russell and Taylor, 2009).

2.2.5 Enterprise integration view of supply chain management

In this view, two types of integration are included, namely horizontal integration and vertical integration (Weston, 1993) (see figure 2.8). Horizontal integration is concerned with the integration of the enterprise with its customers and suppliers. Horizontal integration concerns physical and logical integration of business processes from product demand to product shipment, regardless of the organizational boundaries (Vernadat, 1997). Horizontal integration mainly concerns the flow of material and flow of technical documents. Typical examples are concurrent engineering which require the involvement of cross functional teams for products and process development and JIT management for production control through integrated logistic chains (Weston, 1993). Vertical integration concerns integration between the various management levels of the enterprise, i.e., decision making integration where a management level defines a set of constraints for its lower management levels, which in turn send feedback information to their upper management level (status reports), and so on (Vernadat, 1997).

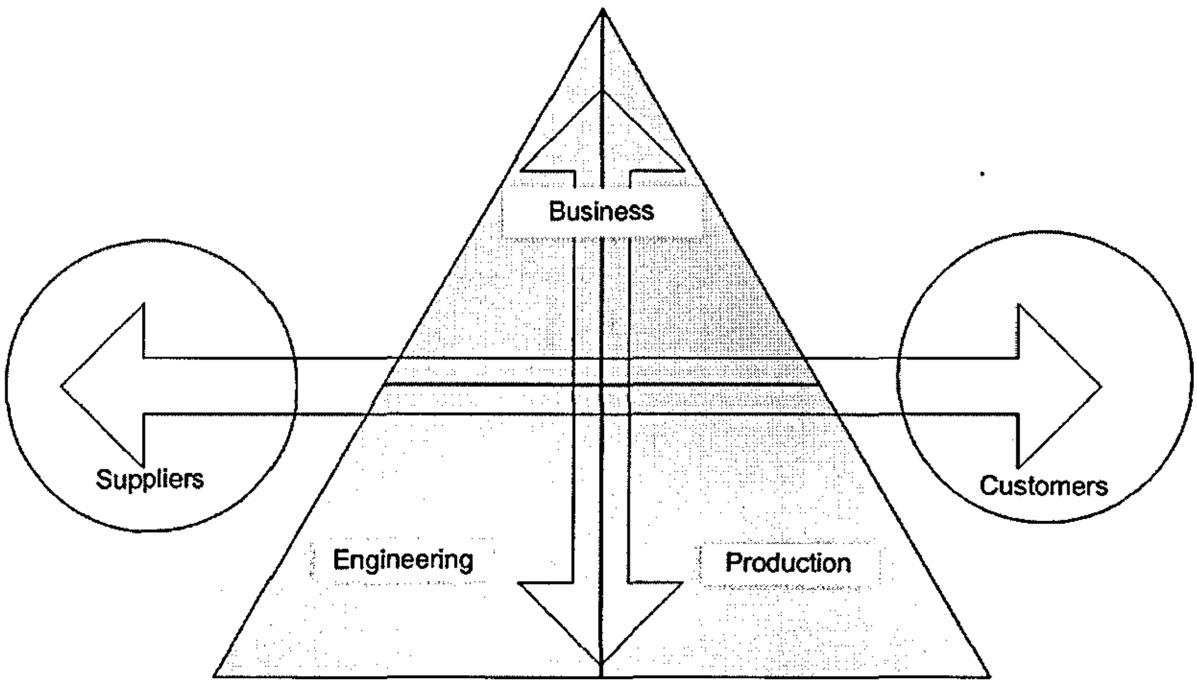

Figure 2.8 Horizontal and vertical integration (Weston, 1993).

2.3 Supply chain complexity

Complex systems are made up by single elements which have intimate connections, counterintuitive and non-linear links: as a consequence, complex systems present self emerging, often chaotic, behaviours (Forrester, 1961). Complexity is the amount of variety at and across processes (Kambil, 2008). Supply networks are becoming more complex and are dynamically changing webs of relationships (Harland et. al., 1999). Complexity in the supply chain can be viewed as a threat and something that needs to be avoided and/or reduced but achieving these objectives may be difficult in practice (Wilding, 1998). An alternative view is that complexity might compel organizations to innovate and learn because if everything stays stable, organizations would not need to develop new structures or patterns of behaviour (McMaster, 1996). Different factors that give rise to complexity are; increase in product/service complexity, e-business, outsourcing, and globalization (Harland et al.,1999).

Global supply chains are complex, dynamic systems that are subject to large time-lags. Complexity causes variability in delivery; which might arise from physical distances. Long distances usually increase transportation and order lead time, which decreases reliability of demand forecasts (Perona and Miragliota, 2004). Measures taken to increase agility often lead to increase complexity (Prater et al., 2001). Different dimensions of complexity of manufacturing and logistics systems are presented in Figure 2.9 (Perona and Miragliota, 2004).

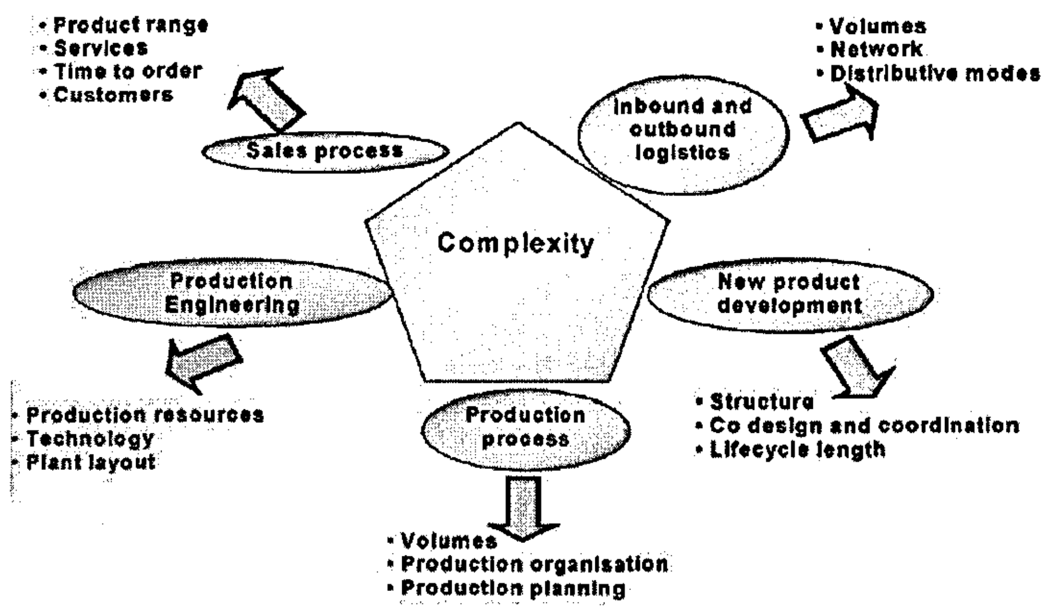

Figure 2.9 Complexity dimensions for manufacturing or logistic systems (Perona and Miragliota, 2004).

Various dimensions of complexity impacting on supply networks are: scale; technological novelty; quantity of sub-systems components; degree of customization of components in the final product/service, quantity of alternative design and delivery paths; number of feedback loops in the production and delivery system; variety of distinct knowledge bases; skills and competencies incorporated in the product/service package; intensity and extent of end user involvement; uncertainty and change of end user requirements; extent of supplier involvement in the innovation and transformation process; regulatory involvement; number of actors in the network; web of financial arrangements supporting the product/service; and extent of political and stakeholder intervention (Harland et al., 2003). Wider product variety, smaller production lot sizes, more tiers and different actors involved in coordinated supply chains also cause supply chain complexity (Perona and Miragliota, 2004). Complexity is a key driver for failure of synchronization among material, information and cash flows across business processes (Kambil, 2008). The supply chain operational reference (SCOR) model, developed by the Supply Chain Council, is a strategic planning tool that allows senior managers to simplify the complexity of supply chain management (SCOR, 2008).

Some responses to that can reduce complexity are; simplification of existing processes through continued re-engineering; reduction of input or output variety; and standardization and modularization of interfaces and processes (Kambil, 2008). Considering the network view of supply chains presented in section 2.2 of this chapter, integration of all the BOM levels within a single factory yields a single echelon midstream of the supply chain network. This is the simplest midstream configuration and is the starting point for adding complexity. The core manufacturing processes for the single plant need to be well defined. When the product BOM begins to push the envelope of manufacturing competency and production cost, it is time to consider subcontracting and outsourcing alternatives (Walker, 2005).

Today's market environment is characterised by diverse customer tastes and preferences, rapid developments in technology, and the management of globalization (Hsu and Wang, 2004). These factors have resulted in the need for a variety of products, which presents major challenges to production managers. The emphasis is on redesigning products and processes so that the negative impact of product variety due to product proliferation can be overcome (Lee and Tang, 1997). Although many such strategies have been developed and implemented, there is a need to develop models to determine optimal solutions, taking into account costs and benefits and other relevant trade-offs or appropriate performance measures and metrics (Gunasekaran and Ngai, 2009). Knowledge of business processes that define real supply chains, and information technology, collectively constitute a powerful and compelling decision technology base for reengineering, integrating, planning, and optimizing supply chains (Bhaskaran and Leung, 1997).

2.4 Supply chain uncertainties

Uncertainty can be defined as "the difference between the amount of information required to perform a task and the amount of information already possessed by the organization" (Galbraith, 1973). Uncertainty is simply the absence of information about the present or future states of specific processes that can impact cash and resource flows across processes (Kambil, 2008).

Due to the generation of uncertainties within supply chains, a balance or equilibrium behaviour between supply and demand is not achieved. This is the case even though many efforts have been applied in order to make it (Wilding, 1997b). A typical response to uncertainty is to build flexibility into the supply chain which is the firm's ability to easily adjust its supply chain to changes and allows it to postpone delivery for some time (Prater et. al., 2001). The potential to increase flexibility depends on environmental, organizational, and technical factors (Prater et. al., 2001).

Wilding, (1998) considered the different major causes of uncertainties and devised a supply chain complexity triangle (see Figure 2.10). The complexity triangle describes three interacting yet independent effects that are known to cause dynamic behaviours experienced within supply chains i.e. deterministic chaos, parallel interactions and demand amplification and combination of these effects can significantly increase the degree of uncertainty within a supply chain system.

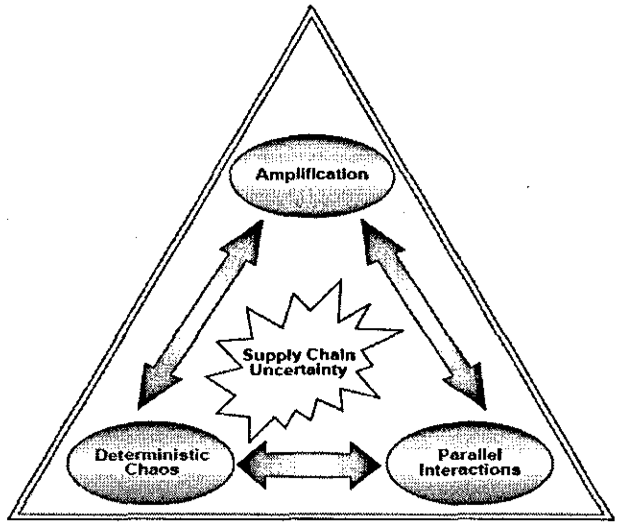

Figure 2.10 The Supply Chain Complexity Triangle (Wilding, 1998).

The "supply chain complexity triangle" provides a useful structure to understand the generation of uncertainty in a supply chain. It is discussed that this triangle results because each source of uncertainty can act as a stimulus for one of the other sources of behaviour to occur. The key implications for management mentioned are as follows (Wilding, 1998):

- Driving down inventory and lead times may not always improve performance. It could result in the system slipping into chaos.
- Simulation of systems and non-linear dynamic analysis of key outputs should be a mandatory part of any supply chain re-engineering proposal.

Another type of uncertainty is change in demand which is amplified as it passes between organizations in the supply chain. This type of amplification behaviour has been summarised as the "Forrester flywheel effect" (see Figure 2.11) (Lee et al. (1997a, 1997b)).

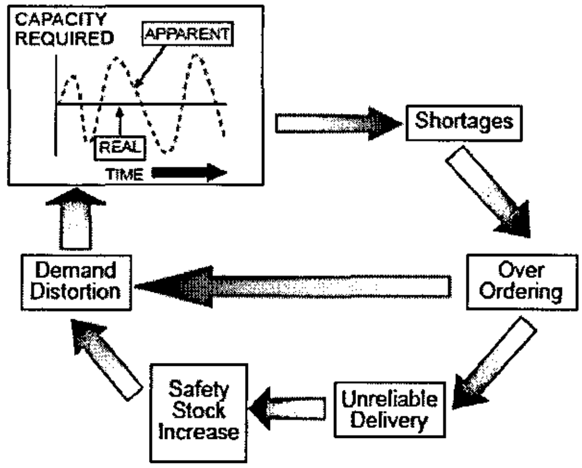

Figure 2.11 Forrester Flywheel Effect (Lee et al. 1997).

Uncertainties related to demand in supply chains is also discussed by Lee et al,. (1997a, 1997b) and described it as "bullwhip" effect. The bullwhip effect is the term devised by Procter and Gamble to describe the amplification and demand distortion that occurs within the supply chain. Four causes of the bullwhip effect are: demand forecast updating, order batching, price fluctuations and rationing and shortage gaming (Towill, 1996b). Ways of reducing demand amplification are strategies such as JIT, vendor integration and time-based management (Towill and Naim, 1993), (Towill, 1996a).

Uncertainties related to quality and performance is discussed by Jones, (1990). It is presented that poor delivery bad quality performance from some suppliers in the supply chain network affects the efficiency of the good suppliers (often JIT suppliers) who then face schedule "ripple" variations caused by the poor suppliers. Uncertainty is a key driver for failure of synchronization among material, information and cash flows across business processes (Kambil, 2008). Supply chains must be flexible enough to cope with the uncertainty of a rapidly changing environment. (Gaudenzi and Borghesi, 2006). Companies develop a supply chain system to address the uncertainty that arises from variability in demand (Gunasekaran and Ngai, 2009). The agile paradigm focuses on the need to deliver a variety of products with uncertain demand (Stratton and Warburton, 2003). Dynamic analysis of behaviour of supply chain provides important information to improve its performances (Pierreval et. al., 2006). Simulation easily incorporates effects of uncertainty (Harrison et al., 2003).

2.5 Supply chain integration

The perceived increased importance of the supply chain to a company's competitiveness reflects a shift from traditional function-based (vertical) management to process-based (horizontal) management. As a result, the tight integration of management processes is increasingly important (Stewart, 1997). Integration across the supply chain is achieved through synchronization of activities at the member entity and aggregating its impact through process, function, business, and on to enterprise levels, either at the member entity or the group entity. Thus, through synchronization of supply chain components, existing bottlenecks in the system can be reduced and possibly eliminated, while future ones may be prevented from occurring (Chandra and Kumar, 2001). Supply chain business process integration involves collaborative work between buyers and suppliers, joint product development, common systems and shared information (Wikipedia, 2009). The goal of the integrated supply chain strategy is to create manufacturing processes and logistics functions seamlessly across the supply chain as an effective competitive weapon that cannot be easily duplicated by competitors (Anderson and Katz, 1998; Birou et al., 1998; Lummus et al., 1998; Lee and Billington, 1995). According to Lambert and Cooper (2000), operating an integrated supply chain requires continuous information flow. Business process reengineering (BPR) can streamline and integrate business functions both internal and external to the organization (Bhaskaran and Leung, 1997). Clearly, there is a need for a mechanism through which these different functions like marketing, distribution, planning, manufacturing, and the purchasing can be integrated together. Supply chain management is a strategy through which such an integration can be achieved (Ganeshan and Harrison, 1995). Supply chain management is typically viewed to lie between fully vertically integrated firms, where the entire material flow is owned by a single firm and those where each channel member operates independently. Therefore coordination between the various players in the chain is key in its effective management (Ganeshan and Harrison, 1995). Two supplier-firms models are presented by Dyer et. al., (1998) to discuss supplier integration, namely "arms length model and "partner model". Their research is based on various studies suggest that compare to the arms length model, Japanese-style partner ships result in superior performance.

2.6 Supply Chain Mapping

Graphical representation and mapping of supply chain is widely used for analysis and re engineering of supply chains. For instance, Meade and Sarkis, (1998) used graphical representation of supply chain entities and relate the entities to analyse strategic logistic and supply chain management systems. Scott and Westbrook, (1991) and Christopher and Gattorna, (2005) used supply chain mapping for representation of supply chain processes and activities in support to re engineer supply chain.

A supply chain map is essentially a time-based representation of the processes and activities that are involved as the materials or products move through the chain. At the same time the map highlights the time that is consumed when those materials or products are simply standing still, i.e., as inventory (Christopher and Gattorna, 2005). A supply chain map is a simple tool to represent often complex supply chains in a form that is, easy to understand and communicate; provides, in itself, a powerful tool for management analysis and diagnosis, so that it enables the areas of greatest opportunity to be readily identified (Scott and Westbrook, 1991). In supply chain maps it is usual to distinguish between 'horizontal' time and 'vertical' time as shown in figure 2.12 (Christopher and Gattorna, 2005). Horizontal time is time spend in processes like transit, manufacturing or assembly, production planning or processing etc. It may not necessarily be time when customer value is being created but at least something is going on. The other type of time is vertical time, which is time when nothing is happening and hence the material or product is standing still as inventory. No value is being added in vertical time only cost (Christopher and Gattorna, 2005). Both the time are shown by horizontal and vertical lines which are drawn to scale (Scott and Westbrook, 1991).

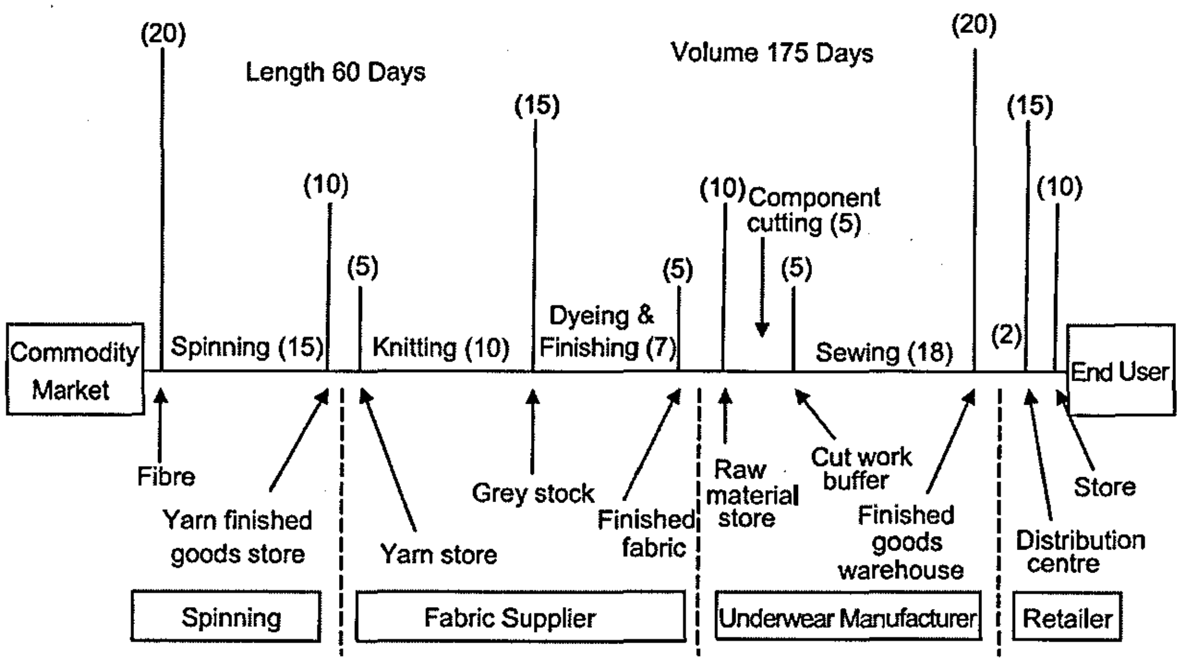

Figure 2.12 Supply chain mapping (Christopher and Gattorna, 2005).

From figure 2-12, pipeline length is the sum of the horizontal lines which is the time spent in processes. Pipeline volume is the sum of the horizontal and vertical lines. The purpose of such an analysis is to identify where either the vertical lines or the horizontal lines can be reduced thereby both improving responsiveness and reducing costs of inventory (Scott and Westbrook, 1991). It is worth noting that a reduction in process time (the horizontal lines) usually brings at least an equal reduction in waiting time (the vertical lines). If a manager knows he can pull the stock through a day quicker he will be prepared to hold a day's less stock (Scott and Westbrook, 1991).

In practice a single organization will be involved with many different supply chains serving different product markets. A preparatory step is to choose a small number of chains which are representative of the major part of the business. Each such chain will have a range of products/customers which have a common set of service requirements and share a common physical pipeline (i.e. through the same major processes and stockholding points) (Scott and Westbrook, 1991).

2.7 Supply chain management issues

Based on the literature discussed in the above sections, a set of supply chain issues were categorised by the present author and are presented in the form of a fish bone diagram (see Figure 2.13). These issues were observed in the literature of supply chain management surveyed by the author during his PhD research. The categorization is made within 6 categories namely: supply, process, control, deliver, and environment. This classification aligns with previous work of Mason-Jones and Towill, (1998), Christopher and Peck, (2004), and Juttner (2005).

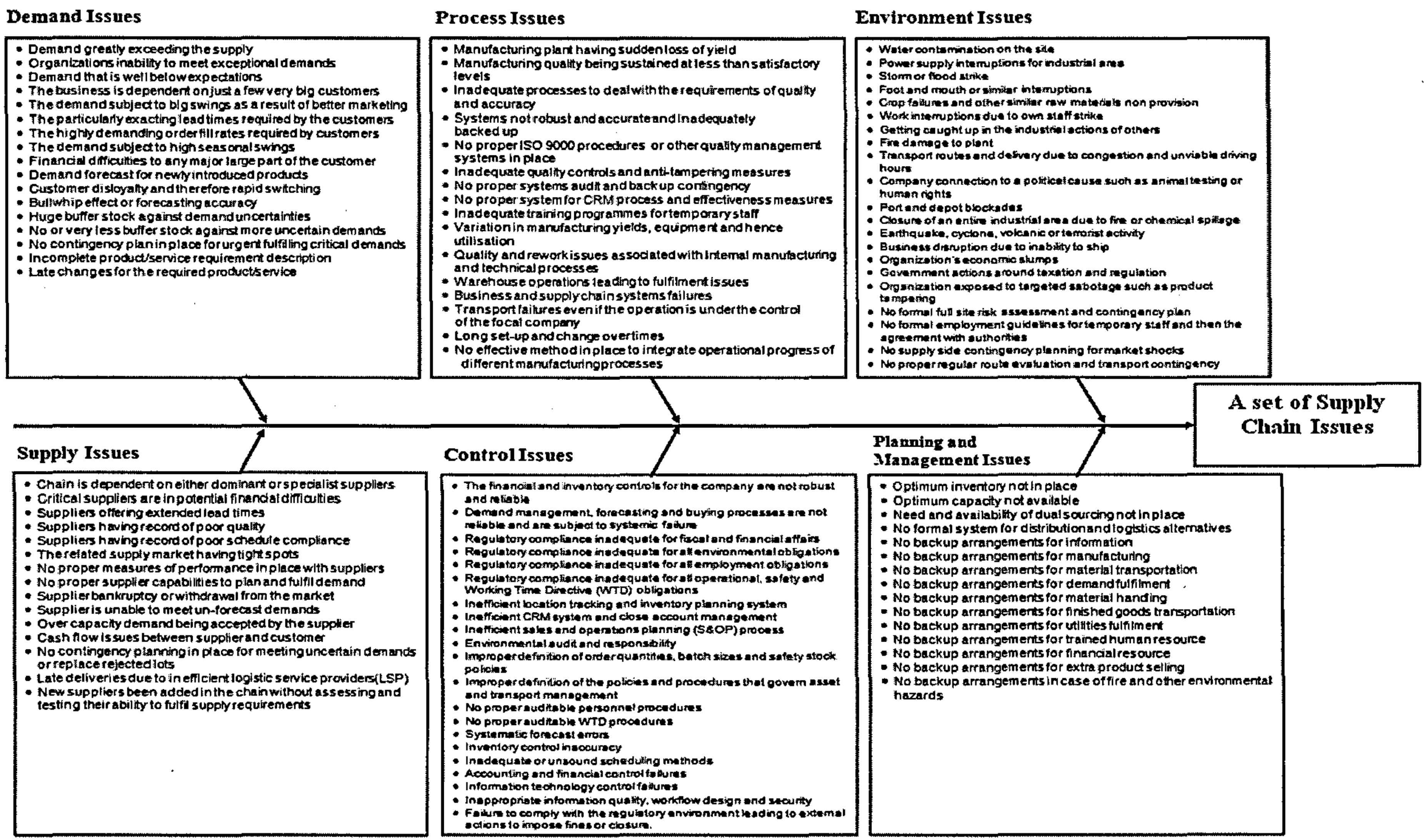

Figure 2.13 Fish bone diagram generated during this research group and to represent supply chain issues.

2.8 Discussion and literature analysis

The author observes therefore that the concept of supply chain is about managing coordinated information and material flows, plant operations, and logistics. A well designed supply chain should provide suitable flexibility and agility in responding to consumer demand shifts without cost overlays in resource utilization (Chandra and Kumar, 2001). Realistic supply chains have multiple end products with shared components, facilities and capacities. The flow of materials is not always along an arborescent network, various modes of transportation may be considered, and the bill of materials for the end items may be both deep and large (Ganeshan and Harrison, 1995). Supply networks are becoming more complex and are dynamically changing webs of relationships (Harland et. al., 1999). Complexity causes variability in delivery (Perona and Meragliota, 2004). Complexity is the amount of variety at and across processes (Kambil, 2008). Complexity and uncertainty are key drivers for failure of synchronization among material, information and cash flows across business processes (Kambil, 2008). Companies develop a supply chain system to address the uncertainty that arises from variability in demand (Gunasekaran and Ngai, 2009). Complexity in the supply chain can be viewed as a threat and something that needs to be avoided and/or reduced (Wilding, 1998). Supply chain management (SCM) has a collection of tools, and when SCM is implemented, the tools are selectively chosen and customised to fit the environment (Plenert, 2007). The future supply chain includes existing leading practices, applications to example supply chains and new ways to calculate the impact on the supply chain (GCI, 2008).

Some important factors contributing towards supply chain complexity are; wider product variety which make supply chain a dynamically changing web of relationships, uncertain and changing demands, smaller production lot sizes, a degree of customization of components in final product/service, quantity of alternate delivery paths, number of feedback loops in production and delivery systems, variety of distinct knowledge bases, and skills and resources required for product/service fulfilment (Perona and Miragliota, 2004), (Harland et al., 2003).

Graphical representation and mapping of supply chain is widely used for analysis and re engineering of supply chains. For instance, Meade and Sarkis, (1998) used graphical representation of supply chain entities and relate the entities to analyse strategic logistic and supply chain management systems. Scott and Westbrook, (1991) and Christopher and Gattorna, (2005) used supply chain mapping for representation of supply chain processes and activities in support to re engineer supply chain. Also dynamic analysis of behaviour of supply chain provides important information to improve its performances (Pierreval et. al., 2006).

From the literature surveyed, it is observed that a supply chain network needs to be designed and created by any enterprise receiving customer orders. Current market and business scenarios indicate an increasing requirement for supply chains that can handle a variety of products, in different quantities, and with different production and delivery lead times. Further more the average lifetime of products is falling; and this impacts in terms of increased product variety that must be processed in any given time frame. To fulfil an increasing need for multi products and services, and multi product and service flows through a supply chain network, generally there is a need for some common processes and hence sharing of common resources. Variable and uncertain demand can result in supply chain networks that are more complex and risky; and this can decrease the achievable performance of any given supply chain network. To deal with this type of complex situation a systematic methodology is required to reduce or minimise impacts of supply network complexity, and to minimise the effect of uncertainty in the supply chain network. Furthermore, there is a need to develop and select a range of suitable techniques for supply chain management that suits any observed supply chain network scenario.

Part B – Review of available modelling techniques that have the potentials to support the life cycle engineering of supply chains

2.9 Enterprise Modelling

The term 'model' has been defined differently in various fields of science and engineering. Weston states that a model is: "a representation of some aspect of an entity under study which can be used to facilitate visualization, analysis, design, etc" (Weston, 1993). Enterprise models capture certain perspectives (or foci of concern) about an enterprise, such as financial, business, information and function views. When formally modelling any complex system it is necessary to decompose (or breakdown) the system into manageable system elements (Monfared. and Weston., 1997). There are many potential benefits from using enterprise modelling in respect of the life cycle engineering of a manufacturing system (Weston, 1996, Fraser, 1994). A model provides insights into system capabilities and highlights alternative solutions and application scenarios that prepare the system to adapt to business change (Craig and Douglas, 1997). Business change may influence many facets of an enterprise, including its processes, communication systems and information requirements, and the way that its resources are organised and operate (Weston, 1998b). To satisfy new business or environmental needs a deep understanding is required of cause and effect relationships and constraints on change. Modelling techniques can help to analyse alternatives and help analytically to determine new system configurations that best fulfil requirements change before any real system reconfiguration needs to be activated (Uppington and Bernus, 1998).

EM is a technique for decomposing processes into sub-processes and unitary activities. Thereby other relevant views and their representational concepts can naturally be attached to process representations, such as to define related information requirements and information flows, required resource system functionality and behaviours, needed material and product flows and resultant value streams and process costs. By formally decomposing a complex (specific, semi-generic or generic) process network into descriptions of its elemental parts and dependencies between parts, subsequent systems integration aspects of organization design and change can be enabled (Rahimifard and Weston, 2005).

EM essentially explicitly captures and helps to communicate requirements for system design and captures interactions among system design elements independent of time. It follows that EMs do not really capture time-dependent interactions among system elements; although some efforts have been made to view enterprise models with respect to time (Monfared, 2000).

2.9.1 Enterprise modelling architecture

Different enterprise modelling architectures have been developed and used around the globe to model and design manufacturing enterprises (ME). Well documented example EM methodologies and architecture include GRAI/GIM – The Graphs with Results and Activities Interrelated/GRAI Integrated Methodology, ARIS – Architecture for Information Systems, PERA – The Purdue Enterprise Reference Architecture, IEM – The Integrated Enterprise Modelling, GERAM – The Generalised Enterprise Reference Architecture and Methodologies, and CIMOSA – Computer Integrated Manufacturing Open Systems Architecture. Chatha compares key strengths and weaknesses of some of these modelling methodologies and architectures in the context of organization design requirement fulfilment as shown in Table 4.1 (Chatha, 2004).

Table 2-1 Comparison of enterprise modelling architectures (Chatha, 2004).

Organisation Design Requirements		CIMOSA	Monfared's Process Modelling Approach	IDEF3	IEM
Process Lifecycle		**	**	**	***
Multi-process oriented organisation structure enforcing decomposition principle	Multi-process oriented structure	*	---	---	---
	Decomposition principle	***	***	**	**
Generic process modelling language for generating semantically rich process specifications		**	***	***	***
Process modelling method to support process lifecycle		***	***	---	***
Modelling concept framework		****	---	---	---
Exceptions handling		**	---	---	---
Resource coordination		---	---	*	---
Coverage	*****Very High	****High	***Medium	**Low	* Very Low

For approximately two decades researchers in the MSI Research Institute at Loughborough University have contributed to Enterprise Modelling developments. The PhD research of (Aguiar, 1995), (Singh, 1994), (Coutts, 2003) and (Monfared, 2000) conceived and deployed enterprise modelling methods and tools. Their approaches to modelling: (1) build upon concepts originally developed as part of IDEF (Kim, 2001), CIMOSA (Vernadat, 1992), GRAI/GIM (Chen, 1996) and the Purdue (Williams, 1992) reference architectures; and (2) have contributed towards GERAM standardization (Bernus, 1996). Since then (Weston, 1998a), (Harrison R, 2001), (West, 2003), (Chatha, 2004), (Byer, 2004), (Ajaefobi, 2004), (Rahimifard and Weston, 2007), (Zhen, Accepted April 2008. In press.), (Masood et al., Accepted August 2008. In press. 2010), (A-Kodua K., 2008), (Wahid, 2008) and (Weston, 2008) have significantly enhanced CIMOSA modelling by building upon its key process oriented decomposition and modelling strengths and addressing some of its previous weaknesses; such as by enabling more effective resource and organization modelling and by unifying the use of enterprise modelling, and (discrete event and continuous) simulation modelling techniques (Rashid et al., Accepted 2009).

In its original form CIMOSA formally specified how process-oriented 'requirement definition' modelling can be achieved in a consistent manner which can be flexibly linked to 'design specification' and 'implementation specification' modelling (see Figure 2.14) (Vernadat, 1996). The CIMOSA enhancements proposed and industrially applied by MSI researchers have maintained and enhanced the original architectural concepts originally proposed (Rashid et al., Accepted 2009).

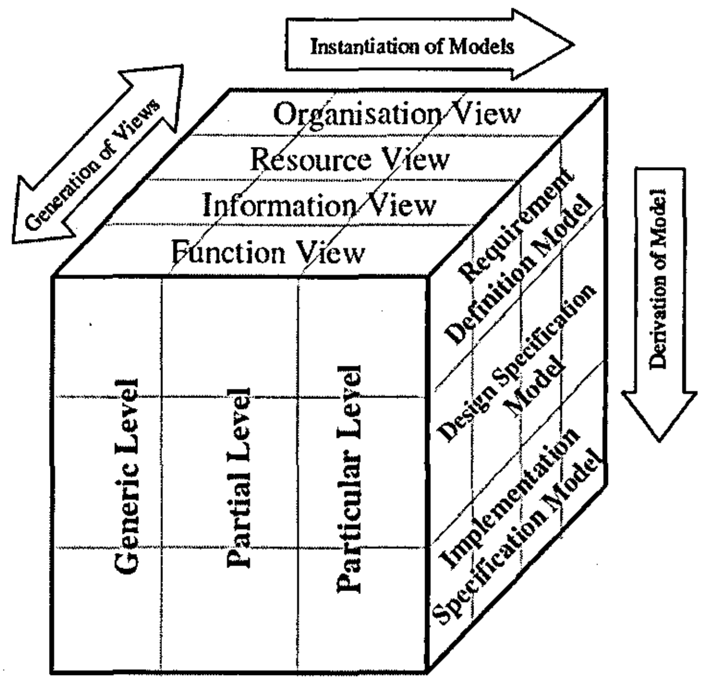

Figure 2.14 The CIMOSA architectural framework (Vernadat, 1996).

The CIMOSA Derivation Process (see Figure 2.14) guides the user through three modelling levels: from the definition of enterprise business requirements (Requirements Definition) through the optimisation and specification of those requirements (Design Specification) to the implementation description (Implementation Description). At each modelling level in the Generation Process the enterprise is analysed from different viewpoints (Modelling Views).

CIMOSA defines four modelling views for different aspects of an enterprise, including: the Function View which describes the workflow of enterprise functions; the Information View, which describes the inputs and outputs of enterprise functions; the Resource View which describes the structure of resources (humans, machines, data processing- programs) which are required to realise enterprise activities; and the Organization View which defines authorities and responsibilities regarding functions, information and resources.

To facilitate reuse of EMs and to reduce modelling effort, CIMOSA defines three levels of generality; namely 'generic', 'semi-generic' and 'particular'. The Generic CIMOSA modelling involves the deployment of basic CIMOSA architectural constructs (building blocks) for components, constraints, rules, terms, service function and protocols. At the semi-generic level so called 'partial models' are created to represent a specific type or section of a manufacturing enterprise. Particular Level modelling related to a single subject enterprise and is defined in the Instantiation Process by the modeller using already prepared building blocks from the Generic and Partial Level and developing new particular enterprise specific components.

The CIMOSA function model consists of a set of modelling constructs (or business entities) that decompose functional processes into structured modelling entities (Monfared, 2000, Chatha, 2004, Weston. et al., 2004, Weston. et al., 2007, Vernadat, 1996), as illustrated by Figure 2.15.

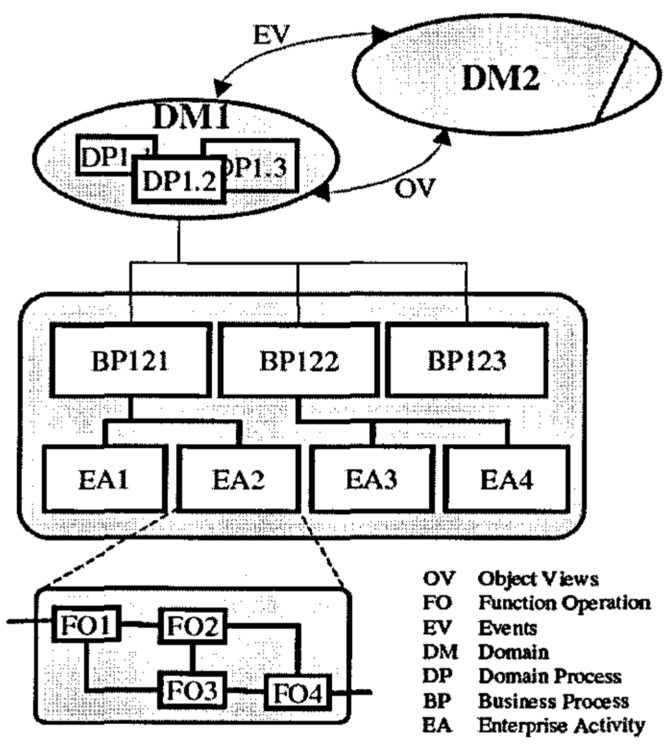

Figure 2.15 The CIMOSA functional modelling (Vernadat, 1996).

Business entities can be explicitly modelled using the following CIMOSA modelling constructs:

- *Domain (DM)* is a construct, which is used to define parts of an enterprise relevant to achieving a defined set of business objectives, i.e. it is used to specify the overall scope and contents of a particular model of an enterprise. A Domain description consists of: Domain Objectives and Domain Constraints, Domain Relationships describing the Domain Boundaries, Domain Objects, and Domain Processes.

- *Domain Process (DP)* is a construct used to define which Enterprise Functions influence the achievement of the related Domain Objectives. Domain Processes are identified during identification of the ME Domain. Each Domain Process is then explicitly described using: CIMOSA function modelling constructs and CIMOSA decomposition principles.

- *Business Process (BP)* is a special type of Enterprise Function, which aggregates all lower level Business Processes and/or Enterprise Activities required to carry out sequence of operation required. A Business Process always has a functional, behaviour and structural part defined, and is initiated by an Enterprise Event so that its execution will result in the fulfilment of the identified business objectives.

- *Enterprise Activity (EA)* is also a special type of Enterprise Function and is defined as a non-decomposable or low-level Enterprise Function. Enterprise Activities describe the basic functionality of the enterprise. Enterprise Activities are not part of any given Business Process as such, but are utilised by one or more Business Processes through their associated set of Procedural Rules. By explicitly defining relationships between Enterprise Activities and Business Processes (vía use of Procedural Rules) it makes it possible to explicitly describe the sharing of Enterprise Activities amongst different Business Processes. It also enables the explicit definition of changes in any enterprise by only altering the set of Procedural Rules while maintaining the basic Enterprise Activity units intact. At the design specification modelling level enterprise activities may be further decomposed into Function Operations, which can make them operational.

2.9.2 MSI Approach to Enterprise Modelling

A Process-Oriented Modelling Approach was developed by Monfared at the MSI Research Institute and will be referred to in this thesis as the RPM EM approach (Monfared, 2000). The RPM EM approach is primarily based on use of the use of CIMOSA requirements modelling concepts. Monfared provided an organised use of four types of graphical modelling diagram known as context-diagrams, interaction-diagrams, structure-diagrams and activity-diagrams. These diagrams are used for documenting relatively enduring aspects of interactions between DPs, BPs and EAs in the form of transfers of physical, information, human or financial entities (Chatha and Weston, 2005). Each one of these diagramming templates are populated with case data and thereby constituted an important fragment of a specific case EM under development and use. Collectively the four types of graphical model can be used to capture and graphically represent a coherent and complementary set of views about process attributes at needed levels of abstraction. Together these diagrams provide a big picture (or organizational context) of the requirements of an organization under study, and of how this big picture is explicitly composed in the current case (or could be composed in future cases into) of dependent process segments. Attributes of these diagram types are summarised as follows (Monfared, 2000):

a) Context Diagram

The context diagram is used to define domains to be modelled using CIMOSA formalisms. The context diagram organises an enterprise into manageable modules and hierarchically breaks down system complexity. These modules are called Domains. Modules that are of concern in a project, and for which models will be produced, are termed CIMOSA-Domains and those which are not of concern are called non-CIMOSA-Domains. Domains may be represented by oval-shaped bubbles. CIMOSA domains may be represented by simple bubbles, while non-CIMOSA domains may be represented by crossed-out bubbles. Contact Diagrams can be decomposed into sub-level context diagrams to identify sub-domains and domain processes.

b) Interaction Diagram

Domains interact with each other by means of events (which typically take the form of requests or triggers to do something) and results (defined as being views on enterprise objects). The interactions among domains take the form of information exchange, human resource exchange, physical resource exchange and events. These interactions are specified by creating interaction diagram. Interaction diagrams can be drawn to identify, define, organise, and represent the interactions involved among domain processes.

c) Structure Diagram

A structure diagram is used to identify key structural dependencies between process segments, by organizing and graphically depicting enduring relationships between the business processes and enterprise activities that collectively compose a domain process, or sub-domain process (Monfared, 2000).

d) Activity Diagram

An activity diagram encodes a sequence of enterprise activities and business processes. Enterprise activities, business processes and control flows are represented by graphical model building blocks. From one viewpoint the activity diagrams explicitly define temporal relationships between process segments and their elements. But only static temporal relationships can be defined using activity diagrams. CIMOSA activity diagrams do not have representational concepts for changes in the states of process variables.

CIMOSA function view diagrams can present and help to analyse a static view of a given set of enterprise processes at some instants in time but are not able to handle product dynamics issues for example; like product volume and product variance and so on. Hence these diagrams cannot be computer executed to enable prediction of organizational behaviours when some change in the system occurs; like change in product volume or product variety or resources etc. Keeping in view these limitations of CIMOSA based static enterprise modelling, complementary modelling concepts are needed (Rahimifard and Weston, 2005).

2.10 System Dynamics and Causal loop diagramming (CLD)

System dynamics has its own paradigm and has established itself as a powerful methodology (Mohapatra and Mandal, 1989). The primary focus in system dynamics is the examination of the effect that one element has on another (Love et al., 1999). System dynamics models are used primarily to study systems that display feedback characteristics (Mohapatra et al., 1994). Therefore, system dynamists propose that a study of causal relations can effectively be conceptualised as a series of influence and causal loop diagrams. An influence diagram simply depicts a succession of causations in which all variables are both causal and affected variables. Essentially, this means that cause and effect relationships can be traced by following the direction of the arrows, starting from any one variable, traversing the loop and coming back to the same variable. Circular cause and effect relationships provide the foundation for building a system dynamics model (Love et al., 1999). Ossimitz points out the two different concepts of systems thinking shown in Figure 2.16 (Schuster, 2003).

a) Systems thinking-1 tends to be related to system dynamics and is not that universal (Schuster, 2003). It may be considered as systems thinking within system dynamics and is quantitative oriented using concepts of stocks and flows for which public domain software, e.g., iThink® and STELLA®, are used (Ossimitz, 1997).

b) Systems thinking-2 is more universal approach and is qualitative oriented (Schuster, 2003). It uses mental models of dynamic and complex systems in terms of feedback and delay loops, however it lacks quantitative analysis (Sterman, 2000).

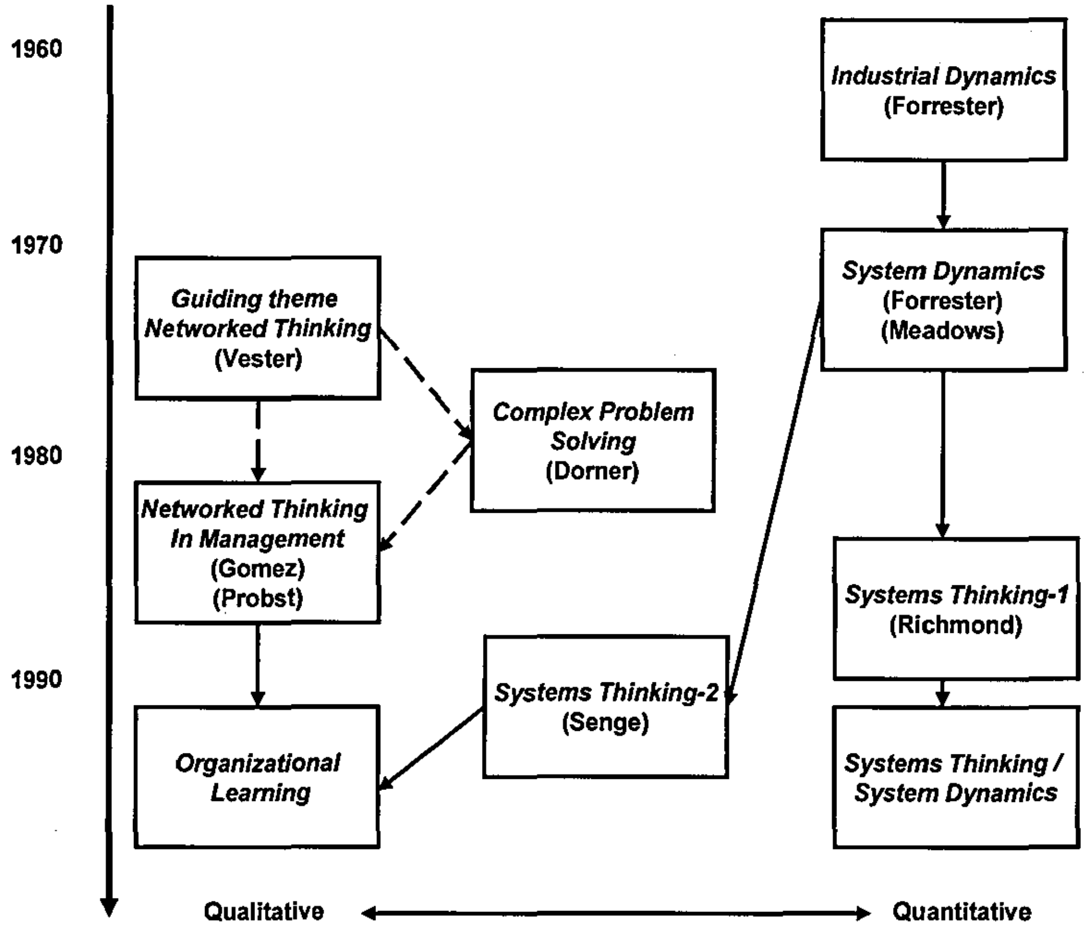

Figure 2.16 Evolution of systems thinking (Schuster, 2003).

Causal loop diagrams (CLDs) are very commonly used to characterise system dynamics as they are easy to understand and show the feedback structure of system dynamic concepts very accurately (Schuster, 2003). It quickly captures hypothesis about the causes of dynamics. It can capture the mental models used by individual and teams (Sterman, 2000). It is a way used for communicating important feedbacks which a modeller believes is responsible for a problem (Sterman, 2000). A causal loop diagram can show explicitly the direction and type of causality among major factors (Love et al., 1999). Causal loop diagrams are flexible and useful for diagramming the feedback structure of systems in any domain. Causal diagrams are simply maps showing the causal links among variables with arrows from a cause to an effect (Sterman, 2000). It is important to mention that these diagrams capture the structure of the system and not its behaviour, not what has actually happened but what would happen if other variables change in various ways (Sterman, 2000). To have a know how about creation of causal loop diagrams (Rashid et al., Accepted 2009) can be considered.

Any CLD should contain a careful selection of variables which are decided on the basis of the issue is under observation. The use of interviews, surveys and archive data relating to the enterprise issue under observation can be of great importance. These interviews either structure or semi-structure causal relations, where useful views of the people involved in the issue(s) give rise to understandings about causal variables (Sterman, 2000). Relationships in the causal loop diagram must be causal and not co-relational. Correlation among variables shows the past behaviour of the system only and do not represent the structure of the system. Rather correlations among variables can be the outcome from behaviour of the model after simulation. If there is an existing correlation in the enterprise among some widely different variables which are not causally related their inclusion within CLDs must be avoided to use (Sterman, 2000).

Limitations of causal loops are that these can never be comprehensive and should not be because 'effective modelling' is the art of simplicity. These are also never final, but always provisional. These maps evolve as the understanding of the modeller improves and as the modelling effort evolves. Causal loop diagrams do not distinguish between stocks and flows but are often helpful in this respect as they encode aspects of a stock and flow structure (Sterman, 2000).

2.11 Simulation Modelling (SM)

Simulation modelling has been widely deployed in many disciplines to replicate and predict behaviours. However in general it is known that because simulation models need to encode both static and dynamic properties of systems then their complexity grows rapidly as either the scope or depth of modelling increases. Therefore their practicability will depend upon a suitable matching of level of modelling abstraction to the problem being tackled (Rahimifard and Weston, 2005). Simulation modelling has been shown to be useful for capturing dependences among design elements of manufacturing organizations that change with time (Chatha and Weston, 2005, Chatha et al., 2003). During simulation modelling experiments, system behaviours can be compared with reference to selected performance measures.

Normally when simulation modelling is performed, a suitable simulation tool is required. Different simulation tools are available like SIMUL8®, Arena®, iThink® etc. Today's discrete event simulation modelling tools provide behaviour analysis capabilities against some system performance measures (Bahrami et al., 1998, Krahl, 2002). It provides means of computer executing discrete event simulations. SIMUL8® is a user friendly tool as it provides a simple pick and place approach to creating graphical and computer executable models (Simul8, 2000). Different types of entities need to be modelled including; work entry points, work centres and work exit points each with a range of attributed properties that correspond to real conditions of an enterprise. It is therefore necessary to populate attributes of the simulation model with specific case enterprise data and rules in order to replicate real working conditions of the enterprise. SIMUL8® also provides optional links to Microsoft Excel® sheet data and also different checks and conditions can be applied when different simulated events occur (Rashid et al., 2007). SIMUL8® is the tool which is used by most researchers in the MSI Research Institute (Rashid et al., Accepted 2009) and therefore good working knowledge of this tool was available to the author.

Generally the modelling of complex behaviours of companies will require assumptions to be made and tested. The reason for making assumptions is to avoid including unnecessary complicated detail into the model, so that different stochastic behaviours of the system can be modelled sufficiently well with manageable modelling effort. Generally in any enterprise, work flows need simplification involving averaging amongst limited available data (Masood et al., Accepted August 2008. In press. 2010, Rashid et al., 2007).

The next step will be to achieve model validation. This is an extremely important step and a fundamental step which is normally required before proceeding to model experimentation. The validation process should also encompass validation of the set assumptions made when modelling to decide if the impact of the assumptions made would mean that the simulation results can be trusted. The validation process can be undertaken in three steps (Rahimifard and Weston, 2007). Firstly the model can be checked thoroughly for each and every entity, to see whether it can replicate the different rules and conditions of the real systems comprising the enterprise. Secondly to consult the relevant officials and expert knowledge holders performing roles in the modelled system, to verify that the as-Is simulation model replicates real system behaviours. Commonly to achieve validation this model needs to be run at slow speeds for some specific time to show the behaviour of work movement through the different entities of the system with respect to time. If it is similar to the real system behaviour then the model structure, composition and behaviours will be verified. Thirdly an important approach can be to populate the model with historical data through the organization for which performance outcomes are already known and to test the simulation results in relationship to the real results. If the results of the real system and model are found to align then it will be considered that the simulation model is validated (Masood et al., Accepted August 2008. In press. 2010, Rashid et al., 2007).

Simulation techniques relate to the systematic use of simulation models and simulation experiments to achieve an end purpose. In this research it will be explained that a modelling technique was used and tested to enable complex supply chains to be studied and analysed, when considering both strategic and operational aspects of those chains. However, as with all simulation models, one can only evaluate the effectiveness of a pre-specified policy rather develop the new ones. It is the traditional question of "What If?" versus "What's Best?" (Ganeshan and Harrison, 1995). A limitation of simulation modelling is that it can handle and analyse models of limited complexity. Generally in the context of organization modelling this means that either it is necessary to focus modelling on a processing segment of limited scope or to model at a higher level of abstraction inter-relationships between a number of processing segments of limited scope. As the complexity of the model grows more assumptions need to be made which then decreases the credibility of the performance results (Chatha. and Weston., 2006).

2.12 Unified use of EM, CLD and SM techniques

For more than two decades the researchers of the Manufacturing System Integration (MSI) Research Institute have researched and prototyped new modelling concepts, architectures, techniques and tools which facilitated the modelling of complex systems. MSI modelling approaches unified the use of Enterprise, Causal Loop, Simulation and Workflow Modelling (Rahimifard and Weston, 2007, Chatha. and Weston., 2006, Zhen, Accepted April 2008. In press., Masood et al., Accepted August 2008. In press. 2010, A-Kodua, Submitted 2008, Wahid, 2008, Rashid et al., 2007, Weston. et al., 2004, Masood et al., 2007, Masood and Weston, 2008a, Masood and Weston, 2008b). Rahimifard and Weston point out that EM offers mechanisms for systematically modelling common processes and relatively enduring structures that govern the way MEs operate (Rahimifard and Weston, 2007). On its own EM have insufficient modelling concepts to represent organizational dynamics. Consequently complementary modelling concepts are needed to enable the capture and reuse of simulation models (SM) that help predict and qualify possible future organizational behaviours. Chatha and Weston explain how enterprise modelling, simulation modelling, and causal loop diagramming provide a rich set of concepts that complement one another and hence can be used together for complex system design, re-engineering ME processes, and for supporting management decision making (Chatha. and Weston., 2006) (see Figure 2.17).

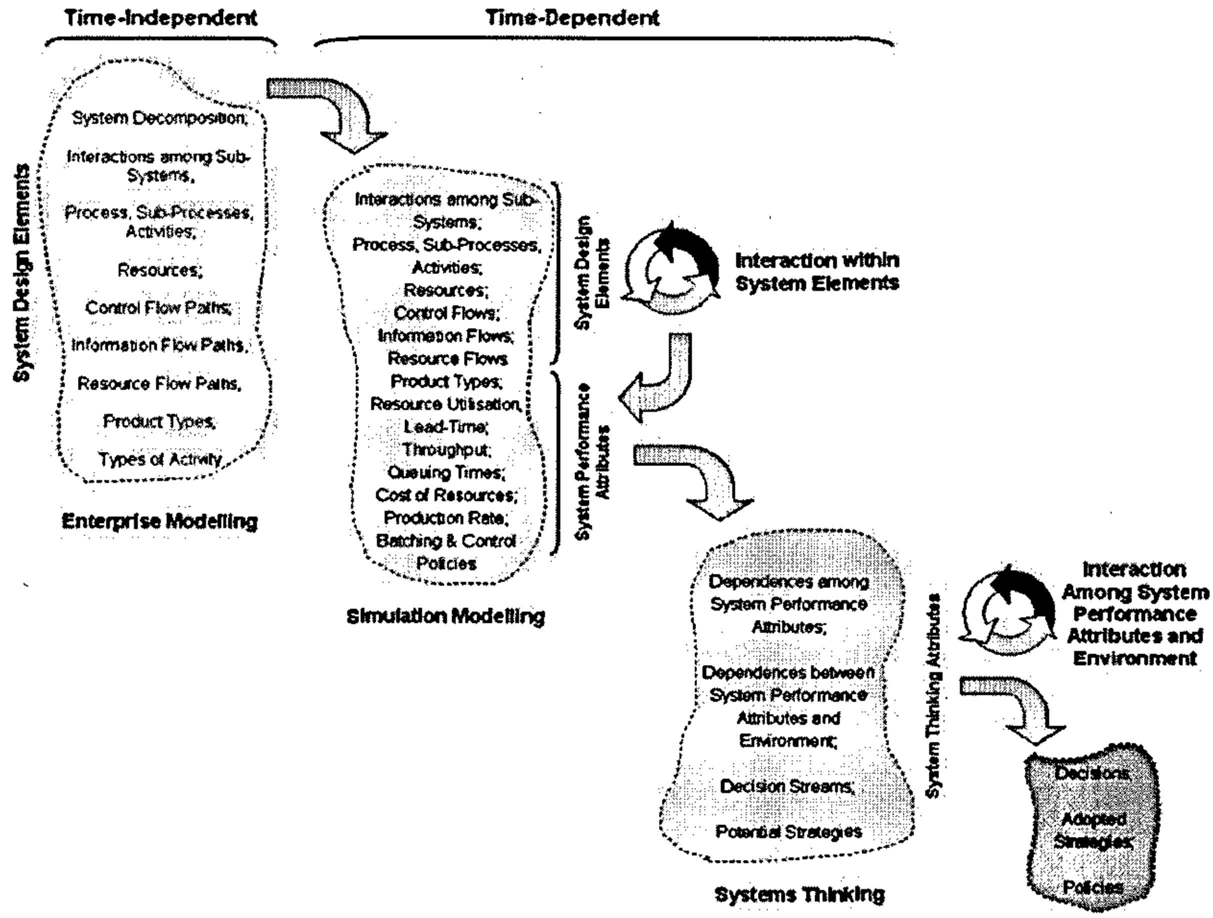

Figure 2.17 Unification of concepts in the selected systems modelling approaches (Chatha. and Weston., 2006).

In summary enterprise modelling provides system decomposition and integration principles which can form a backbone of systematic technique for designing systems and capturing time-independent (static) attributes of systems. Simulation modelling approaches on the other hand is well suited for capturing time-dependent attributes of systems and thus pertains to analyzing system behaviours; however, some simulation modelling techniques (including discrete event simulation modelling) are ill suited to analysis of dependences among modelled systems. For example, how the performance of a limited scope production system under study will impact on a wider scope and more complex business system, and vice versa. This is where systems thinking can be most valuable. Systems thinking can potentially capture key aspects of dependencies' performance measures. Also this kind of thinking can provide a step towards selecting and achieving targeted behaviour analysis of an isolated system when it is interacting with a wider scope, more complex context or environment. Thus, all three (EM, SM and CLD) approaches to model-driven system design provide useful concepts that are important at different stages and abstraction levels of system design and performance analysis; and each complements the other (Chatha. and Weston., 2006).

Weston et al. proposed a four step systematic approach to creating coherent sets of simulation models that can interoperate to replicate and predict changing organizational behaviours (Weston et al., 2006) (see Figure 2.18).

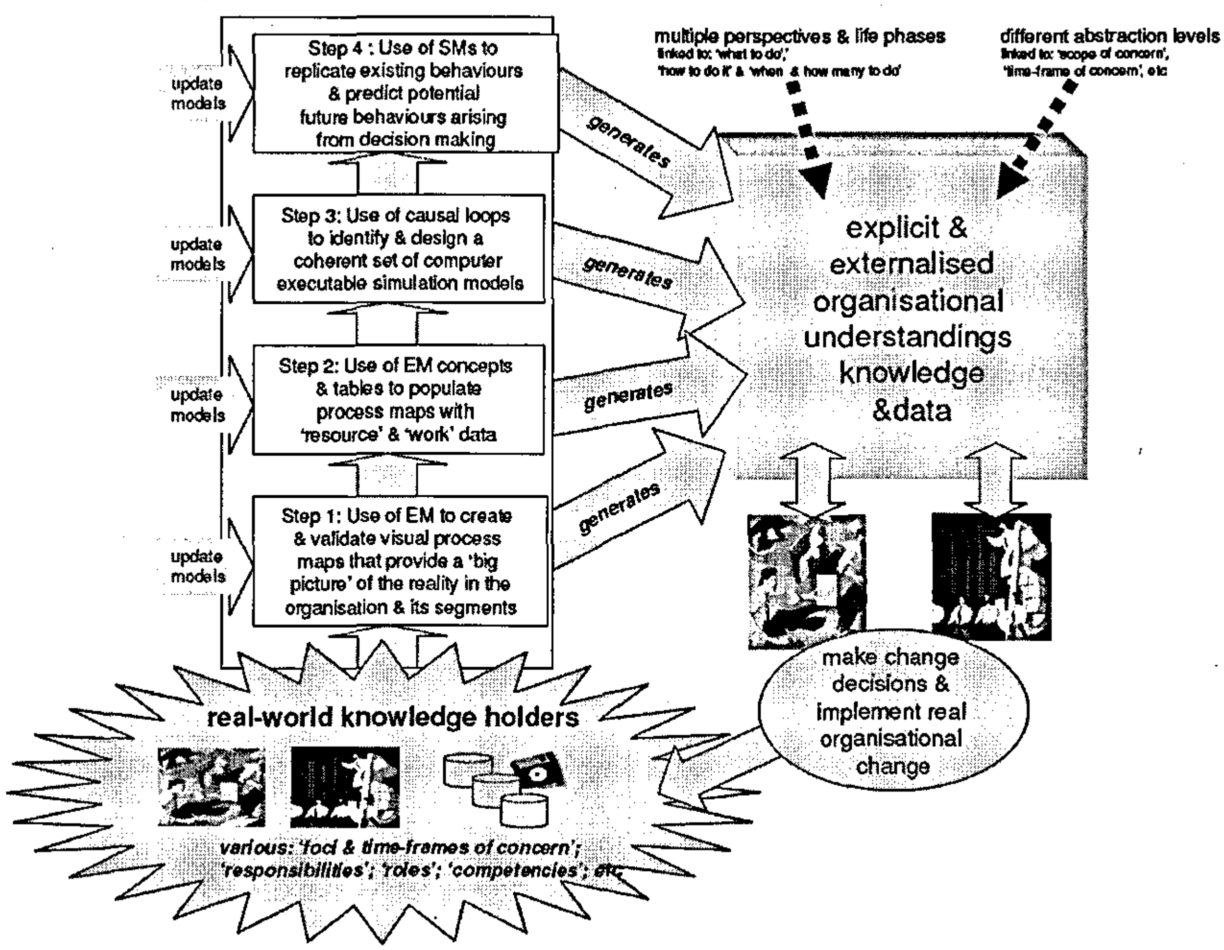

Figure 2.18 Modelling approach for development and deployment of coherent simulation models (Weston et al., 2006).

The systematic modelling technique, presented in figure 2.18 can usefully structure and support a unified use of enterprise models, causal loops and simulation and workflow modelling to enable enriched understanding and analysis of specific organizational dynamics. It provides an explicitly defined foundation for model unification and simulation model interoperation. Early findings when modelling a number of small and large manufacturing organizations have been very encouraging using this method. Although significantly more extensive testing is required in this respect to evaluate the full range of benefits and drawbacks of using such an approach to enable various possible aspects of organization design and change (Weston et al., 2006).

2.13 Discussion, and literature analysis

Following are some of the observations deduced from literature review related to different modelling techniques

a) It is observed that CIMOSA based enhanced enterprise modelling techniques developed at MSI Loughborough University can usefully capture a big picture of processes observed in any enterprise; which can be a small portion of a shop floor or a wide chain of interacting companies. Selection of the focus and extent of the enterprise modelling depends on the purpose and the context of modelling. The big picture of enterprise processes can be created from various perspectives namely information, cash, physical (material) and human view points. The big picture can be created from a specific context, which helps to maintain a focus for modelling work. These models can be used to visualise the processes of concern in any enterprise. The CIMOSA-MSI enterprise modelling can identify and represent different actors/stakeholders involved, interaction of the actors with each other from various perspectives of information, cash, human and physical (material), structure of the interacting processes and logical flows amongst processes.

b) It is observed that causal loop diagramming can be used to understand and represent systems dynamics associated with causal relationships between different variables of the system. Change in any variable may affect other associated variable, and the outcomes may be a positive or a negative effect on the entire system.

c) It is observed that discrete event simulation modelling and continuous simulation modelling can be used to graphically visualise the work flows through different processes and quantify different what-if scenarios. For different uncertain changes, different ways of configuring valuable human and technical resources can be tested and results can be quantified. In this regard, the suitability of industry best practices can be analysed in the context of the specific case enterprise. Furthermore, quantitative results obtained from simulation modelling can be helpful to predict future behaviour of the systems and can support analysis leading to improved system design, implementation, operation and on-going change.

d) It is observed that the work related to the integrated use of different modelling techniques (like enterprise modelling, causal loop diagramming and simulation modelling) provide an analytical basis for underpinning organization design and change (OD&C). However, there is a need to test case the application use of unified modelling concepts in many different business-wide contexts, and in respect of various industry sectors. This is an area of ongoing research in MSI Research Institute (Chatha and Weston, 2006). The research reported in this thesis contributes to that initiative. Particularly it does so by developing and testing the use of a 'new model driven methodology of lifecycle engineering supply chains'. The purpose of so doing is to enable better, faster and most cost effective engineering of supply chains, than was feasible prior to the conception of this new methodology.

Chapter 3: Research aim and general research methodologies

The purpose of this chapter is to present the research aim and objectives. The chapter includes a brief discussion about some requirements associated with the thesis aim and objectives and presents some candidate techniques to fulfil the research requirements. It also includes some statements of obvious concepts about research, general research methodologies and some data collection methods. The purpose of presenting the general concepts about research is to describe the style of research appropriate for this research environment, research problems and objectives and research cases. Furthermore, choice of general research style and data collection method is presented in this chapter. At the end of the chapter a general research approach is presented which will be adopted in rest of the thesis.

3.1 Research aim and objectives

Having considered key problems and issues associated with complex supply chains[1], and having reported the literature on these topics in Chapter 2, it was observed that industry at large requires an improved analytical basis for designing and changing complex supply chains. Therefore the overall aim of this research was "to develop and test use of an integrated modelling methodology to support decision making about complex supply chains". To fulfil this aim, the following objectives were defined.

Objective 1. To study state of the art modelling techniques that have potential for the analytical design of complex supply chains.

Objective 2. To develop an integrated modelling methodology for the analytical design of complex supply chains.

Objective 3. To case test and update the integrated modelling methodology for the analytical design of complex supply chains.

3.2 Gap analysis

This section will outline what is required to achieve the aim and objectives of this project and will consider the extent to which currently available techniques have potential to satisfy those requirements.

3.2.1 What is required

Based on literature analysis (see Chapter 2), it was observed that graphical representation and mapping of supply chain is an important requirement for re-engineering supply chains and hence it is widely used for analysis and re engineering of supply chains. For instance, Meade and Sarkis, (1998) used graphical representation of supply chain entities and relate the entities to analyse strategic logistic and supply chain management systems. Scott and Westbrook, (1991) and Christopher and Gattorna, (2005) used supply chain mapping for representation of supply chain processes and activities in support to re engineer supply chain. The graphical representation and mapping can only analyse structural and relatively most enduring characteristics of the system (Rahimifard and Weston, 2005). Dynamic analysis of behaviour of supply chain provides important information to improve its performances (Pierreval et. al., 2006). Therefore, both static and dynamic analysis of the supply chain is required to be included in analytical design of complex supply chains.

Keeping in view the above requirements and to achieve the aim and objectives of this research, an integrated modelling methodology for the analytical design of complex supply chain is needed with capabilities to:

- graphically represent and explicitly describe key characteristic properties of complex supply chains.
- analytically explore dynamic properties of complex supply chains, so as to provide analytic means of reasoning about impacts of uncertainty in complex supply chains, such as those introduced due to changes in demand, supply, make, delivery and return processes.

- predict possible futures of complex supply chains in response to possible uncertainties that may arise.
- quantify and predict behavioural aspects of complex supply chains due to observed impacts of uncertainties and to assess possible risks should potential uncertainties arise.

3.2.2 What modelling techniques currently exist?

A number of different enterprise modelling (EM) techniques have been used by industry and academia to represent businesses and companies from various perspectives. These EM techniques can capture, and enable reuse of knowledge normally distributed amongst many knowledge holders who have various company and business roles. This knowledge captured can include relatively enduring models of process information, material, finance and human and technical resource perspectives on the subject enterprise. A primary constraint on the application of any EM technique is its focus on modelling structural rather than time dependent behavioural characteristics of the enterprise. This is however a necessary constraint on EM techniques as their prime purpose is to capture a big picture of an enterprise and to decompose this big picture into essentially decoupled elements that can be analysed in detail. Therefore the inclusion of both structural and behavioural aspects into the big picture would make any developed EM overly complex. However the literature review showed the importance of modelling dynamic, time-dependant characteristics of complex supply chains to enable performance prediction and measurement when alternative candidate supply chain configuration are conceived and developed. With this second modelling purpose in mind it was observed that causal loop diagramming and simulation modelling are capable of modelling time-dependant characteristics of complex systems such as complex supply chains. e.g. As yet EM, CLM and SM have not been used in a coherent fashion to support the lifecycle engineering of complex supply chains. Hence this purpose will explore and develop the extent to which such a coherent use can realise the project aim and objectives.

3.3 General review of research and research methodology

It was necessary to adopt well proven general renowned methods during this PhD study. Hence the following more general literature review was conducted.

3.3.1 What is research?

There are several ways of defining what is meant by 'research methods' which can range from fairly informal research based upon clinical impressions, to the strictly scientific research which adhere to conventional expectations of scientific procedures (Kumar, 1999). Research can be defined as a systematic and methodological search for knowledge and new ideas or as producing knowledge and relating theory to reality (Tangen, 2004). It has also been defined as the systematic study of materials and sources in order to establish facts and reach new conclusions (AskOxford, 2009). It can be defined as an investigative inquiry that uses scientific methodology to systematically explore either a known or unknown study area with a view to authenticating and validating existing assumptions or theories, proffering possible solutions to some known problems, and generating some new concepts, problems and/or hypothesis for further investigation (Ajaefobi, 2004).

3.3.2 Type of research

Research can be classified from three perspectives (see Figure 3.1) (Kumar, 1999);

a) The application of research study,
b) The objectives in undertaking the research, and
c) The type of information sought.

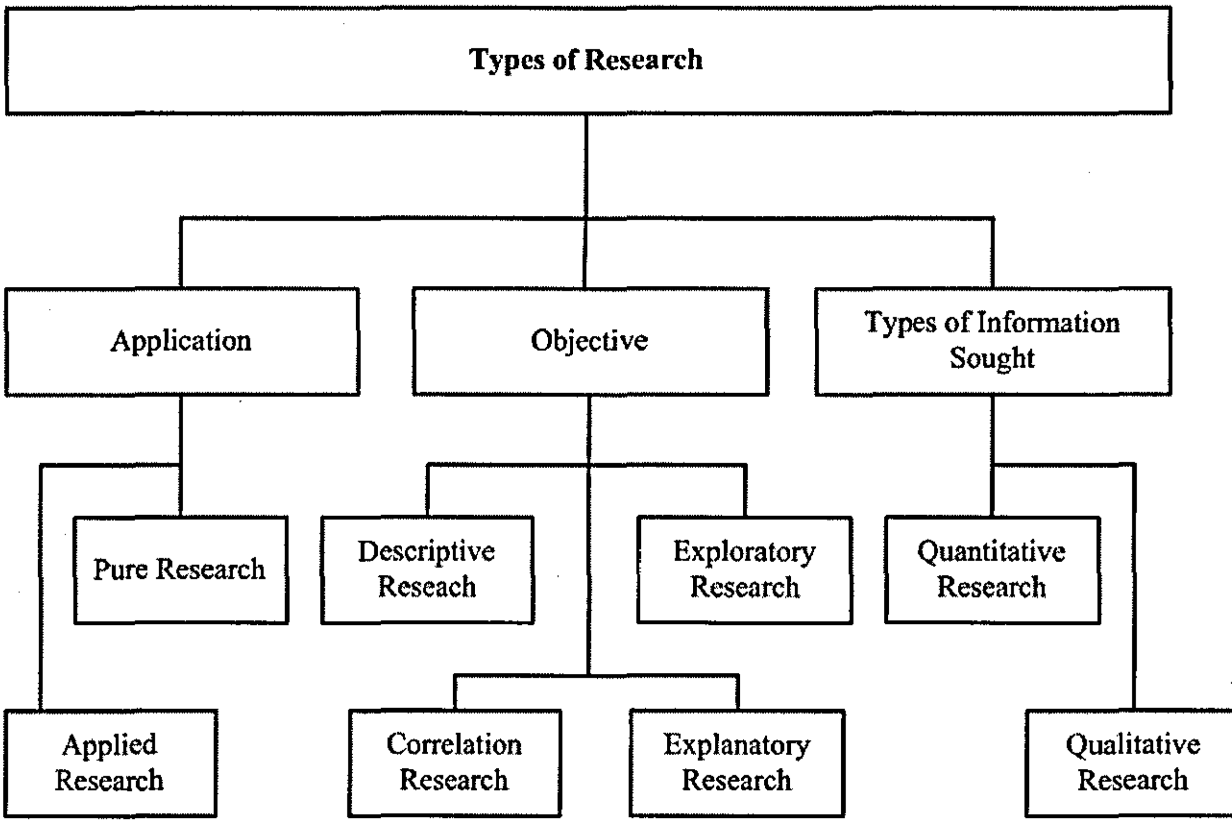

Figure 3.1 Types of Research (Kumar, 1999).

(Kumar, 1999) described in detail all the types of research shown in figure 3.1. Brief description of these research types are presented below.

i. Pure research – is concerned with the development, examination, verification and refinement of research methods, procedures, techniques and tools that form the body of research methodology.

ii. Applied research - is concerned with the research techniques, procedures, and methods that form the body of various aspects of a situation, issue, problem or phenomenon so that information gathered can be used in other ways such as for policy formulation, administration and the enhancement if understanding of a phenomenon.

iii. Descriptive research – attempts to describe systematically a situation, problem, phenomenon, service or program, or describe attitude towards an issue.

iv. Co relational research – is conducted to discover or establish the existence of a relationship/association/interdependence between two or more aspects of a situation.

v. Exploratory research – is carried out to investigate the possibilities of undertaking a particular research study. This type of research is also called a 'feasibility study' or a 'pilot study'. It is usually carried out when a researcher has a little or no knowledge about the areas of research to be explored.

vi. Explanatory research – attempts to clarify why and how there is a relationship between two aspects of a situation or phenomenon.

vii. Qualitative research – A research is classified as qualitative if the following conditions exist; if the purpose of the study is primarily to describe a situation, phenomenon, problem or event; the information is gathered through the use of variables measured on nominal or ordinal scale (qualitative measurement scales); and if analysis is done to establish the variation in the situation, phenomenon or problem without quantifying it.

viii. Quantitative research - A research study is classified as quantitative if the following conditions exist; if it is required to quantify the variation in a phenomenon, situation, problem or issue, if information is gathered using predominantly quantitative variables, and if the analysis is geared to ascertain the magnitude of the variation, the study is classified as a quantitative study.

3.3.3 Choice of research methodology

In this study the choice of research methodology was made on the basis of the research environment, research problem, and research case studies included. The environment of this research required selection of different techniques to graphically represent and describe a phenomenon or an issue and then to apply and analyse different alternative ways to combine the techniques to develop the required methodology for the analytical design of complex supply chains. This was observed to required use of both numeric and subjective data and data analysis. The research problems of this research are to develop an integrated methodology for analytical design of complex supply chains, and to use this integrated methodology to find its usefulness. Therefore, case studies are required in this research to test usefulness of the integrated methodology.

Keeping in view the needs of this research, the author deduced that applied research, descriptive research and combination of quantitative and qualitative research are the relevant types of research required to be undertaken. The reason is because this research used research techniques, procedures and methods that form the body of research methodology and are applied to the collection of information about various aspects of a situation, issue and problem. So this research study possessed the characteristics of applied research. The research attempt to describe systematically complex supply chain problems and issues and to describe some predicted behaviours of complex supply chains for different simulated complex supply chain designs. This dimension is related to descriptive research. Furthermore, the complex supply chain research study required the application of qualitative methods to capture and describe complex supply chains and establish causal relationships among different variables of the complex supply chains. To analyse the variables simulation modelling added a quantitative dimension.

To summarise, this research has some characteristics of applied research, descriptive research and combination of qualitative and quantitative research.

3.3.4 Data collection methods

There are two major approaches to gather information about a situation, person, problem or phenomenon. Sometimes, information required is already available and need only be extracted. However, there are times when the information must be collected. Based upon these broad approaches to information gathering, data are categorised as (Kumar, 1999);

a) Primary data, and

b) Secondary data.

Information gathered using the first approach is said to be collected from secondary sources whereas the sources used in the second approach are called primary sources. Different methods of data collection related to each of the sources are presented in Figure 3.2 (Kumar, 2005).

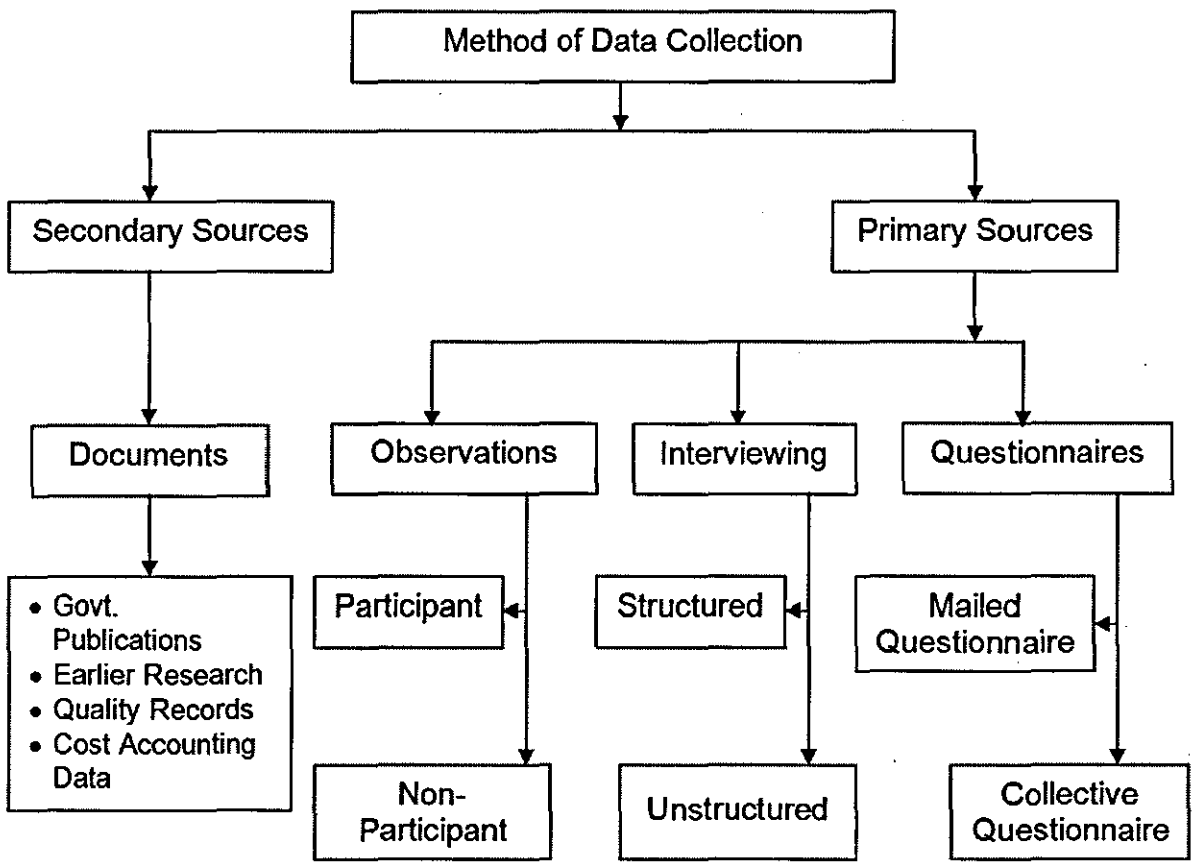

Figure 3.2 Methods of Data Collection (Kumar, 2005).

3.3.5 Choice of data collection methods

Keeping in view the type of research chosen in section 3.3.3, i.e., applied research; descriptive research and combination of qualitative and quantitative research, both primary and secondary sources of data were required. The choice of the data collection method and its reasons are presented in Table 3.1.

Table 3-1 Choice of data collection methods.

Data Source	Data Collection Method	Data Collection Method Type	Appropriateness to the Research	Remarks
Primary	Interviewing	Structured	Yes	*Semi structured* interviews of relevant people can be required in case study to understand the complex supply chains and its related issues.
		Unstructured	No	
	Observation	Participant	Yes	Walk through to observe and capture actual details of complex supply chains activities can be done along with the participation of the process owner to verify the captured activities.
		Non-Participant	No	---
	Questionnaire	Mailed Questionnaire	No	---
		Collective Questionnaire	No	---
Secondary	Documents	Sales and Orders Data	Yes	Can be required to know about the product variance, product volume, and product mix needed to be fulfilled by the complex supply chains.
		Process charts for different processes	Yes	Can be helpful to understand different processes of complex supply chains.
		Value stream maps	Yes	Can be helpful to understand improvement potentials and bottlenecks in complex supply chains.

Data Source	Data Collection Method	Data Collection Method Type	Appropriateness to the Research	Remarks
		Quality Records	Yes	Can be useful to understand level of rework/rejection and their probable impact on complex supply chains.
		Departmental performance records	Yes	Can be useful to understand performance levels of different departments contributing to complex supply chains.
		Design Data	Yes	Can be useful to know about BOM of the observed products and an idea about the product geometrical complexity and tolerances.
		Earlier Research Data	Yes	Can be a very useful source to avoid the segments of work already done.

To summarise, this research requires use of both primary and secondary data collection methods including interviews, observations and different types of case company documents if available.

3.4 General research approach and selection of general research method

On the basis of research scope, research objectives, and research environment, the following proposed steps were undertaken through different stages of this research as presented in Table 3.2.

Table 3-2 General Research Approach and General Research Method

General Research Steps	Description
Gap Analysis and research objectives	It is apparent from the literature survey that there was a need for an integrated methodology for analytical design of complex supply chains. The required methodology should include following capabilities. • It should graphically represent and explicitly describe key characteristic properties of complex supply chains. • It should analytically explore dynamic properties of complex supply chains, provide analytic means of reasoning about impacts of uncertainty in complex supply chains, such as those introduced due to changes in demand, supply, make, delivery and return processes. • It should predict possible future of complex supply chains due to uncertainties arise. • It should quantify and predict behavioural aspects of complex supply chains due to observed uncertainties or risks (potential uncertainties).
Design of an integrated methodology for analytical design of complex supply chains. methodology	To meet the aim and objectives, different candidate methods were analysed to fulfil the required capabilities of the integrated methodology for analytical design of complex supply chains.
Use and test integrated methodology for analytical design of complex supply chains on some case supply chains.	To test and verify the integrated methodology for analytical design of complex supply chains, an extensive case study was conducted. This was required to see which capabilities of the integrated supply chain methodology are working well and which of them need to be enhanced.
Analyse the case study application of the proposed integrated methodology for analytical design of complex supply chains.	It was necessary to analyse the suitability and benefits of the proposed and developed integrated methodology for analytical design of complex supply chains in respect of the case studies supply chain. Also it was necessary to identify problems and potential improvements in the proposed methodology.
Enhance the proposed methodology	Also required was to enhance the proposed methodology to

General Research Steps	Description
	better perform the supply chain analytical design functions for which it was developed.
Test and verify the enhanced methodology in a case study complex supply chains.	Next it was necessary to use and test the enhanced methodology in a case study to determine if the methodology is fit for purpose.

Table 3.2 presented the general research approach and general research method which will be used to develop and test the integrated methodology for analytical design of complex supply chains to fulfil needs of this research.

Chapter 4: Design of an integrated methodology for the analytical design of complex supply chains

The purpose of this chapter is to develop an integrated methodology for the analytical design of complex supply chains. This chapter starts with presenting the need for such a methodology to satisfy the research objectives previously stated. To fulfil this purpose this chapter makes a case for (a) selecting a suitable set of modelling techniques and (b) developing a systematic way of using the selected techniques to support and engineer complex supply chains. Through achieving (a) and (b) an integrated methodology for the analytical design of complex supply chains will be developed.

4.1 General requirements of an integrated methodology for the analytical design of complex supply chains

Based on literature analysis (see Chapter 2), it was observed that graphical representation and mapping of supply chain is an important requirement for re-engineering supply chains and hence it is widely used for analysis and re engineering of supply chains. For instance, Meade and Sarkis, (1998) used graphical representation of supply chain entities and relate the entities to analyse strategic logistic and supply chain management systems. Scott and Westbrook, (1991) and Christopher and Gattorna, (2005) used supply chain mapping for representation of supply chain processes and activities in support to re engineer supply chain. The graphical representation and mapping can only analyse structural and relatively most enduring characteristics of the system (Rahimifard and Weston, 2005). Dynamic analysis of behaviour of supply chain provides important information to improve its performances (Pierreval et. al., 2006). Therefore, both static and dynamic analysis of the supply chain is required to be included in analytical design of complex supply chains. Therefore the overall aim of this research was "to develop and test use of an integrated modelling methodology to support decision making about complex supply chains". To fulfil this aim, the following objectives were defined.

Objective 1. To study state of the art modelling techniques that have potential for the analytical design of complex supply chains.

Objective 2. To develop an integrated modelling methodology for the analytical design of complex supply chains.

Objective 3. To case test and update the integrated modelling methodology for the analytical design of complex supply chains.

To achieve the aim and objectives of this research an integrated modelling methodology for the analytical design of complex supply chains is needed with capabilities to:

- graphically represent and explicitly describe key characteristic properties of complex supply chains.
- analytically explore dynamic properties of complex supply chains, so as to provide analytic means of reasoning about impacts of uncertainty in complex supply chains, such as those introduced due to changes in demand, supply, make, delivery and return processes.
- predict possible futures of complex supply chains in response to possible uncertainties that may arise.
- quantify and predict behavioural aspects of complex supply chains due to observed impacts of uncertainties and to assess possible risks should potential uncertainties arise.

To implement the required methodology for supply chain analysis, suitable candidate techniques are required, such as those itemised in Figure 4.1, which will need to be used collectively on systematic basis.

Supply chain representation, visualisation	Supply chain bottleneck identification/ Description	Understanding Supply system dynamics	Supply chain uncertainty qualification	Supply chain qualitative behaviour prediction	Supply chain quantitative analysis
Candidate Technique(s) ?	Candidate Technique(s) ?	Candidate Technique(s) ?	Candidate Technique(s) ?	Candidate Technique(s) ?	Candidate Technique(s) ?

Figure 4.1 Supply chain analysis needs.

A variety of candidate techniques were surveyed and analysed in chapter 2 which have potential to support some of the above mentioned characteristics. Specific features associated with the selected examples of those techniques are discussed in the following subsections.

4.1.1 Enterprise modelling (EM) and potential use of the enhanced CIMOSA based MSI technique

From the literature survey, it was observed that the CIMOSA based enhanced enterprise modelling technique developed at MSI Loughborough University can usefully be used to explicitly represent and decompose a 'big picture' of the network of processes used by any enterprise. It can also facilitate the detailing of structural aspects of some focused shop floor section of that ME or alternatively allow abstract representation of the ME and its supply chain domains.

Selection of the scope and focus of enterprise modelling depends on the purpose and the context of the current modelling exercise, and particularly for what the enterprise model is to be used for. The big picture of enterprise processes can be created so as to encode various perspectives of the ME, which will be of concern to potential or specified model users. The perspectives may include: processing and activity requirements, flow controls, information, cash, physical (material) and human resources. The big picture can be created for one or more specific 'contexts' which helps to maintain a focus of the modelling work. Essentially these models can be used to visualise the processing requirements of an enterprise such that it adds value to 'products' and 'services' needed by 'customers'. CIMOSA-MSI enterprise modelling can identify and represent different actors and stakeholders involved, and interactions between those actors centred on the flow of information, cash, human and physical (material); thereby it can explicitly represent the structure of the interacting processes and logical flows of processes. For the above reasons enterprise modelling was selected by the present authors as a best in class technique to statically model, represent and visualise complex supply chains from 'defining the processing requirements' point of view.

4.1.2 Causal Loop Diagramming (CLD)

Also described in the literature survey is how causal loop diagramming can be used to understand and represent systems dynamics associated with causal relationships that link different variables of complex systems. Change in any variable can affect other associated variables with a positive or a negative effect on the complete system. Therefore, causal loop diagramming was also selected as a technique to be used as an integral part of understanding and assessing the dynamics of complex supply chains. Here it was presumed that causal loop diagramming would enable qualitative understandings to be developed about complex supply chains behaviours when any given complex supply chains is subjected to uncertain conditions caused by selected variables. For example, change in demand, change in supply, change in resource availability, change in plant performance, change in production and inventory management, change in delivery or indeed change in some 'mix' of these different variables.

4.1.3 Simulation Modelling (SM)

Also observed in the literature survey was that simulation modelling can be used to graphically visualise 'flows' through complex supply chains 'processes' and 'resources'; and thereby can quantify likely outcomes from different what-if scenarios. For different combinations of uncertain conditions, different resource configurations can be tested and results can be quantified. In this regard, the suitability of industry best practices can be analysed, as can new emerging manufacturing paradigms (from academia and industry) in any specific case enterprise. Furthermore, it is presumed that quantitative results from using simulation modelling can be helpful to predict future behaviours of complex supply chains and can support analysis leading to improvement in given complex supply chains. However, it was also clear that some systematic step wise technique of simulation modelling would be needed to undertake complex supply chain modelling which in general will involve interaction between many dependent variables. Both discrete event simulation (DES) modelling and continuous simulation (CS) modelling could prove useful, so that both are selected as an integral part of the supply chain analysis methodology to graphically visualise and quantify behaviours of work flows through alternative complex supply chains. Selection between DES and CS modelling techniques depends on the requirements of simulation. For instance, if requirement of simulation is to simulate a scenario at a high level of abstraction or for taking a policy decision in complex supply chains then CS is expected to prove most appropriate, while to implement the policy and to verify its impacts on operational level activities DES is likely to prove most suitable. Also expected was that simulation modelling would quantify aspects of complex supply chains behaviour under different uncertain changes with this could help to quantify aspects of associated risks.

4.1.4 Combined use of EM, CLD and SM techniques

Furthermore the literature survey observed that the work related to the use and integration of different modelling techniques like enterprise modelling, causal loop diagramming and simulation modelling techniques has in other application domains, provided an analytical basis for underpinning key aspects of organization design and change (OD&C). However, in view of the context of this study it was necessary to scope and focus an integrated use of these modelling approaches, by specifying and testing their systematic use as potentially widely applicable methodology which supports analyses needed by relevant actors as they engineer aspects of complex supply chains of concern to them.

4.1.5 Key observations about the use of different modelling techniques

Table 4.1 was constructed to summarise the intended purpose of the modelling techniques selected as base technologies to realise an integrated methodology for the analytical design of complex supply chains.

Table 4-1 Key observations about use of different modelling techniques.

Concept Reviewed	Summary of Purpose	Observations/Comments
Enterprise modelling (EM)	The CIMOSA EM architecture has been used by many researchers around the world and extensively in MSI to capture the big picture of the processes of an enterprise operating within a specific business context.	EM is not capable to model and test dynamic aspects of an enterprise.
Causal loop diagramming (CLD)	CLD has been widely used to capture the mental models for different dynamic situation presented in terms of cause and its effects.	Causal Loop modelling can facilitate representation and understanding about complex system dynamic. However, on its own it cannot quantify issues numerically.
Simulation modelling (SM)	Simulation modelling was used to simulate different what-if scenarios and numerically quantify different performance variables.	Small process portions of an enterprise can be simulated precisely but as the size of model grow it become too complex and degree of precision decrease. Large process portions of an enterprise can be simulated at abstract level.
Combined use of EM, CLD and SM	Research was conducted at MSI to unify EM, CLD and SM to address different problems and support decisions of manufacturing enterprises.	There is a need to test case the application use of unified modelling concepts in a business-wide context and in respect of various industry sectors (Chatha and Weston, 2006).

Based on the key observations presented in Table 4.1 about their potential to fulfil the required characteristics of an integrated methodology for the analytical design of complex supply chains, the candidate modelling techniques presented in Figure 4.2 were selected and their use was subsequently case study tested; as described in following thesis chapters.

Supply chain representation, visualisation	Supply chain bottleneck identification/ Description	Understanding Supply system dynamics	Supply chain uncertainty qualification	Supply chain qualitative behaviour prediction	Supply chain quantitative analysis
Enterprise Modelling (EM)	EM & Candidate Technique to Describe Issues ??	Causal Loop Diagramming (CLD)	Causal Loop Diagramming (CLD)	Causal Loop Diagramming (CLD)	Simulation Modelling (SM)

Figure 4.2 Supply chain analysis needs and candidate techniques.

Figure 4.2 shows a static match between the required characteristics of an analytical design methodology for complex supply chains and state of the art candidate techniques currently available for use by industry. The selected EM, CLD, and SM tools and techniques can provide some of the modelling capabilities required to develop an integrated analytical methodology for complex supply chains. However, to present and describe explicitly the issues, bottlenecks and potential improvements identified by EM, it was expected that additional techniques would need to be developed as part of this study; primarily to enable mapping between, and thereby integrated use of, the various modelling techniques that would need to be deployed when analyzing complex supply chains.

4.2 Design of an integrated methodology for the analytical design of complex supply chains

In this PhD. research, an integrated methodology composed of enterprise modelling, causal loop diagramming and simulation modelling is developed to fulfil the need for the analytical design of complex supply chains. Key characteristic requirements associated with the complex supply chains methodology are to present and explicit describe issues, bottlenecks and potential improvements, for which currently no available modelling techniques exist. To fulfil this need, use of a new 'table' namely a "Domain table" was proposed; and use of such a table was developed as part of this research. The domain table 'relates' data entities which parameterise supply chain properties from different perspectives associated with information, physical (material), financial and human aspects. The general structural design of such a domain table is illustrated in Table 4.2.

Table 4-2 The proposed "Domain Table".

<table>
<tr><th colspan="6">Domain Table for CIMOSA-Conformant Domain(s) – DM</th></tr>
<tr><td colspan="2" rowspan="2">DPs and BPs</td><td colspan="4">Domain issues related to Enterprise Modelling Entities</td></tr>
<tr><td>Information</td><td>Physical</td><td>Human</td><td>Financial</td></tr>
<tr><td rowspan="2">DPs</td><td>BPs</td><td>**</td><td>**</td><td>**</td><td>**</td></tr>
<tr><td>BPs</td><td>**</td><td>**</td><td>**</td><td>**</td></tr>
</table>

** Description of issue(s) with reference to related EA(s)

The designed purpose of the proposed domain table is to explicitly list and describe issues, bottlenecks and potential improvements for any CIMOSA conformant domain (which is an entity or part of an entity selected for in depth modelling and analysis). These issues will be shown in a structured way by keeping these under specific categories namely information, physical, human and financial (cash). The usefulness of the domain table is to be verified and tested.

With the development and introduction of the new domain table as an integral part of enterprise modelling, the subsequent use of causal loop diagramming and simulation modelling can be systemised, when analyzing a supply chain.

Hence it was proposed that a synergistic use of enterprise modelling, causal loop diagramming and simulation modelling, with their key integration aspects realised and explicitly defined by the proposed domain table, could support analytical design of complex supply chains. This constituted an enhancement of the modelling methodology previously proposed by Chatha and Weston, (Chatha and Weston) and Weston et. al., (Weston et al.) and by so doing focused integrated modelling on supply chain analysis. A description of the new supply chain analysis methodology proposed was described in a refereed journal publication of the present author(see (Rashid et al., Accepted 2009)). The combined modelling methodology for supply chain analysis is conceptually represented by Figure 4.3.

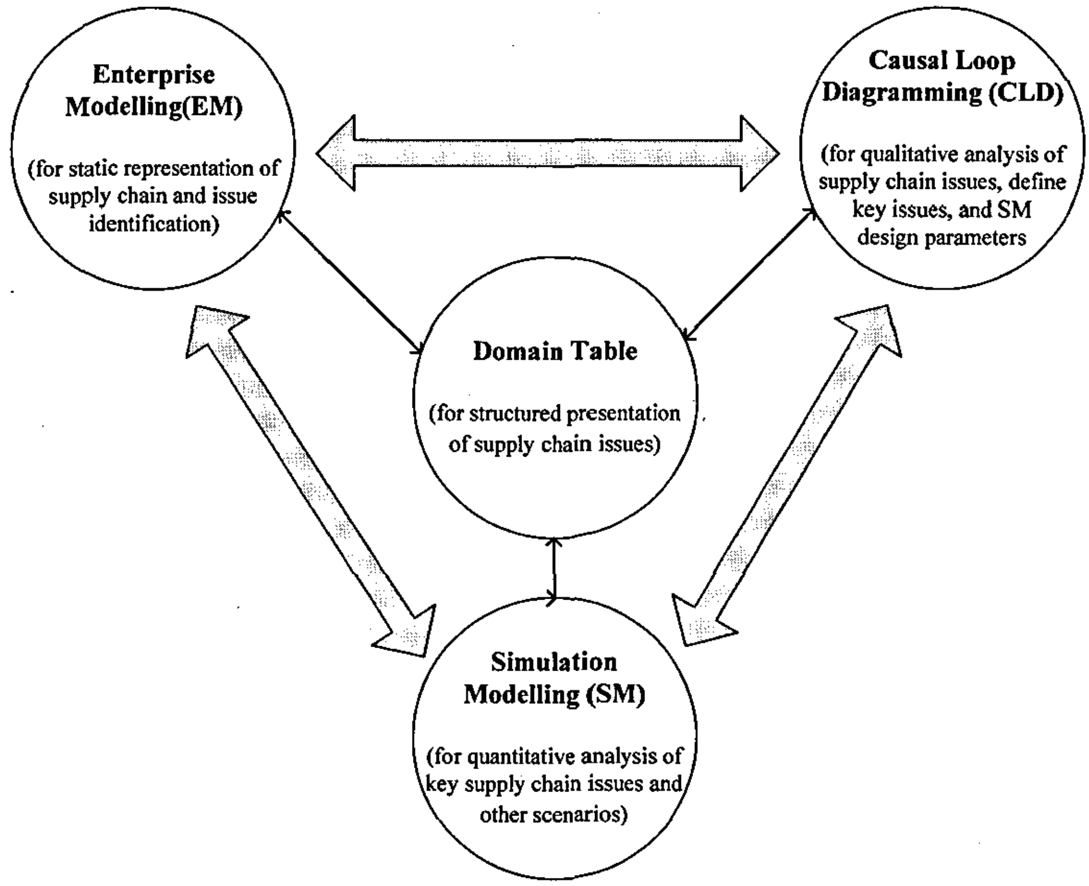

Figure 4.3 The proposed combined modelling methodology for comprehensive analysis of supply chain.

A brief explanation of the use of each element of the proposed supply chain analysis methodology and an overview of synergistic aspects expected from achieving integrated modelling is presented below.

a. CIMOSA enterprise modelling constructs linked to the MSI enterprise modelling graphical approach will be used to create holistic enterprise models of complex supply chains to model relatively enduring structural dependencies between supply chain entities. These supply chain models are holistic because they can capture end to end supply chains at different level of abstraction. These models will be a source of understanding about different supply chain entities/actors, different processes included in the entities, interaction of the processes with in the entities and outside the entities from various perspectives of information, physical (material), cash and human, structure of processes associated with the entities, and flows of the processes from customer order to the supply of desired product/service in a given supply chain.

b. Following which the domain table will be developed in this research to capture attributes of issues related to selected domains identified during CIMOSA based enterprise modelling. These tables will cover data from different perspectives associated with information, physical (material), financial and human entities which are used for enterprise modelling of the CIMOSA conformant domain(s).

c. The causal loop diagramming (CLD) technique is then used to understand and represent supply chain dynamics. CLD is used to explore key causal effects related to the issues defined by the domain tables. The resultant causal loops will provide a source of qualitative exploration of supply chain dynamics under different uncertain conditions within the context defined by enterprise modelling. Also causal loops are used for designing parameters associated with needed simulation experiments which subsequently are used to quantify supply chain dynamics related to key issues of concern to that enterprise.

d. Simulation modelling will be used to quantify and visualise dynamic supply systems and different flows through supply chain entities. The key issues identified by the causal loop diagrams will be focused with a view to quantification using simulation modelling. Business processes or enterprise activities related to the key issues will be found from the domain table. When designing and developing the simulation models, CIMOSA based graphical models will be used to view specific process segments found from the domain table. Simulation model design parameters will be deduced from a study of the causal loops. Design parameters will include variables and performance parameters relative time based behaviours of which need to be quantified during simulation modelling experiments. Simulation modelling will be performed by using a computer based simulation modelling tool. Either a discrete event simulation (DES) or a continuous simulation (CS) or both can be used. The selection of the simulation technology depends on the problem to be simulated. For example, simulations at a high level of abstraction in support to make policy level decisions for complex supply chains like selection of suitable paradigm in complex supply chains, size of inventory required in case of a selected paradigm, inventory turnover for selected paradigm etc., CS can be used. For problems where in-depth details are required to be modelled and the implementation of the policies are required to be tested for different small segments of the whole supply chain, DES can be used.

4.3 Research approach to use the proposed integrated supply chain analysis methodology

To use the proposed supply chain analysis methodology, the following research approach was devised and is presented below (see Figure 4.4). Also a list of instructions to apply the proposed methodology is documented in Table 4.3.

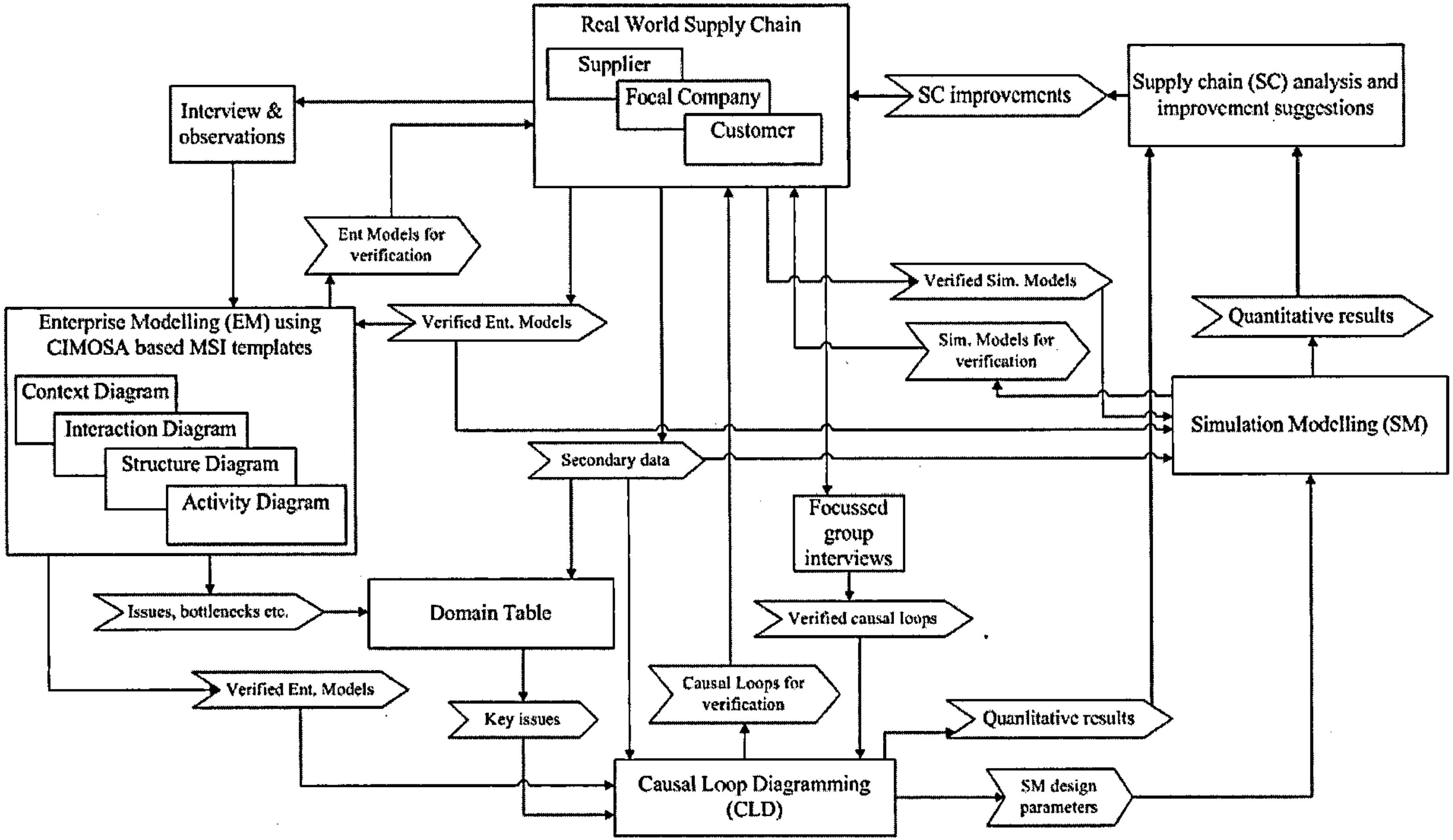

Figure 4.4 Research approach to using the proposed supply chain analysis methodology.

Table 4-3 Guidelines for the applications of the integrated methodology for case supply chain

Steps of Integrated Methodology	Step Description	Guidelines for Application	Data Collection Method	Expected Outcome
Enterprise Modelling	Create enterprise model for graphical representation of the focussed enterprise and its supply chain	• Use the four CIMOSA-MSI enterprise modelling graphical templates and populate these with data of the focussed enterprise and its supply chain • Verify the enterprise model from the related knowledge holder in the supply chain • Use the verified enterprise model for graphical representation and static structural analysis of the supply chain	• Introductory visits and shop floor walk through of the focal enterprise • Semi-structured focussed group interviews of supply chain knowledge holders • Participant observations	Verified enterprise model in the form of 'Context diagram', Interaction diagram', Structure diagram' and 'Activity diagram' representing big picture of processes of the focal enterprise and its supply chain
Domain Table	Create the domain table for explicit description of the issues of focussed enterprise and its supply chain	Use the standard template of the domain table and populate it with the data about observed issues of the focussed enterprise and its supply chain	• Data collected for creating enterprise models • Some secondary data like quality and performance records	A domain table explicitly representing issues of the focussed enterprise and its supply chain
Causal Loop Diagramming	Create causal loop diagram(s) to understand dynamics about some important issues of supply chain	• Construct causal loop diagram(s) for some important issues of the supply chain • Verify the causal loop diagrams from the related knowledge holder in the supply chain • Use verified causal loop diagrams for qualitative analysis of supply chain and define KPI's for performing simulation modelling	• Information and understanding already conceived focussed group interviews, and participant observation of supply chain knowledge holders	Verified causal loop diagram(s) created for some important supply chain issues, exploring and presenting dynamic issues of supply chain related to the issues and in a way defining KPI's for simulation modelling
Simulation Modelling	Create simulation model to numerically	• Construct simulation model for the related process segment of the supply chain • Validate the simulation model from the	• Supply chain process information presented in the 'Activity diagrams'	Validated simulation model for a related process segment of the

	quantify important issues of supply chain and predict future behaviour of the supply chain in that case	relevant knowledge holders of the supply chain • Use the validated simulation model for the numerical quantification of the supply chain issues and predict future behaviour of the supply chain	• Key performance indicators presented by the causal loop diagramming • Some secondary data like process duration, work flows, resource utilization and availability etc.	supply chain, which can be used for the quantitative analysis of the important issues of supply chain

4.3 Novelty and potential benefits of the proposed supply chain analysis methodology

The proposed combined EM, CLD and SM, along with the use of the proposed domain table to support the analysis of complex supply chains, is a new concept. Its novelty is associated with three things; i) the newly developed domain table was designed to provide an explicit description of issues, bottlenecks and potential improvements, ii) it constitutes a new combination of EM, CLD, SM techniques which can be systematically applied and iii) it is targeted at the new focused field of supply chain analysis for which no previous analysis methodology of equivalent coverage existed.

In combination the modelling techniques, namely EM, CLD and SM, prove much of the required functionality needed for supply chain analysis. However, no previously available tool was available to explicitly describe supply chain issues, bottlenecks and problems in a structured way which is expected to be realised by the new domain table proposed as a part of this research.

The proposed integrated methodology for analytical design of complex supply chains is expected to be useful in performing following tasks in the case 'parking and valeting enterprise'.

- graphically represent and explicitly describe key characteristic properties of the selected complex supply chain.
- analytically explore dynamic properties of a couple of important issue of the selected complex supply chain, so as to provide analytic means of reasoning about impacts of uncertainty in the complex supply chain associated with the selected issues.
- predict possible futures of the selected complex supply chain in response to a couple of selected uncertainties that may arise.
- quantify and predict behavioural aspects of the selected complex supply chains due to the observed impacts of uncertainties and to assess possible risks should potential uncertainties arise.

Chapter 5: Case study 1: Use of the proposed integrated methodology for the analytical design of complex supply chains: The case of parking and valeting enterprise

In this chapter, the integrated methodology for analytical design of complex supply chains proposed in chapter 4 is used and tested in a case study parking and valeting company (referred to as "ABC"). This chapter initially introduces the case enterprise and its supply chain. After which, following the designed steps of the proposed methodology, EM is conducted and some of the models related to the case study are presented in this chapter. Further to EM, the domain table is populated for the case study. Then developed causal loop diagrams are presented using inputs from the domain table. Simulation modelling is then performed and presented. In the last section, some suggestions are made to improve ABC's supply chain.

5.1 Case Study Introduction

The case study enterprise conducts business via the provision of vehicle parking and valeting services. The case study company is a medium stay vehicle parking and valeting SME operating at a UK airport. ABC has 20 employees including 8 regular employees while 12 are shift employees. ABC operates 7 days a week and 24 hours a day. The customers of ABC can be categorised broadly into two. First are 15% of the total customers of ABC that book their parking space directly with ABC by using a website or by calling ABC to book space and/or valeting; and at this time money is debited. While others are sent by brokers (travelling service companies) who direct their customers to ABC; to which arrival and departure details are provided to ABC by fax. These brokers contribute 85% of the ABC's total customers on average. All the booking details of either the direct customers or the broker customers are uploaded in a customised data base developed in MS Access which is capable of keeping the data and retrieving it when required but is not useful enough for dealing with capacity and scheduling matters. ABC has a maximum parking capacity of 220 vehicles; while it's valeting capacity 15 to 20 vehicles per day depends upon the extent of valeting required.

ABC can be referred to as a developing SME and a lot needs to be done in all the different aspects of its business processes from its strategic policy decisions through to the tactical and finally its operational decisions. For instance, ABC has not communicated its business policy to the relevant members of the staff and no well defined and quantifiable objective and targets are set for people carrying out different functions. Role description seems to be inappropriate and the relevant training of human resource seems to be insufficient especially in the case of shift staffs which are composed of 60% of the total. This leads to low customer service quality at the reception check in activity and increased risk of accident or vehicle break down during parking and valeting process. Considering the aspect of communication with the brokers which are the major source of business, ABC management decided that on a daily basis the brokers should be faxing the bookings for their customers for parking and valeting at ABC; but still in 20 to 25% of cases when customers arrive at ABC reception to drop off vehicles no record of their booking is available in the data of ABC. This is mainly due to the reason that no method of reconfirmation is realised between the brokers and ABC; as a consequence customers have to wait in a queue at the reception. This decrease the customer service performance of the ABC's supply chain which need to be quantified and analysed.

To enable understanding and analysis of ABC's supply chain problems, issues and potential needs, the proposed integrated methodology for the analytical design of complex supply chains was used. To realise the methodology, EM, CLD and SM modelling techniques are used in the designed combination with the domain table. CIMOSA based multi perspective enterprise modelling (EM) is used to understand, represent, visualise and explicitly describe the ABC supply chain processes, its most enduring characteristics, and present different issues and constraints that impact on supply system behaviour. The domain table was populated with the issues and problems identified for ABC, mainly by using the EM. Causal loop diagramming (CLD) was used to explore dynamics of the supply system related to the identified issues. CLD's were also used to analyse qualitatively the behaviour of ABC's supply chain system due to different supply chain uncertainties. Simulation modelling was then used to quantify behaviours of ABC's supply chain system as it faces different supply chain uncertainties.

5.2 Creating Enterprise Models of the ABC Supply Chain

To provide a 'big picture of ABC, and thereby to enable strategic, tactical and operational decision making within ABC, a CIMOSA model of ABC's supply chain was created using four types of graphical modelling template namely 'Context Diagram', 'Interaction Diagram', 'Structure Diagram' and 'Activity Diagram' templates. By filling in these templates with specific ABC process data, a holistic (but static) model of ABC's different working domains and their decomposition into Domain Processes (DPs), Business Processes (BPs) and finally in to Enterprise Activities (EAs) was achieved. This model also documents relatively enduring aspects of interactions between DP's, BP's and EA's in the form of transfers of physical, information, human or financial resources. Careful construction of these diagrams led to the creation of an 'As-Is' picture of ABC supply chain business processes which can lead to benefit in a variety of ways. For instance, process data elicited by conducting semi structured but focused group interviews of relevant personnel is positioned into the wider context in which ABC operates. The main objective of such interviews was to understand and explicitly describe knowledge separately held by ABC knowledge holders into an holistic, relatively enduring characterization of selected supply chain process domains (both internal to ABC and external) related to the scope of this particular case study research i.e., "ABC Vehicle Parking and Valeting and its supply chain". The focused group interviews held with ABC (knowledge holders) managers fleshed out agreed understandings about five process domains. One of those domains, which were the main focal point of concern to the ABC, was explicitly modelled as a CIMOSA conformant domain. In this case the domain "Vehicle Parking" (DM2) was modelled in detail as a CIMOSA conformant domain while the other four were essentially treated as 'black boxes', i.e. as CIMOSA non-conformant domains (see context diagram in Figure 5.1).

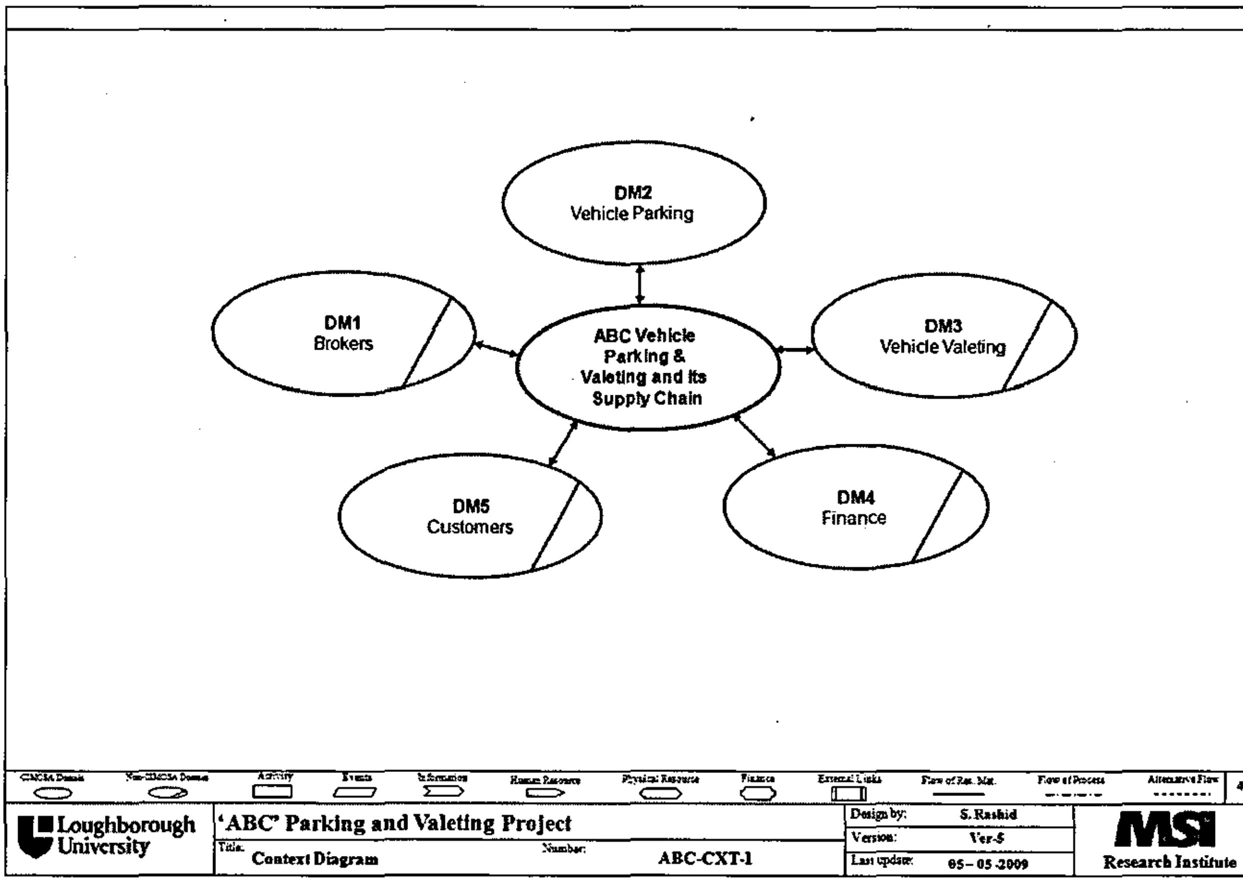

Figure 5.1 Context Diagram for "ABC Vehicle Parking and Valeting and its Supply chain".

However as later explained the interactions between DM2 and the other four domains were modelled using an 'interaction diagram'. The reason for not modelling the other four domain in detail were; a) the knowledge holders and data was available only for the vehicle parking domain (DM2), and b) the domain DM2 was the most important domain associated with the focus of the case study research project because mainly DM2 was interacting with customers and brokers and processes included in DM2 were contributing more than 80% of ABC's revenue.

The CIMOSA conformant domain "Vehicle Parking" (DM2) was decomposed into a set of interacting domain processes (DP's), business processes (BP's) and enterprise activities (EA's). Various types of interactions were realised via the interchange of information, human resource, physical resource and financial resource types. The focused group interviews were essential for understanding and capturing specific characteristics of ABC processes and interactions among different domain processes (both CIMOSA and non CIMOSA domain processes). The interviews were also the prime source of information used to create enterprise models for the CIMOSA domain, "Vehicle Parking" domain (DM2) which functions to realise a related domain process which in this study was referred to as "Vehicle Parking Management and Realisation" (DP2). The remaining four non CIMOSA domains DM1, DM3, DM4 and DM5 need to realise domain processes "Broker's Coordination" (DP1), "Vehicle Valeting Management and Realisation" (DP3), "Finance Control" (DP4) and "Customer's Interaction" (DP5), respectively. Interactions between these five domains processes are presented in the "top level interaction diagram" (see Figure 5.2). This diagram visually documents interactions between domain processes that belong to five domains of responsibility associated with the parking and valeting process (which is in fact realised by ABC and its brokers and customers). Also this diagram represents the exchange of either information, physical resources, human resources and finance between the five domain processes.

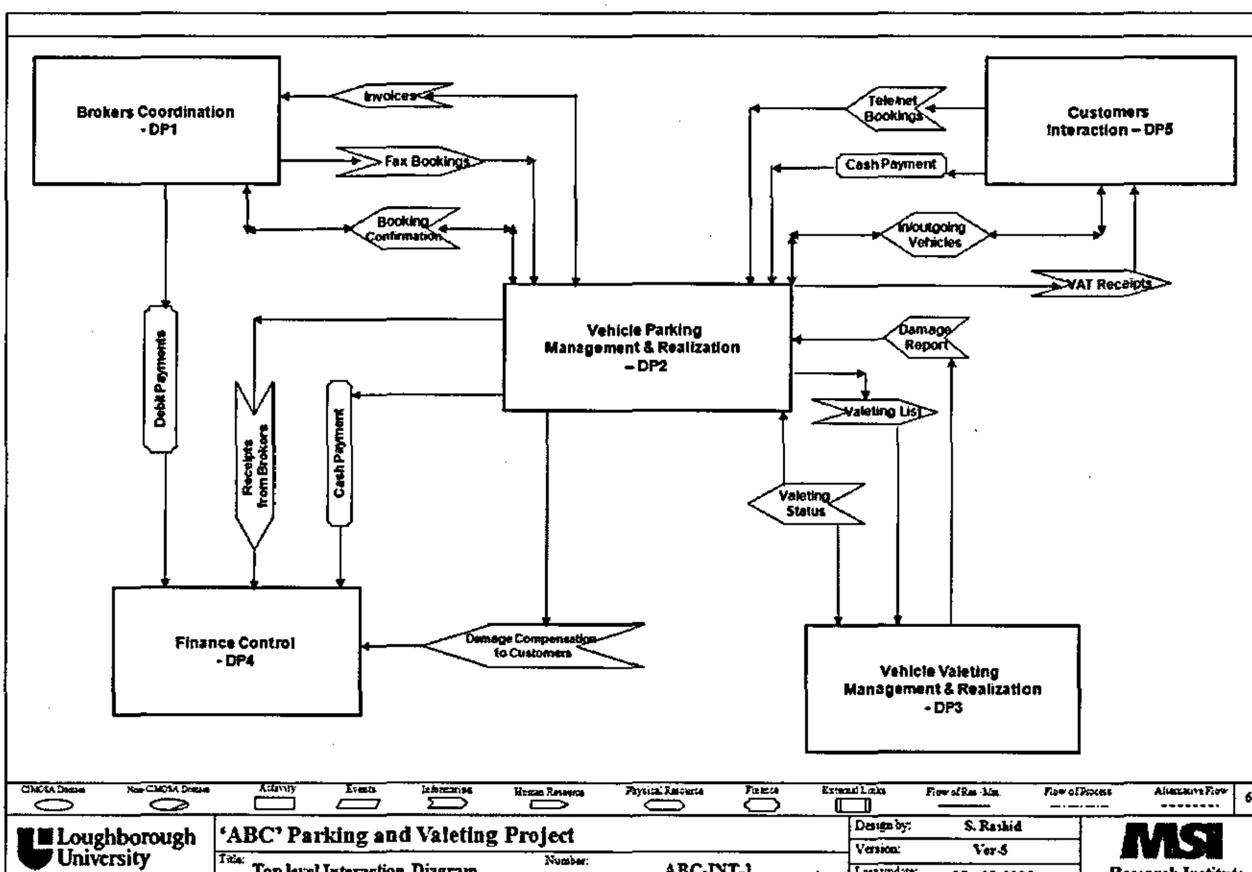

Figure 5.2 Top level interaction diagram for "ABC Parking & Valeting and its Supply Chain".

Figure 5.2 shows that most interactions occur between DP2, "Vehicle Parking Management and Realisation" and the remaining four domain processes i.e., DP1, DP3, DP4 and DP5. Clearly DP2 is a central and important domain process and that provided further justification for why DP2 was modelled in detail in this study.

When studying the case company through the focused group interviews it was observed that domain process DP2 "Vehicle Parking Management and Realisation" can be decomposed into five business processes BP2.1 "Interaction with Brokers", BP2.2 "Interaction with Customers", BP2.3 "Plan and Control Vehicles", BP2.4 "Vehicle Parking" and BP2.5 "Customer Support Management". Key aspects of integration of these business processes with each other and with other domain processes associated with the non CIMOSA domains were then explicitly modelled in the interaction diagram created for DP2 (see Figure 5.3).

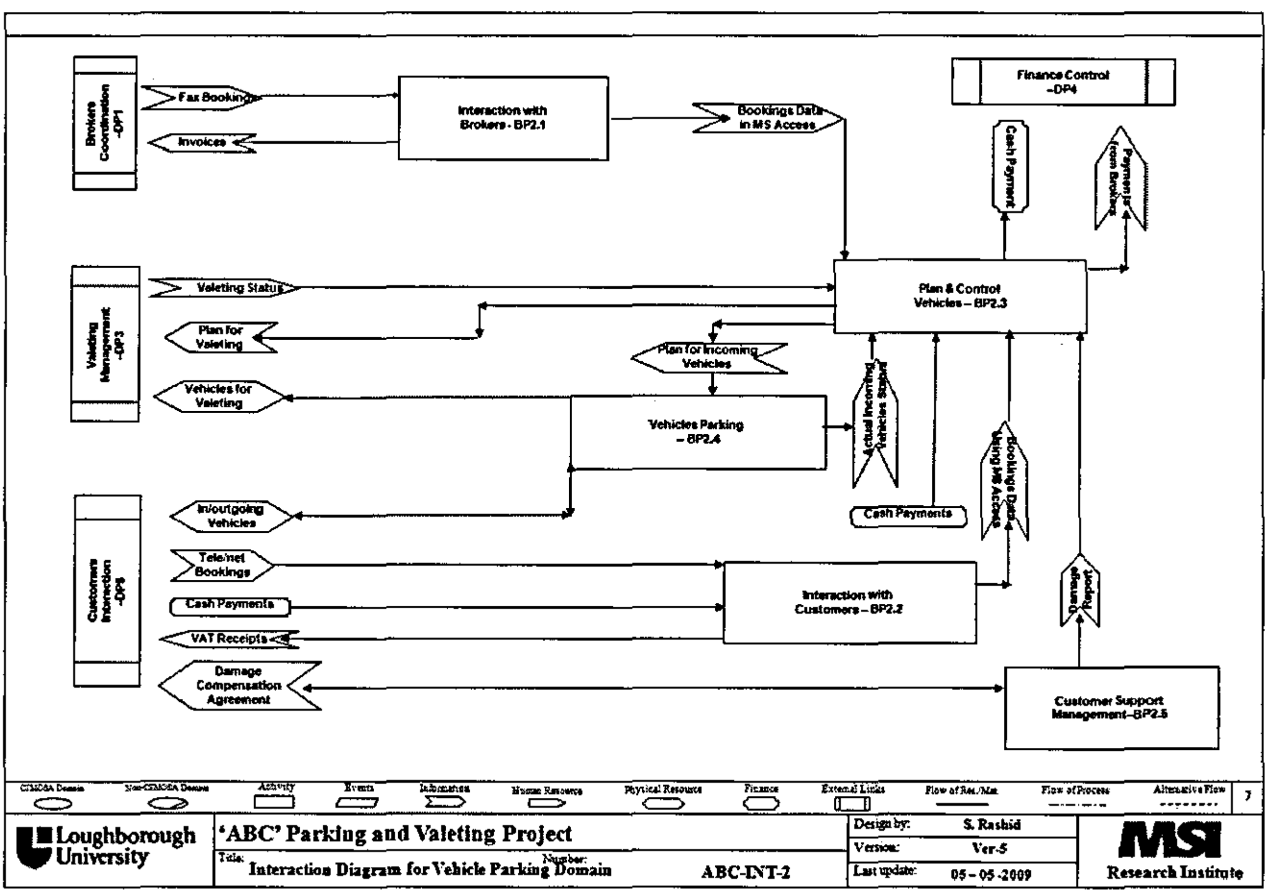

Figure 5.3 Interaction diagram for "Vehicle Parking" domain (DM2).

Figure 5.3 shows interactions between different internal and external domain processes and business processes in the ABC supply chain in terms of information, human, physical and financial resources. This provides a standard (applicable to almost all customers, brokers and services provided) way of viewing interactions, although the view provided is not dynamic but is essentially a static and structural view. During focused group interviews it was decided that some interactions were causing delays in forthcoming processes in the supply chain. For example, one important reason for delays in supply chain processes was information shortfall between "Brokers Coordination" (DP1) and "Interaction with Brokers" (BP2.1). The method for information exchange (as shown in figure 5.3) was through brokers by fax to ABC. It was highlighted by the focused group that in most cases either the booking information faxed to ABC had a shortfall (with less entries provided by customers than ABC would have preferred) and in some cases bookings were faxed after the arrival of customers to ABC. In some instances ABC lost faxed bookings which could not be totally ignored. Information related to this issue, along with information about some other issues related to human, physical and financial resources were subsequently recorded in the "Domain Table".

Structure diagrams were constructed to explicitly describe the structural decomposition of different domain processes into business processes and enterprise activities of a specific domain. This diagram presents business processes needed for realizing the objectives of the domain. The structure diagram for DP2 is presented in Figure 5.4.

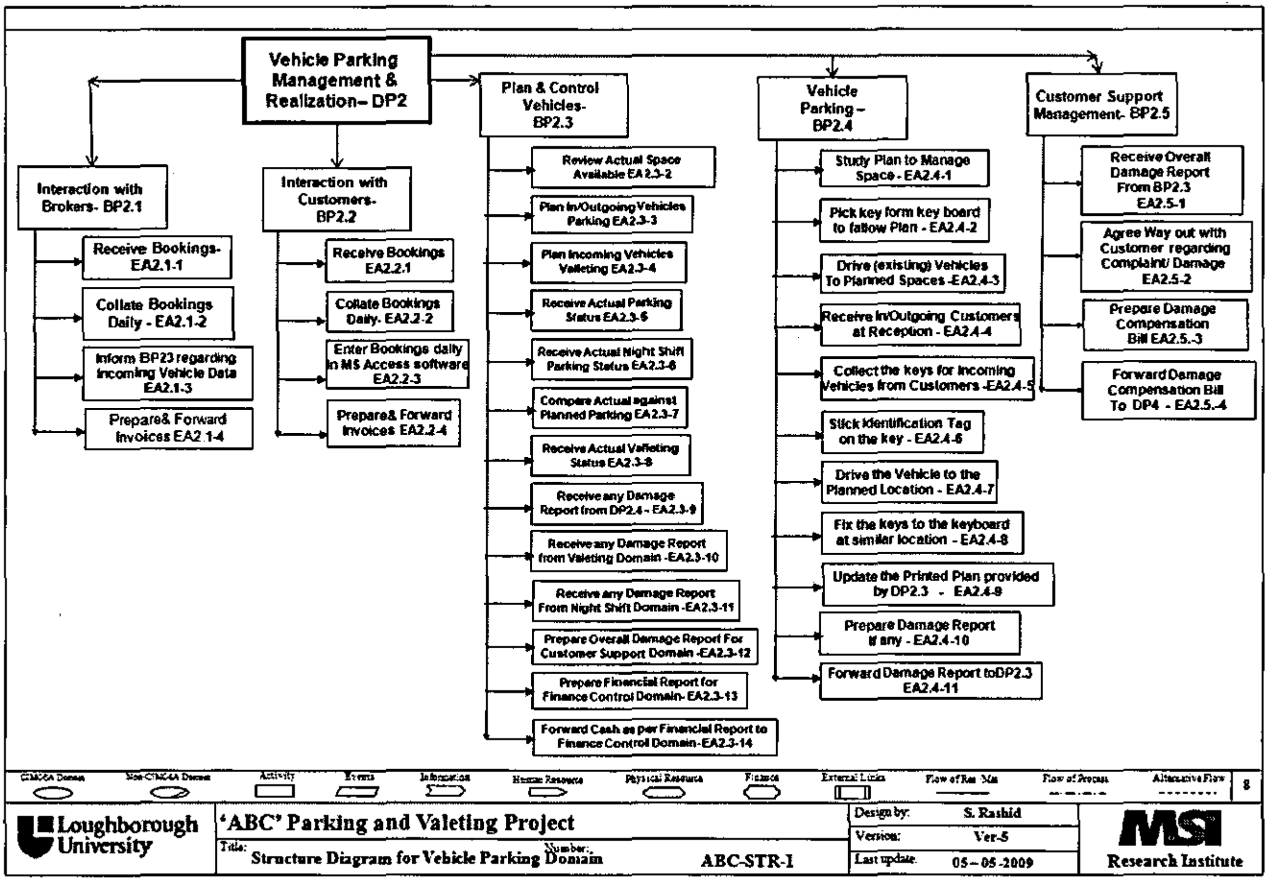

Figure 5.4 Structure diagram for ABC "Vehicle Parking" domain (DM2).

The figure 5.4 shows how DP2 was decomposed into BPs and their constituent EAs. To capture BPs included in the structure diagram for the DP2, initially specific process data which was captured through focused group interviews was used. The process data related to inclusive EAs were gathered through participant observations for the inclusive BPs. In the participant observations of actual processes, step by step activities were observed and recorded along with their specific time data. Where ever it was required, detailed questions were asked from the process owner (the participant) for clarification/verification.

The most detailed level of business process realisation is represented in the form of activity diagrams. Process information gathered to develop activity diagrams was through participant observations for the required BPs. Figures 5.5 and 5.6 represent activity diagrams for the ABC "Vehicle Parking" domain (DM2) which include the five business processes; BP2.1 "Interaction with Brokers", BP2.2 "Interaction with Customers", BP2.3 "Plan and Control Vehicles", BP2.4 "Vehicle Parking" and BP2.5 "Customer Support Management". These activity diagrams can be attributed with additional modelling constructs (not shown here for the sake of clarity) to detail interactions between enterprise activities and to explicitly describe the sequence of enterprise activities (and possibly precedence conditions that regulate the flow of activity execution), and the resources required to realise activity elements depicted by the activity diagram.

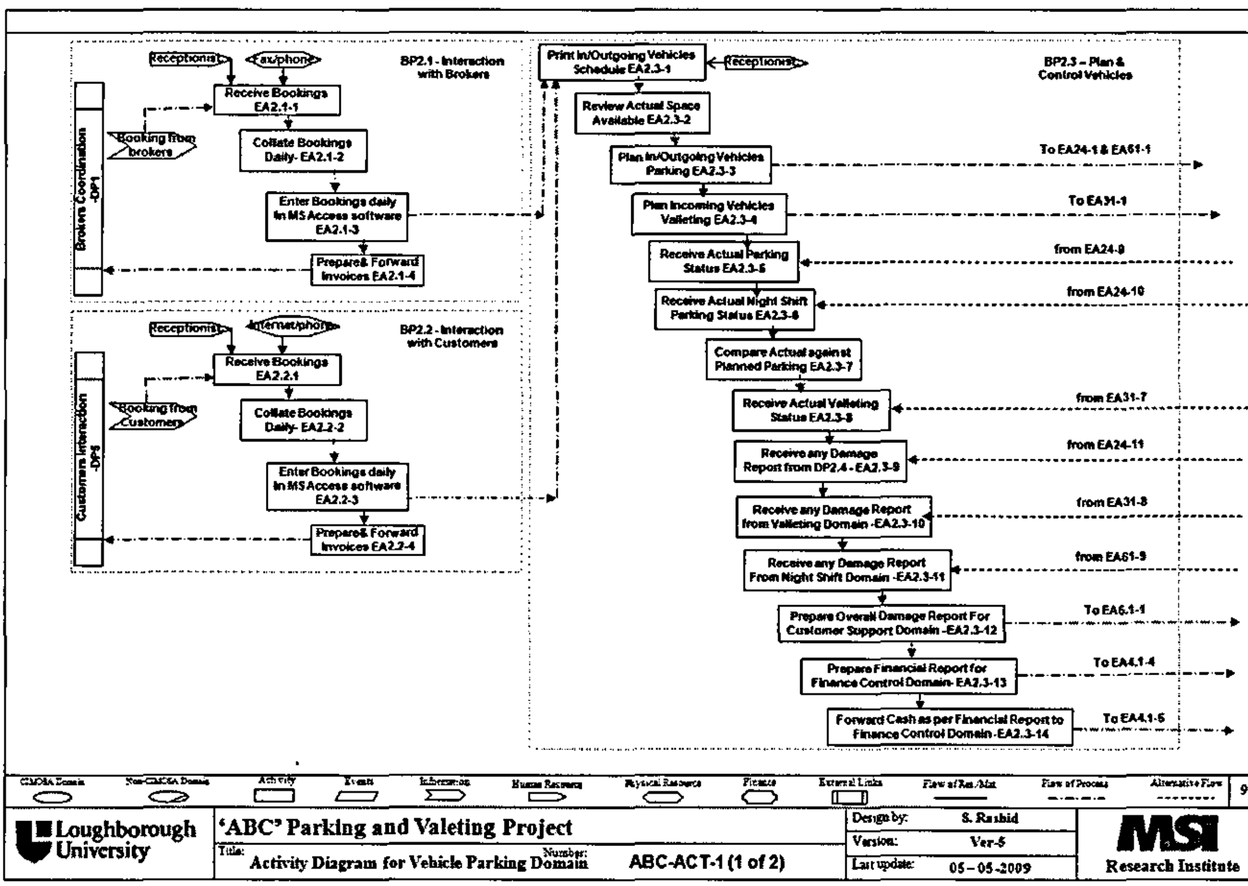

Figure 5.5 Activity diagram for ABC Parking domain (sheet 1 of 2).

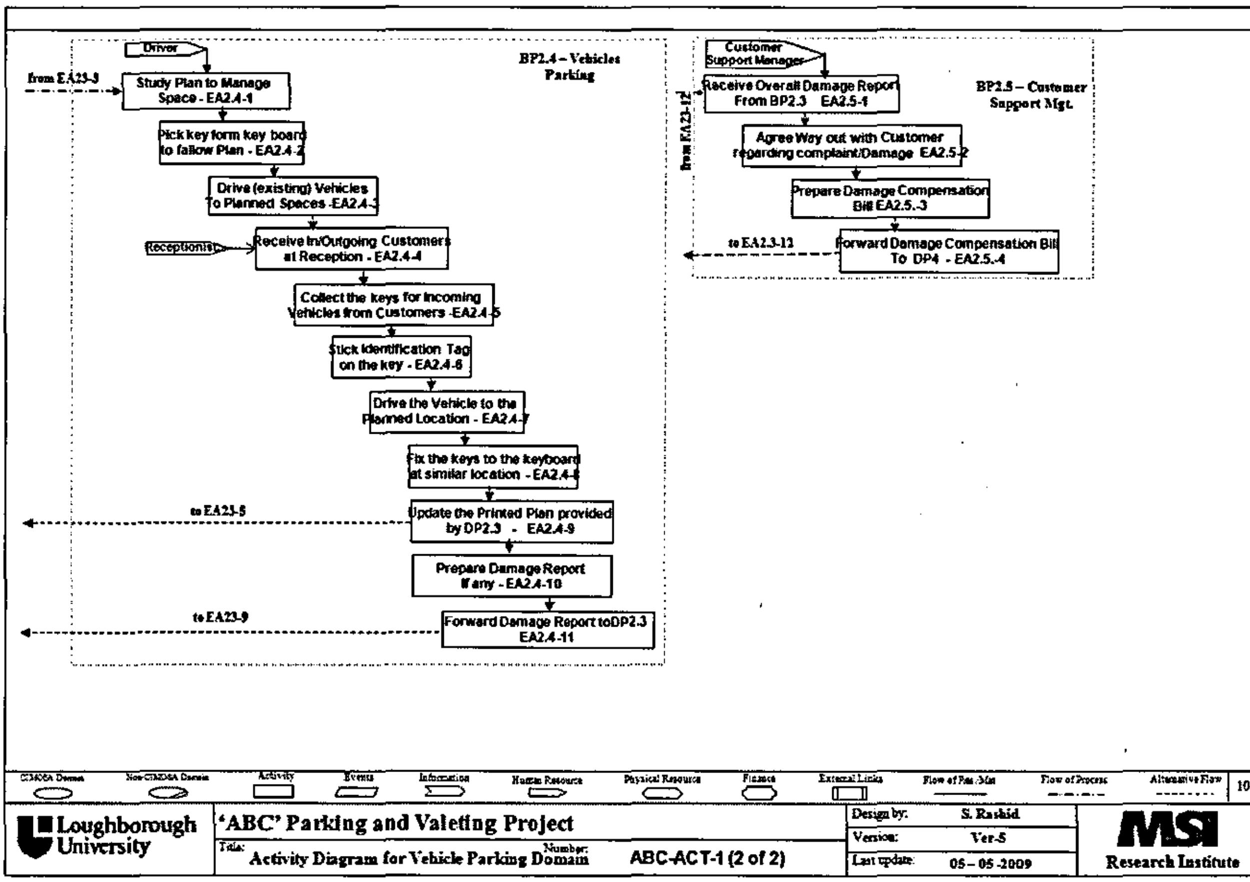

Figure 5.6 Activity diagram for ABC Parking domain (sheet 2 of 2).

The enterprise models of day to day parking and valeting operations of the ABC were created only to capture static relationships, i.e. relationships that did not change with time, (e.g., as new customers or brokers were added to the enterprise or as new instances of parking and valeting occurred) within the enterprise which were structural in nature in the sense that they were considered to be constant (or enduring) during the timeframe of modelling. Information gathered through the focused group interviews and the participant observations raised different issues which are also recorded into the domain table (as shown in table 5.1). One important issue discussed is about training shortfall for the fulfilment of the customer's vehicle pick up or drop off process at the ABC reception. From figure 5.6 the related enterprise activities are "Receive In/Out going customers at reception" (EA2.4.4), "Collect the keys for incoming vehicles from customers" (EA2.4.5), "Stick identification tag on the key" (EA2.4.6), "Drive the vehicle to the planned location" (EA2.4.7), "Fix the key to the keyboard at similar location" (EA2.4.8) and

"Update the printed plan provided by BP2.3" (EA2.4.9). Having created these enterprise models of ABC's related information, and physical, human and financial entities associated with DM2 derived from the focused group interviews and participant observations to associate ABC issues of concern to related BPs. Five BPs (BP2.1 "Interaction with Brokers", BP2.2 "Interaction with Customers", BP2.3 "Plan and Control Vehicles", BP2.4 "Vehicle Parking" and BP2.5 "Customer Support Management") related to DM2 are tabulated in a column in the developed domain table (see table 5.1), while for each BP issues are classified under the four entities (information, physical, human and finance).

Table 5-1 Domain table for CIMOSA conformant domain DM2.

Domain Table for CIMOSA-Conformant Domain(s) - DM2						
DPs and BPs		*Domain issues related to Enterprise Modelling Entities*				
		Information	*Physical*	*Human*	*Financial*
DP2	*Interaction with Brokers – BP2.1*	Delays in sending faxed bookings from brokers (in 20-25% cases) [EA 2.1.1]	-	Receptionist not trained for manually uploading faxed bookings data in data base of ABC [EA2.1.1, EA2.1.2, EA2.1.3]	Delays in sending invoices to brokers [EA2.1.1, EA2.1.2, EA2.1.3]
	Interaction with customers – BP2.2	Incomplete/in correct customers booking information [EA2.2.1]	-	Untrained receptionist performing customer telephonic bookings and upload bookings [EA2.2.1, EA2.2.2, EA2.2.3]	VAT receipts not ready [EA2.2.4]
	Plan and control vehicles – BP2.3	Inappropriate planning techniques for in/outgoing vehicles [EA2.3.1 to EA2.3.8]	-	Un skilled receptionist related to using planning and control techniques [EA2.3.1 to EA2.3.8]	Inappropriate method of cash transfer to finance control domain [EA2.3.4, EA2.3.5]
	Vehicle parking – BP2.4	-	Vehicle damage during parking [EA2.4.3]	i) Untrained receptionist for customers check in at reception office [EA2.4.4 to EA2.4.9] ii) Careless driving during vehicle parking [EA2.4.3, EA2.4.7]	-
	Customer support management – BP2.5	Inappropriate method to sought out damage compensation [EA2.5.1 to EA2.5.4]	-	-	-

For the current case study, two important process segments of ABC's enterprise model were selected for detailed consideration. Both of these issues were considered by ABC knowledge holders/managers to have a significant impact on supply chain performance. These issues were briefly discussed during discussion about the top level interaction diagram (figure 5.3) and the activity diagram shown in figure 5.6. These issues are:

i) Interaction with Brokers (BP2.1): Issues related to the information perspective of BP2.1 were important to consider here. That refers to activity EA2.1.1 "Receive bookings" by ABC from its brokers (see figures 5.3 & 5.6). In 20 to 25% cases, the bookings are not sent to ABC in a timely way by its brokers which causes problem in customer checking in at ABC reception.

ii) Vehicle Physical Parking & Control (BP2.4): Issues related to the human perspective of BP2.4 were observed to be important to consider here. That refers to activities EA2.4.4 "Receive in/outgoing customers at reception, EA2.4.5 "Collect the keys for incoming vehicles from customers, EA2.4.6 "Stick identification tag to the key", EA2.4.7 "Drive the vehicle to the planned location", EA2.4.8 "Fix the key to the keyboard at similar location" and EA2.4.9 "Update the printed plan provided by BP2.3" (see figure 5.6). This customer check-in process needed a properly trained receptionist especially at times when customer data is not available in the data base. In such situations the receptionists are required to call the relevant broker and confirm whether the customer waiting to dropping off the vehicle was actually sent by the broker to ABC. This short fall of information caused delays in the check in process and if receptionists were not trained it would take too long to sort out the matter and that resulted in poor customer service at reception. So in that case a good performance outcome of supply chain was not met.

The developed EM of ABC helped to understand, document and represent the supply chain processes from different perspectives namely information, physical, finance and human and at different levels of abstraction by using context diagram, interaction diagrams, structure diagram and activity diagrams. Thereby the EM helped to identify different issues and constraints of the ABC domain under observation. The issues related to CIMOSA processes or activities are formally classified and presented under information, physical, human and finance entities using the domain table presented in table 5.1. As the EM is a static modelling technique it is not capable of handling and analyzing the actual running (i.e. time-based dynamics) of enterprise systems. To address this deficiency, causal loop diagramming and simulation modelling was deployed. Causal loop diagrams can be used to explore, model and analyse dynamic aspects of workflows through supply systems, related to issues of concern to the enterprise. In the case of ABC, it was necessary to determine what causal relationships between work and system variables should be modelled. To facilitate and document this process the domain table was used (see table 5-1). In this case study 13 issues were identified for ABC but the remainder of this case study will only describe how causal loops and simulation models were developed for two main issues of concern of ABC supply chain; which were prioritised by the enterprise models of the ABC discussed already in this section.

5.3 Causal Loop Diagramming (CLD)

Enterprise modelling identified two important issues which were understood to have a significant effect on the performance of the ABC supply chain, namely: a) information shortfall at ABC's database on broker customer's bookings and b) untrained receptionist, at the reception office of ABC. Causal loop diagramming was used to seek structures of the system that give rise to good and bad behaviours related to these two issues. Here causal loop diagramming was designed to find different causal variables, feedback loops and mental models related to those issues.

To graphically represent and explain dynamic impacts associated with ABC problem areas, causal loop diagrams were constructed. The focus of concern for causal loop modelling was initially the issue of broker customer booking information short fall. The causal loop diagram shown in figure 5.7 was created based on the information and understanding conceived during focused group interviews and participant observations. This involved the identification of cause and effect relationships leading to growth or decay in variables and resultant loops, as identified via the signing of relationships and propagated impacts of causal relationships within closed loops. In figure 5.8 some links have a positive (+) sign while others have negative (-) signs. The positive (+) link means that if the value of a causal variable increases the result is an increase in the affected variable. The purpose of these signs (positive (+) and negative (-)) is to mark whether the causal loop is reinforcing or balancing. If there is no negative (-) link or even number of negative (-) links in a loop then it is a reinforcing loop as identified by "R". If there are odd numbers of negative (-) links in a loop then it is a balancing loop identified by "B". Reinforcing loops reinforce any induced change in a closed loop while a balancing loop opposes change. In figure 5.7, both loops identified are reinforcing loops, namely R1 and R2. The central issue of information shortfall at the ABC reception is defined as the difference between the required information at ABC and that information provided by brokers related to incoming customers booking details. This information was required at check-in when customers arrive at ABC to drop off their vehicles. The link polarity assigned to the link between "Information shortfall at ABC reception" and "Customer check-in time" is in such a way that if the information shortfall increased, it results in an increase in the customer check-in time and vice versa. So a positive (+) sign was assigned to the link. Similarly link polarities were assigned to all the links.

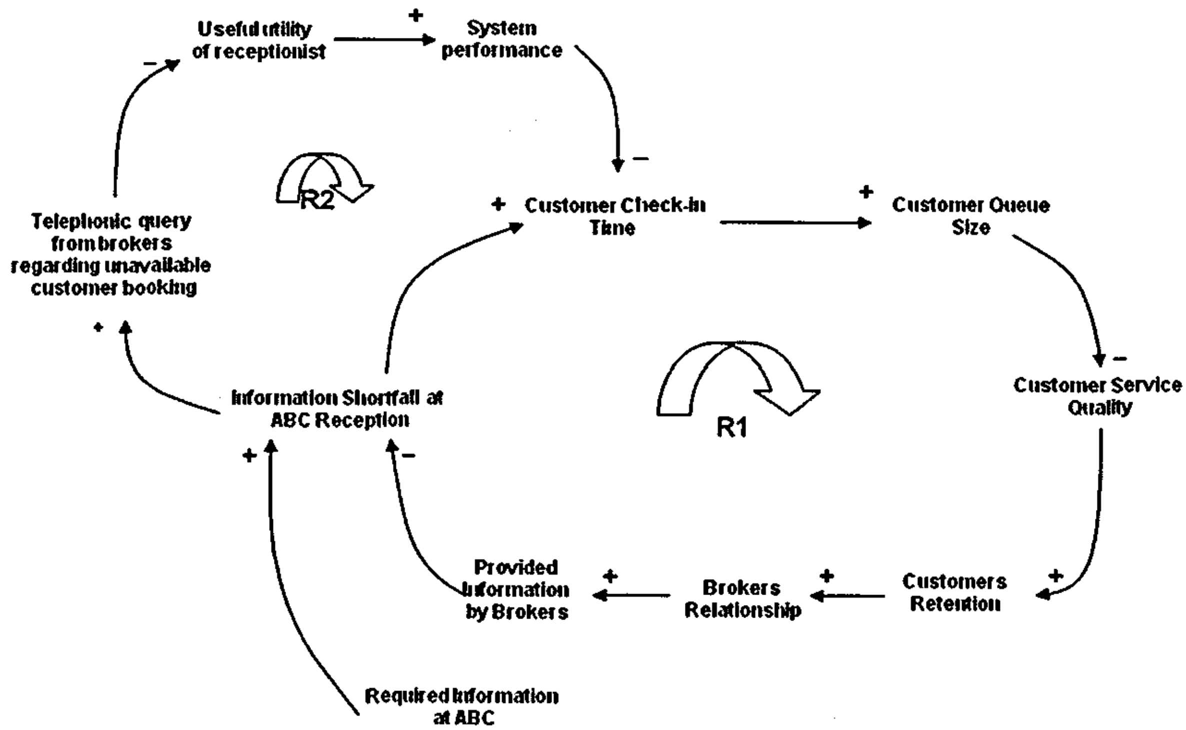

Figure 5.7 Causal Loop Diagram to show the Effect of Information shortfall at ABC.

In figure 5.8, it can be observed that R1 has two negative (-) links; this being an even number means that an induced change is reinforced. R2 has four negative (-) links which is also an even number, hence changes in this loop are also reinforced. To understand loop R1, a case of step increase in information shortfall at the ABC reception can be considered. The effect on the next causal variable (customer check-in time) would be an increase because of the positive (+) link polarity assigned to "customer check-in time". The same trend of an increase in "customer check-in-time" will increase the customer queue size; also because of a positive (+) sign linking the variables. But the negative (-) polarity between the "customer queue size" and the "customer service quality" reverses the situation. Here an increase in the "customer queue size" will lead to a decrease in "customer service quality". Again there is a positive (-) link polarity between "customer service quality" and "customer retention". In this case a decrease in "customer service quality" would decrease "customer retention". In the same way decrease in the "customer retention" would decrease the "broker relationship" which would decrease "information provided by brokers" and it would further increase the "information shortfall at ABC reception" due to a negative (-) polarity between the last two variables. The important point to note is that we started with a condition that in the loop R1, if the "information shortfall at ABC reception" is increased from its current state then loop R1 will result in further increase in "information shortfall at ABC reception". This shows that in this reinforcing loop the change reinforces.

The other reinforcing feedback loop R2 was constructed to explore the effect of information shortfall at ABC on useful utilization of receptionist and supply chain performance. This causal loop diagram (see figure 5.8) shows that an increase in "information shortfall in ABC" would increase "telephonic queries" from brokers which would decrease the "useful utilization of receptionists" and so decrease the "system performance". A decrease in "system performance" would increase the "customer check in time" and in the same way as R1 the loop would end by a further increase in "information shortfall at ABC". As the current issue of information short fall is an unlikely situation which is reinforced by reinforcing feedback loops while balancing feed back loop(s) can counter the situation. Therefore structure of the R1 and R2 causal loops was used to explore possible dynamic behaviours following an increase in information shortfall, where it was generalised that "if the causal variable representing the issue to be observed defines a likely situation then more reinforcing causal loops are needed and less balancing causal loops are required. While if the causal variable representing the issue to be observed defines an unlikely situation then more balancing causal loops are needed and less reinforcing causal loops are required".

Consider further the second issue of an untrained receptionist working at the reception office of ABC. The causal loop diagram for this issue is shown in figure 5.8. Training shortfall was considered as the difference between the required trained man power working at ABC reception and the available trained man power at ABC. This trained man power is required to provide a required level of customer service which was needed to improve ABC's supply chain performance.

Figure 5.8 has two reinforcing feedback loops i.e., R3 which identifies effects of training shortfall and R4 which can help to explore the effect of training shortfall at ABC on useful utilization of receptionist and system performance. R3 shows that if there is an increase in training shortfall at ABC reception then this will result in an increased customer check in time at ABC's reception which would increase the customer queue size which would result in a decrease of customer service quality. A decrease in customer service would consequently increase the requirement for trained man power, which would increase the training shortfall at ABC's reception.

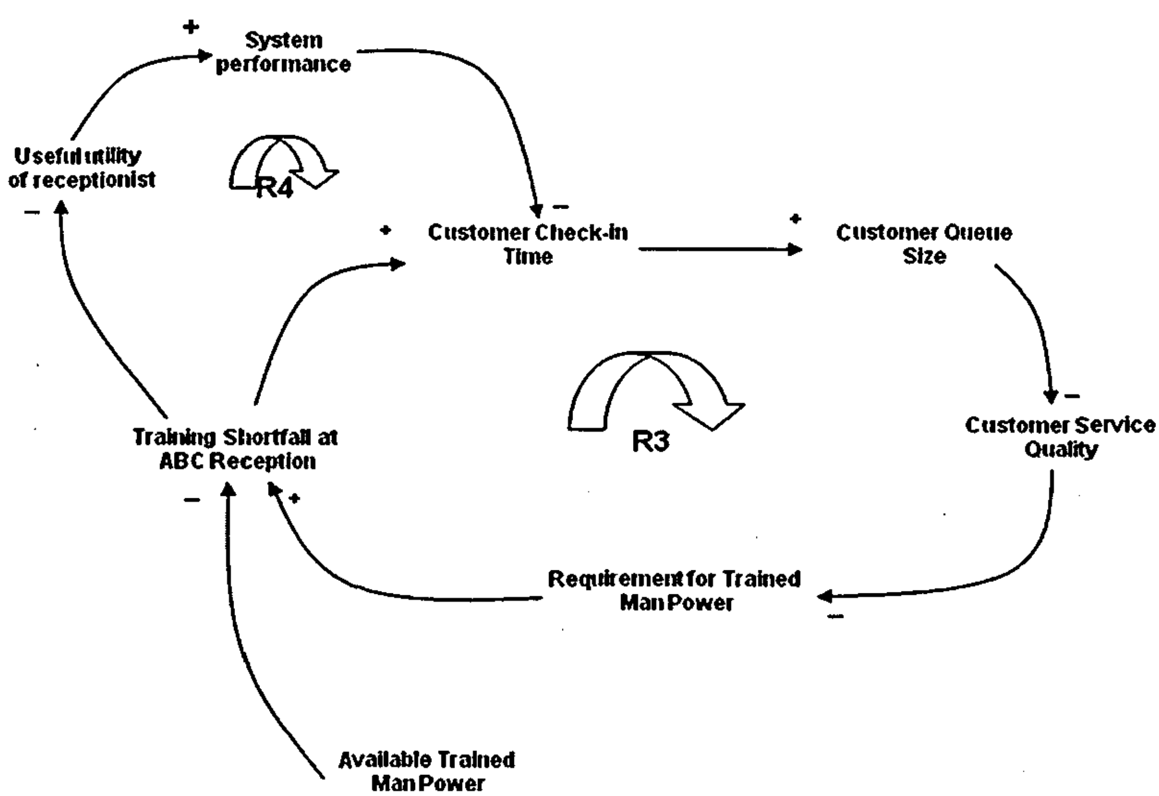

Figure 5.8 Causal loop diagram to show the effect of training shortfall at ABC reception.

The other reinforcing feedback loop, R4 was constructed to explore effects of training shortfall at ABC on useful utilization of receptionist and system performance. The causal loop diagram showed that an increase in training shortfall at ABC would decrease the useful utilization of receptionists and so decreased the system performance. A decrease in system performance would increase the customer check in time and, in the same way as R3, the loop would end by a further increase in training shortfall at ABC.

Having considered cause and effect relationships presented by the causal loop diagrams (figures 5.7 and 5.8), key effects of information and training shortfall at ABC reception were summarised by table 5.2. The selection of key effects was done on the basis of variables which were known performance indicators for the supply chain under observation and could be objectively quantified using simulation modelling. For instance, customer queue time, customer queue size and useful utilization of receptionists are three important performance indicators for the supply chain of ABC at its reception with issues of information and training shortfalls.

Table 5-2 Cause and effect table for information and training shortfall at ABC.

Supply Chain Issues / **Supply Chain Performance Indicators**	**Increase in Information Shortfall at the ABC**	**Increase in Training shortfall at the ABC**
Customer Queue time	Increase	Increase
Customer Queue Size	Increase	Increase
Useful Utilization of Receptionist	Decrease	Decrease

It was concluded that the causal loop diagrams usefully explored dynamic effects related to the issues under consideration and also identified relationship polarity among issues and their related effects. The explored dynamic effects were used to define supply chain performance indicators, as shown in Table 5.2. Used on their own however, causal loop diagrams cannot quantify numerically the dynamic effects related to selected problem issues identified for ABC. Dynamic effects related to the selected issues, for which causal loop diagrams were constructed, needed to be quantified in numeric terms and hence these were the performance variables for simulation modelling.

5.4 Simulation Modelling (SM)

Simulation modelling was used to quantify the impacts of ABC's supply chain behaviours on chosen performance indicators; where these indicators relate to the selected problem issues of information and training shortfall in the ABC's supply chain. Key effects deduced from the causal loop diagrams are arranged in table 5.2 with respect to key supply chain performance variables the time-based behaviours of which needed to be quantified by simulation modelling. A simulation model for ABC which was related to the issues under observation was developed using understandings and data previously coded by ABC's EM and its associated causal loop diagrams. The process structure of the simulation model was developed to conform with CIMOSA based diagrams especially its interaction diagrams and activity diagrams (see figures 5.2, 5.5 and 5.6). Process dynamics data was also collected during visits to ABC for understanding the system and developing enterprise models. That data included historical cases/records and/or estimates of: a) customers inter arrivals times, b) queuing rules, c) processing times (estimated) for different work entities (customers orders), and d) priority rules among different work entities. Causal loop diagrams (CLD) explored some causal effects related to such issues and their simulated impacts were then quantified via experiments performed using the simulation model of ABC (see figure 5.9).

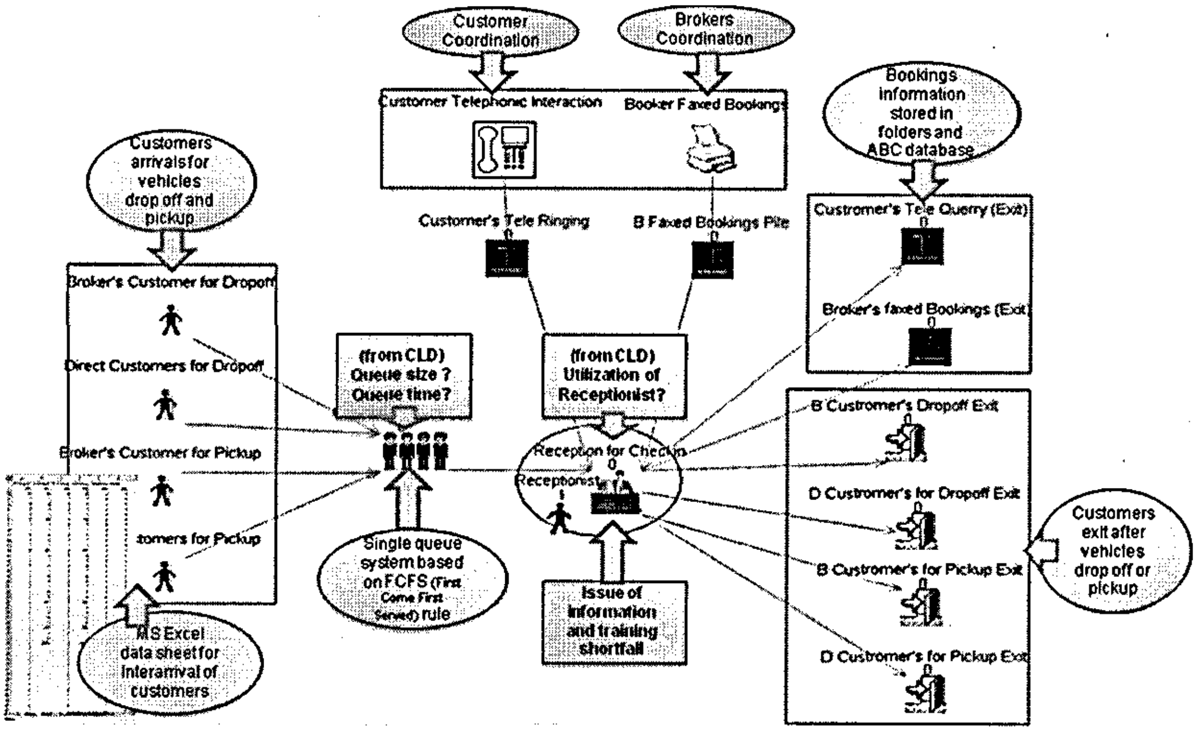

Figure 5.9 Simulation model of ABC supply chain issues.

Discrete event simulation (DES) was used for simulation modelling because of its ability to simulate precisely the time based system behaviour for the small process segment under observation. The DES tool used for simulation modelling was SIMUL8®. To populate the model with ABC data and rules, it was necessary to replicate real working conditions of ABC. Using modelling constructs provided by SIMUL8®, dynamic properties of selected activities were coded. In this case EA2.1.1 and EA2.4.4 to EA2.4.9 were the selected activities which were related to the observed issues of information and training shortfall. The selected activities were then modelled by a computer executable graphical model in the form shown by figure 5.9. Actual dynamic data was used directly in the simulation model by inputting most of that data via an MS Excel sheet. Also different visual logics were applied to characterise, and therefore replicate during model execution, the work flows through ABC's supply chain.

A key assumption made in the case of ABC was that simplification of work flows needed to be made by averaging limited available data. In the case of ABC the time to perform customers service activities at the reception desk were assumed to have a fixed value which was decided on the basis of time observations of the real system to perform those jobs and then averaging to yield a suitable value.

Simulation model validation, related to the assumption made and the designed structure of the simulation model, was carried out in three steps. Firstly the supply chain simulation model was checked thoroughly for each and every entity, to see whether it replicates the different rules and conditions of the real system of ABC. Secondly relevant officials performing jobs in the modelled system were consulted, like in this case ABC's receptionists were consulted to verify that the As-Is simulation model replicates real system behaviours. To adhere to this the model was run at slow speeds for some specific time to show the behaviour of work movement through the different entities of the system with respect to time. Results obtained from the model were similar to the real system behaviour, so it was assumed that the model was verified. Thirdly an important approach was to populate the model with historical data about ABC work flows through the system for which performance outcomes are already known and to test if the simulation results correspond to the real results. Results of the real system and model were found to align; hence it was considered that the simulation model was validated.

The validated simulation model of ABC's supply chain was then used to undertake an analysis of prime concerns to ABC i.e., information and training short fall at ABC reception. Related to the information short fall issue for an average of 23% of customers sent by brokers to drop off their vehicle (i.e., 39 out of 170), when they arrived at reception, it was found that data had not yet been faxed to ABC from the broker. It was estimated that 50% extra processing time was needed by the receptionists; because first they must call the relevant broker in order to reconfirm that the customer was in fact sent to ABC rather than to some other parking facility in the vicinity. Once that fact is confirmed then the customer is checked in. Related to the issue of training short fall ABC has observed that the training of its human resource is problem some and the untrained staff take approximately 30% extra time to perform reception activities as compared to a trained receptionist. So testing both situations is carried out by using the validated simulation model to simulate time-based behaviours of supply chain performance parameters identified by causal loop diagrams; like average customers queue sizes, customers queue times and the utilization of the receptionist. The customers' inter-arrival data to ABC reception to drop off and pick up their vehicle was collected in the form of an MS Excel sheet. The data used is presented in figure 5.10.

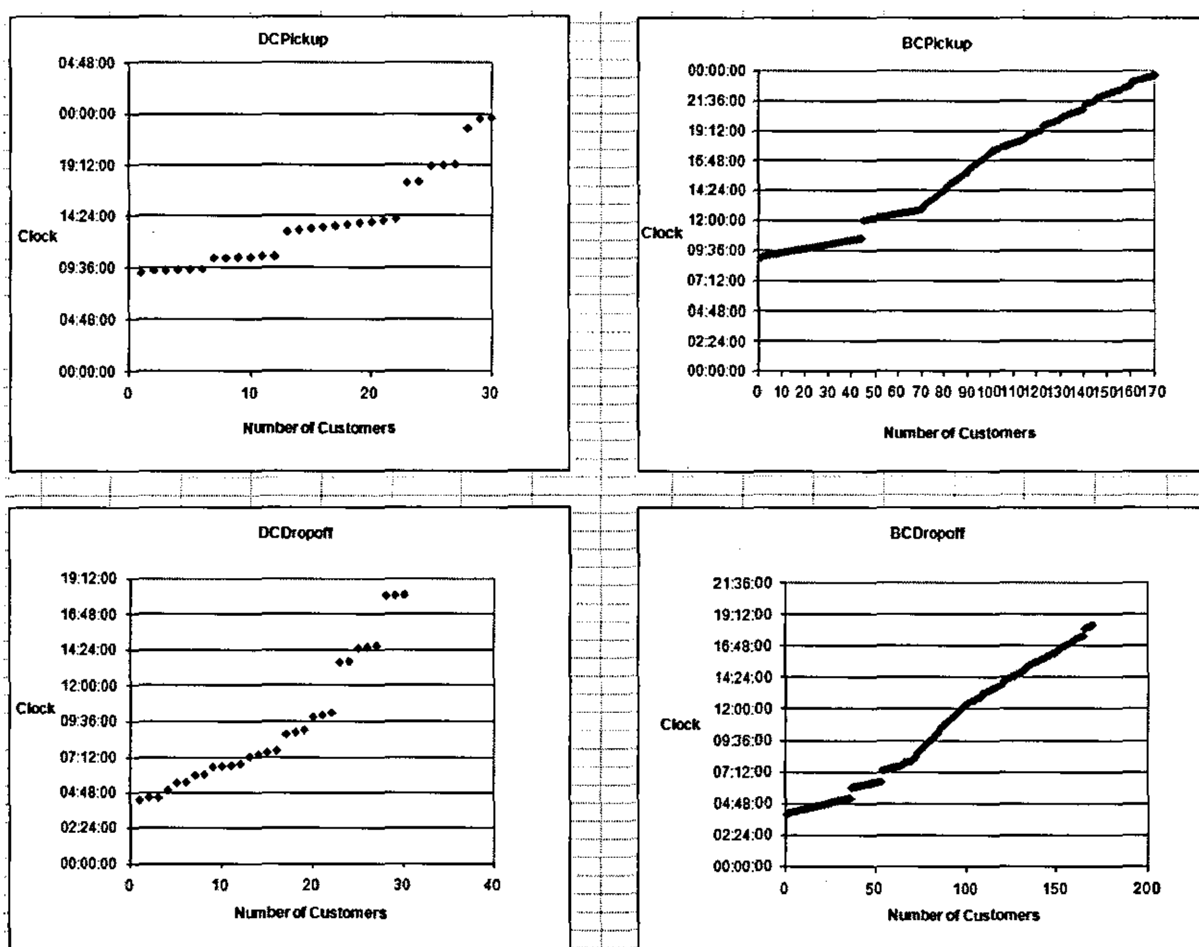

Figure 5.10 Customers arrival data at reception of ABC.

The data is an averaged representation of inter arrivals of customers to the reception of ABC during 24 hours of a working day. The arriving customers can be classified into four different classes based on the purpose of customer arrival (either drop off or pick up vehicle) and source of customer to ABC (either direct customers to ABC or from brokers). The average daily customer arrivals to drop off their vehicle is 200 customers out of which 170 customers were brokers related customers and 30 were direct customers while same was the number of customers coming to pick-up their vehicles daily, on average for both the classes From this data shown in figure 5.10, it was observed that a large gap occurs in arrivals of customers in the start of working day which is after 12am mid night up to early morning while later on there was a steady arrival of customer throughout the day till the end of working day which was up to 12 am mid night. The results collected from the simulation experiment are shown in table 5.3. •

Table 5-3 Result of information shortfall and training short fall ABC reception.

Supply Chain Performance Indicators \ Supply Chain Issues		Information shortfall at ABC (a)	Training shortfall at ABC (b)	Cumulative effect of (a) and (b)	System without issues (a) and (b)
Process time at reception (minutes)	DC drop off	2.00	2.60	2.60	2.00
	BC drop off	2.23	2.60	3.38	2.00
	DC pick up	1.00	1.30	1.30	1.00
	BC pick up	1.00	1.30	1.30	1.00
Max. Customer queue time (minutes)		20.82	37.00	63.52	13.00
Max. Customer queue size (numbers)		10.00	15.00	20.00	7.00
Average utilization of receptionist (percentage)		44.38	54.17	63.38	41.67
Max. utilization of receptionist (percentage)		1.00	1.00	1.00	1.00

DC Direct Customer,
BC Broker Customer

The results presented in table 5.3 show that in the ABC supply chain, both the issues of information short fall and training shortfall were very significantly increasing customer waiting times (and thereby customer queue sizes) although at the same time receptionists became relatively more busy. Both of these issues lead to a decrease in the performance of ABCs supply chain in terms of both increased waiting time in the queue and decreased useful utilization of the receptionist at the ABC reception. The simulation model helped to predict the supply chain performance in worst case scenarios when both the issues happen at once, i.e. in the presence of an untrained receptionist when broker related customers drop off their vehicle and for whom data is not available in the database so that the receptionist has to call back to brokers for reconfirmation of their bookings. Results of this situation represent an unbearable scenario for customers of ABC; in terms of them waiting for long times in queues at ABC reception.

To avoid such a worse case situation in the supply chain of ABC, some improvements were suggested and there benefits were quantified and compared in terms of the same supply chain performance indicators, namely: customers queue time, customers queue size and useful utilization of the receptionist. The results of this scenario are presented in the next section of this chapter (section 5.5).

5.5 Improvement suggestions for ABC's supply chain

Following are the suggestions deduced by the author from experience of using the proposed integrated methodology for the analytical design of supply chain to analyse ABC's supply chain.

i. Daily comparison/tally of faxed bookings with the brokers, which can minimise probability of information shortfall between the ABC and its brokers;

ii. Common/shared customer bookings data base between the ABC and its brokers, which can overcome the problem of information shortfall at the ABC;

iii. Man power training at ABC reception, which can lead to a better customer service at the ABC reception due to a decrease in customer waiting time in a queue and hence it improve supply chain performance;

iv. Redesign supply chain to achieve decreased customer waiting times, and increased utilization of resources (human and equipment) at ABC's reception. In this regard, different scenarios can be developed and tested. For example instead of an existing single queue system with a first-come-first-serve (FCFS) dispatching rule at ABC's reception, a two queue system can be tested especially for peak service hours.

All of the above suggestions needed further research work to conduct a feasibility study to quantify benefits of each of the suggestions and to analyse the total cost of their implementation.

5.6 Usefulness of the proposed integrated methodology for the analytical design of supply chain for the ABC

In the ABC case study the integrated methodology for the analytical design of complex supply chains was tested and much of the characteristic functionality of the proposed methodology was verified as being (1) purposeful, (2) viable and (3) providing an enhanced basis for quantitative and qualitative analysis, relative to other supply chain methodologies published in the research literature.

For instance, the CIMOSA based MSI EM templates have successfully represented, described and graphically documented big picture of the ABC processes from a supply chain view point. The developed models captured and graphically presented different important perspectives about supply chains, like needed transfers of information, physical, finance and human resource. This alone can help stakeholders to better understand ME needs and to position their own role relative to others. Also the EM identified some issues, bottlenecks and potential improvements in ABC's supply chain. The identified issues, bottlenecks and potential improvements were arranged in a structured way in the domain table; i.e. in four categories, namely information, physical, finance and human.

Causal loop diagrams were created for a couple of selected problem issues, namely information shortfall and training shortfall at ABC's reception. The causal loop diagrams explored system dynamics associated with the selected issues. Also causal loop diagrams usefully analysed qualitatively dynamic behaviour of the system associated with the selected issues in case of any uncertainty or change introduced to the system. Furthermore, the causal loop diagrams helped in the identification of supply chain key performance indicators (KPI's) for the selected issues.

Also simulation modelling was performed which supported a quantitative analysis of dynamic behaviours of the supply system associated with the selected issues. The simulation results were presented in a manner which can be communicated to ABC stakeholders, using the selected supply chain KPI's.

Based on above discussion about the usefulness of the integrated methodology in the ABC case study, a table is presented below (see Table 5.4).

Table 5-4 Performance of the integrated methodology in case of the ABC enterprise and its supply chain

What is expected	Use of the proposed Integrated Methodology	Benefits
• graphically represent and explicitly describe key characteristic properties of the selected complex supply chain.	Enterprise Modelling is used to create Enterprise model of ABC	The enterprise model resents supply chain processes and described key characteristic properties of the selected supply chain
	A domain table is created for selected CIMOSA conformant domain of ABCs supply chain	The domain table created for a CIMOSA conformant domain DP2 explicitly shows the characteristic properties and issues of ABCs supply chain for DP2
• analytically explore dynamic properties of a couple of important issue of the selected complex supply chain, so as to provide analytic means of reasoning about impacts of uncertainty in the complex supply chain associated with the selected issues.	Causal Loop Diagramming is used to explore dynamic properties of a couple of important issues of ABCs supply chain	A couple of causal loop diagrams are created for two supply chain issues namely information shortfall and training shortfall at ABC reception. Both the causal loop diagrams explored dynamic properties of the selected supply chain issues. These diagram are also used as a basis for qualitative analysis of supply chain. Also causal loop diagrams help defining key performance indicators for supply chain associated with the two selected issues.
• predict possible futures of the selected complex supply chain in response to a couple of selected uncertainties that may arise.	Causal Loop Diagramming is used to explore dynamic properties of a couple of important issues of ABCs supply chain	
• quantify and predict behavioural aspects of the selected complex supply chains due to the observed impacts of uncertainties and to assess possible risks should potential uncertainties arise.	Simulation modelling is used to quantify impact of selected issues on the supply chain performance.	Simulation model for required segment of ABC supply chain is developed and validated. Simulation model helped to simulate impact of selected issues on supply chain performance and resulted in numerically quantified the KPIs.

Chapter 6: Enhancement of the integrated methodology for the analytical design of supply chains

The purpose of this chapter is to analyse the usefulness of the proposed integrated methodology for the analytical design of supply chains (M1) which was used in case study 1 (the case of a parking and valeting supply chain). An analysis of the weaknesses of M1 helped identify some general improvement potential in respect of (1) data collection and retention tool, used during enterprise modelling and (2) use of a suitable computer tool when drafting enterprise models. Both of these improvement potentials were addressed and an additional technique and tool was adopted to improve methodology M1, in regard to (1) and (2) respectively, prior to its use in case study 2. Also it was observed that case study 2 (the case of a Point of Purchase (POP) equipment manufacturing supply chain) involved significantly greater complexity than case study 1; this was because the case enterprise has to realise a high product variance across its multi product supply and value chains. Therefore to handle the increased complexity, a further improvement to M1 was deemed to be necessary; namely that an additional technique needed to be added into M1 to enable classification of products prior to the application of simulation modelling for the multi product flows through case company 2 and its supply chain. The introduction into M1 of a new product classification technique, plus the addition of an improved data collection and retention tool, and an enhanced drafting tool lead to the design and application of an enhanced integrated methodology for the analytical design of supply chains which is referred to as M2.

6.1 Usefulness of the Integrated Methodology for the Analytical Design of Supply Chains (M1) in respect of the ABC Parking and Valeting Case Study and some New Requirements

In the ABC case study, the methodology M1 was used and most of the designed characteristics of M1 were found to usefully provide the required functionalities. All four prime entities of M1 namely Enterprise Modelling (EM), the domain table, Causal Loop Diagramming (CLD), and Simulation Modelling (SM) worked successfully in a unified and designed way. For instance, use of the CIMOSA based MSI enterprise modelling (EM) templates successfully represented, described and graphically documented a big picture of ABC's supply chain from key perspectives namely information, physical, finance and human view points. Also the developed EM helped identify and eliminate prime problem issues, related bottlenecks and areas for potential improvement. The domain table populated with issues, bottlenecks and potential improvements became a central repository to document the issues associated with the four perspectives of ABC's supply chain. Causal loop diagrams usefully explored system dynamics associated with the problem issues selected for further analysis. Also causal loop diagrams helped to analyse qualitatively the dynamic behaviour of the supply chain system associated with the selected issues. Furthermore, the causal loop diagrams help in the identification of supply chain key performance parameters for the selected issues. Simulation modelling also proved to be useful, complementing the other prime elements, by analyzing quantitatively the dynamic behaviour of the supply chain system with particular emphasis on the selected problem issues. The simulation results were presented using key performance parameters for supply chain.

The case study 1 (case of the ABC parking and valeting supply chain) was simple yet provided a complete case of using and testing M1. 5 business processes (BPs) were modelled to capture the big picture of the process network required to fulfil customer's orders. However, the effort and time associated with collecting data to populate the enterprise modelling templates and to graphically presenting the models using a computer was rather high. For instance, it took more than 20 man-hours to collect the required process data. This is because there was no structured tool used to collect data and a plain piece of paper was used to record the data captured during the interviewing of relevant knowledge holders. Also the Microsoft Power Point computer software was used to graphically draft the enterprise model which consumed a lot of effort and time (more than 24 man-hours) to draft

5 BP's on the computer. Furthermore, the variety of work that the case 1 enterprise needed to fulfil to satisfy customer's service requirements was not very high with only four slightly different process variants being required at the reception of the ABC. All work types were dealt with suitably by creating a common enterprise model to represent the different process variant. Also simulation model development for the four types of work was straight forward and no formal technique was found to be necessary to classify the work types.

6.2 Requirements of Case Study 2: A Case of an Engineer to Order (ETO) Point of Purchase (POP) Equipment Manufacturing Enterprise

Case study 2 was started after completion of case study 1 and in the couple of introductory visits it became evident that case study 2 is a lot more complex than case study 1 due to the following reasons; ETO production in case 2 required the capture of 45 different business processes (BP's) to fulfil customer requirements. Furthermore these BPs needed to service more than 3 major business sectors, with 12 to 15 major customers, and to realise more than 50 different types of product for which basic raw materials and customised components necessitated co-coordinated supply by 700 raw materials and components suppliers (some located overseas). To cope with the significantly greater complexity of case study 2, an efficient tool was required to capture and retain process data quickly and completely in order to replace the plain paper and pen approach used in case study 1. Also needed was an ability to present graphically such a large number of business processes (45 BP's) as compare to 5 BP's in case study 1. Therefore a better tool was required compare to the use of MS Power Point software which took a lot of time and effort in EM creation for case study 1. Furthermore, to deal with the high product variance there was no functionality available in methodology M1. So a new technique was required to deal with the issue of high product variance.

6.3 Enhancement of the methodology M1

To fulfil the requirements described in section 6.1 and 6.2, some enhancements are proposed in M1. The proposed enhancements are shown in figure 6.1 using a hierarchical representation.

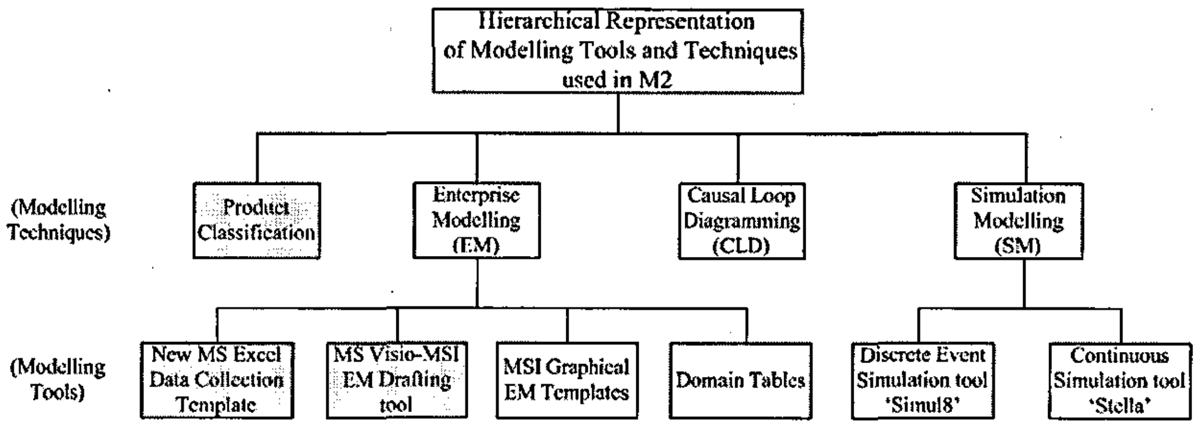

Figure 6.1 Enhancement in the methodology M1.

Figure 6.1 shows the enhancements proposed as highlighted boxes). This also shows that M2 is essentially M1 plus a new product classification technique, plus an MS Excel data collection template, plus an MS Visio-MSI drafting tool to support enterprise modelling.

The enhanced integrated methodology (M2) included all the concepts used in the methodology M1 namely enterprise modelling (EM), causal loop diagramming (CLD) and simulation modelling (SM) and domain table. Also M2 use the proposed technique of product classification. The integrated use of EM, CLD and SM in M2 is also the same as for M1. However, the proposed product classification is introduced to support the conceptual design of SMs by breaking down the complexity associated with the product variance that can arise in a multi product supply chain (see figure 6.2).

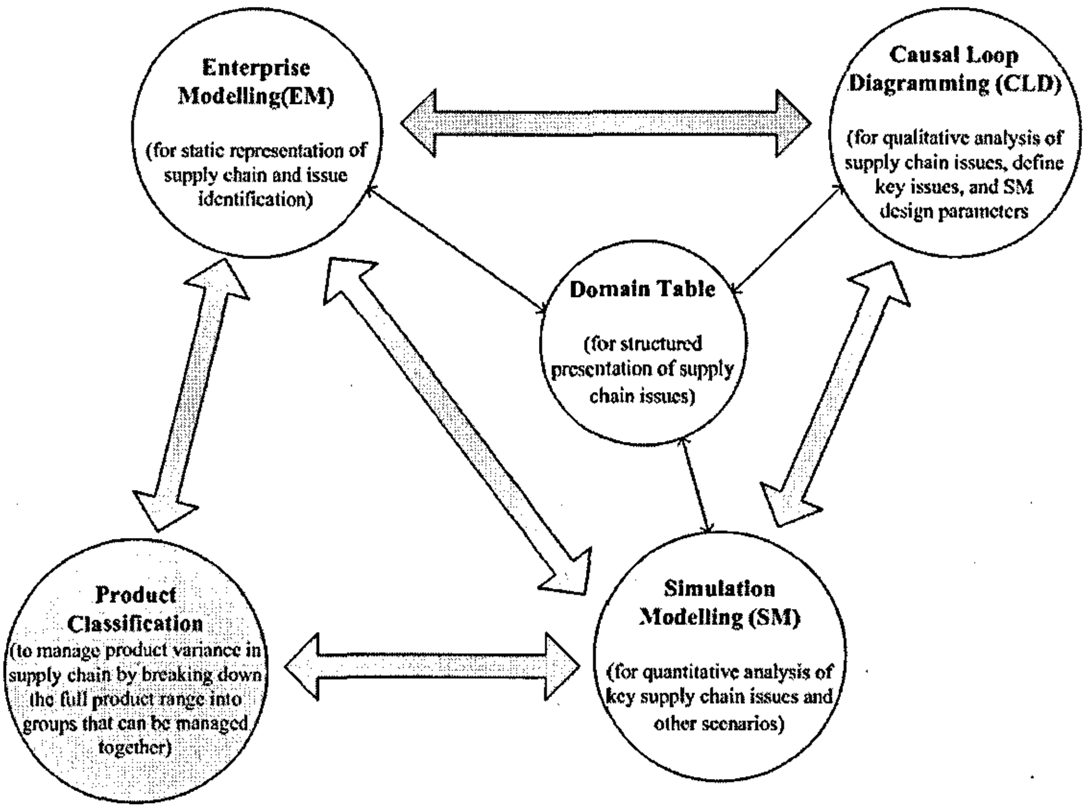

Figure 6.2 Concept of enhanced integrated methodology for analytical design of supply chain (M2).

In figure 6.2, the concept of enhanced integrated methodology for the analytical design of complex supply chains is presented. In comparison to M1, at the conceptual level there is only the addition of a product classification technique. The product classification technique was designed to support simulation modelling in terms of breaking down the complexity introduced by product variance. To perform the product classification, business processes information and data is required which is primarily derived from data captured during enterprise modelling.

Details off each of the proposed new entities are presented in following sub sections.

6.3.1 Product classification to manage product variance in supply chains

The creation of a product family is the 'breaking down of the full product range into groups that can be managed together, or share a significant part of a value stream'. The purpose of product classification in the context of this thesis is to support the analytical design of multi product supply chains. Product classification was designed and developed to complement use of the integrated methodology for the analytical design of supply chains (M1). The product classification should facilitate and complement the use of simulation modelling by managing a large number of required products in to a few product classes. It is then much easier to design simulation models and to construct feasible simulation experiments when there are a large number of product types to be realised by any subject ME. The selection of criteria to decide what should constitute a product class is very important so that the product classes identified can suitably support simulation modelling without the need for un acceptably high levels of approximation/simplification, which can distort the simulation results. For instance, if in the same product class high variation of products exist in terms of the criteria factors, the product class cannot be supportive to simulation modelling and it can give rise to inappropriate simulation results. The generic product classification is presented in figure 6.3.

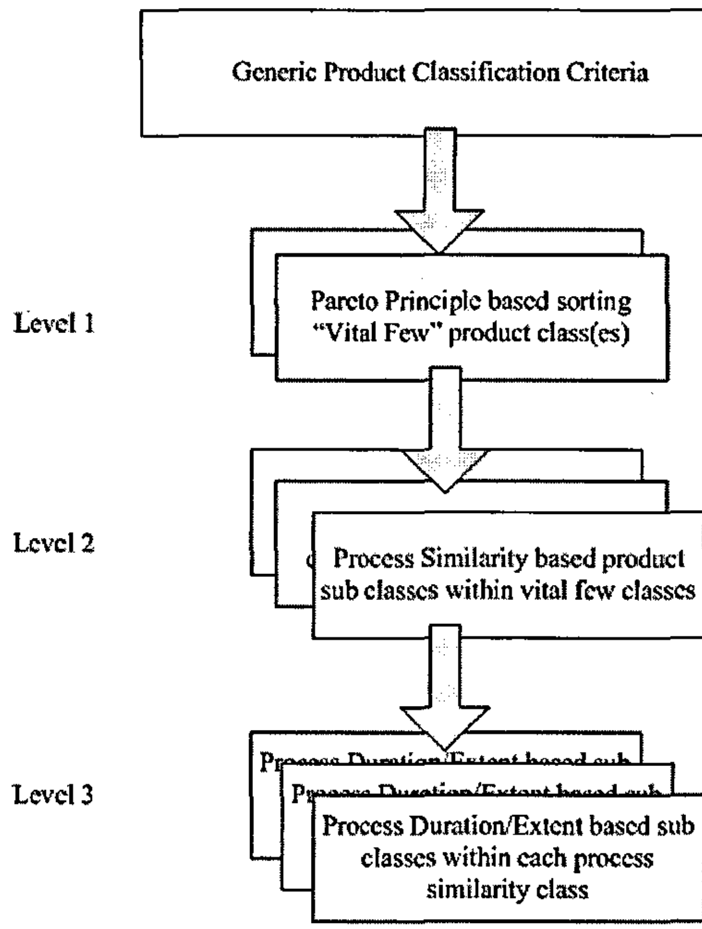

Figure 6.3 Generic product classification criteria.

Figure 6.3 shows the generic product classification criteria proposed and adopted in this study which have three levels. Product classification level 1 refers to the selection of a vital-few class(es) of products. The concept of vital few is associated with the Pareto Principle which present the idea that 80% of demand might be generated from 20% of products (Christopher and Towill, 2001) or 20% of products might be consuming 80% of the resources. There can be several views/factors based on which vital-few product class(es) can be chosen. Some of those views are presented in figure 6.4.

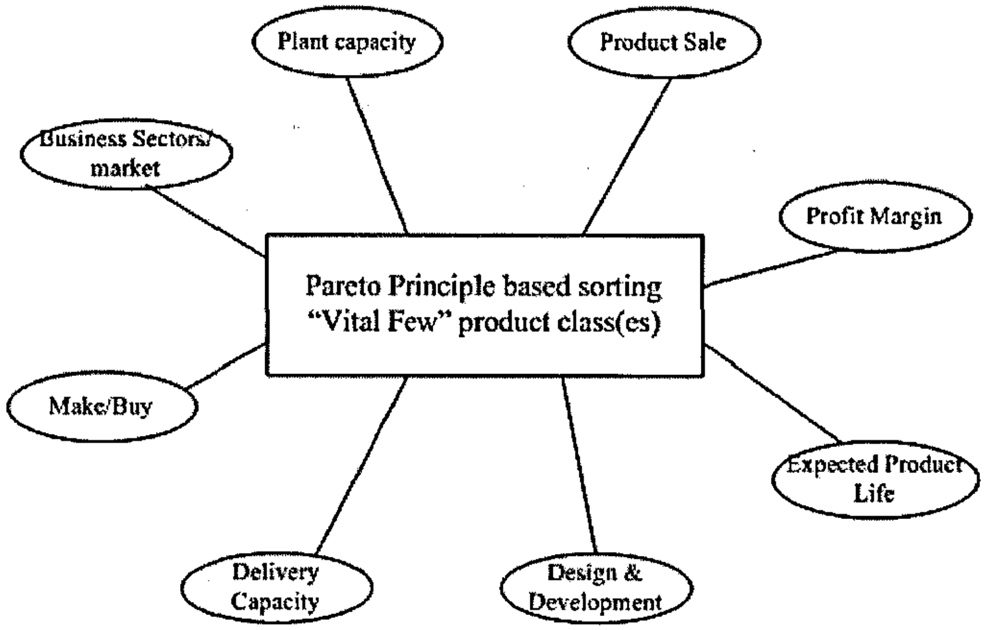

Figure 6.4 Some views to select the Vital-few product class(es).

Figure 6.4 shows some important views which can be taken into account while selecting vital few class of products. The selection of any or combination of the views is related to the purpose/application of the product classification. For instance, if the purpose of product classification is to analyse and improve the design of a production plant, then the potential view might be "plant capacity" and/or "Make/buy" etc.

The reason to use the concept of Pareto vital few at the 1st level of product classification is because this can give rise to a product class(es) which is vital from some view point. For instance, if the purpose of some analysis is to implement a le-agile supply chain, then it is crucial to know about the vital products (20% product having demand volume of 80% of the total demand) and for which lean concepts like process standardization and levelled scheduling can be done, while for the rest of trivial and/or many products agile techniques can be used (Christopher and Towill, 2000).

Level 2 of the product classification criteria (figure 6.3) refers to the identification of product sub classes based on "Process similarity" among the products. It means that all the products which undergo through the same processes for its realisation will be grouped together as a sub class. However, which type of processes to be considered depends on the purpose/application of the product classification. For instance, if the purpose of product classification is to analyse and improve a production plant, then the potential view might be "plant capacity" and/or "Make/buy" and therefore the processes to consider can be processes related to plant capacity and/or make/buy and so processes like production processes are selected for the purpose of doing "process similarity" and no need to consider other processes like sales, general administration etc.

Level 3 of the product classification criteria (figure 6.3) refers to the identification of product sub classes within each process similarity based product class on the basis of the "Process duration/extent" to realise a product. For instance, products within the product similarity based sub class which need more processing time relative to the one that needed less processing time may be kept in a different sub class. The range of processing time within this sub class and the number of these sub classes can be dependent on the depth of analysis required.

To implement the proposed product classification, a step by step approach is presented in figure 6.5.

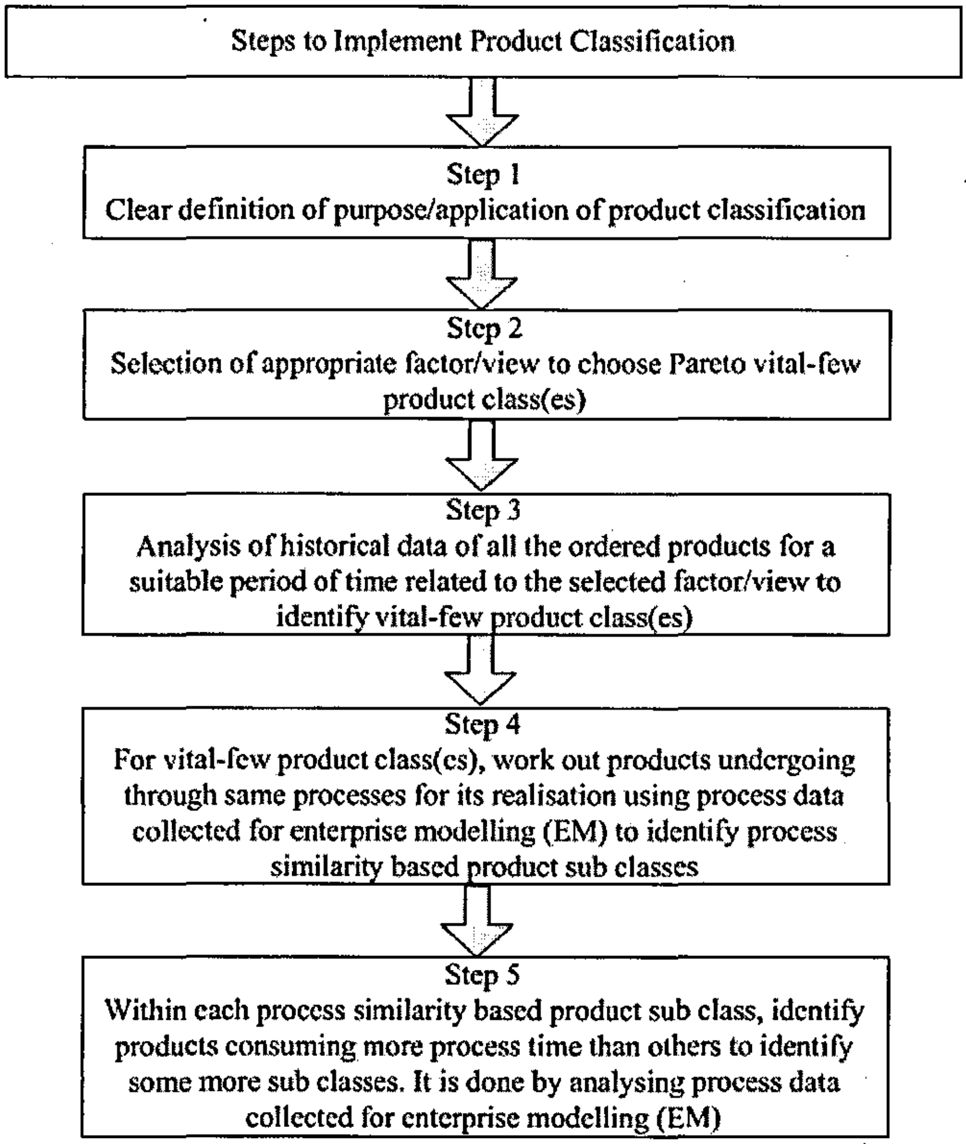

Figure 6.5 Step by step approach to implement product classification.

Figure 6.5 presents a five steps approach to implementing the proposed product classification. Each of the steps is self explanatory. However, in step 3, selection of a suitable period for the analysis of data to identify vital-few products depends on factors like accuracy of the analysis required, and availability of data. The greater the accuracy required the more detailed data analysis might be required.

The product classification implementation approach presented in figure 6.5 can be used partially or completely depending on the requirement or purpose of the product classification.

For instance, if a product classification is used to support the development and use of a simulation model to analyse in depth operational activities, then all 5 steps of the product classification implementation might be required. In the case of simulating at a high level of abstraction to analyse alternate policies, only the first one or two steps of the product classification implementation might be sufficient to fulfil such a purpose.

6.3.2 MS Visio-MSI computer based tool for graphical representation of enterprise models

A new MS Visio based tool was developed by MSI colleagues to facilitate the graphical representation of the four CIMOSA based MSI enterprise modelling templates; namely context diagrams, interaction diagrams, structure diagrams and activity diagrams (see figure 6.6). In this new tool, graphical constructs are provided as model building blocks for the four important viewpoints that constitute CIMOSA-MSI requirements modelling namely information, physical, human and financial are created for use. Any of these graphical constructs can be picked and pasted using the MS Visio software onto modelling sheets and can be parameterised by typing and filling some fields associated with the graphical construct. Also the MS Visio tool has a provision for flexibly linking different graphical constructs using lines and arrows which makes it very convenient and quick to create the graphical models. It was expected that the use of this tool would decrease the time and effort needed to create graphical enterprise models using a computer as compare to the previous approach of using MS PowerPoint software. Implementation of this tool needed MS Visio and MSI developed files of shapes and their underlying programming to enable the shapes to be assigned with their descriptions. Implementation of the tool needed to pick the required graphical construct from the MSI developed file of shapes, paste the construct on the software screen to automatically generate a popup field to assign descriptions to the pasted graphical construct, fill the fields with descriptions of the graphical construct, then after completing the pasting of all the constructs to link the constructs using the provided lines and arrows functionality. In this way it was expected that all the four CIMOSA-MSI EM templates namely context diagrams, interaction diagrams, structure diagrams and activity diagrams can be developed conveniently.

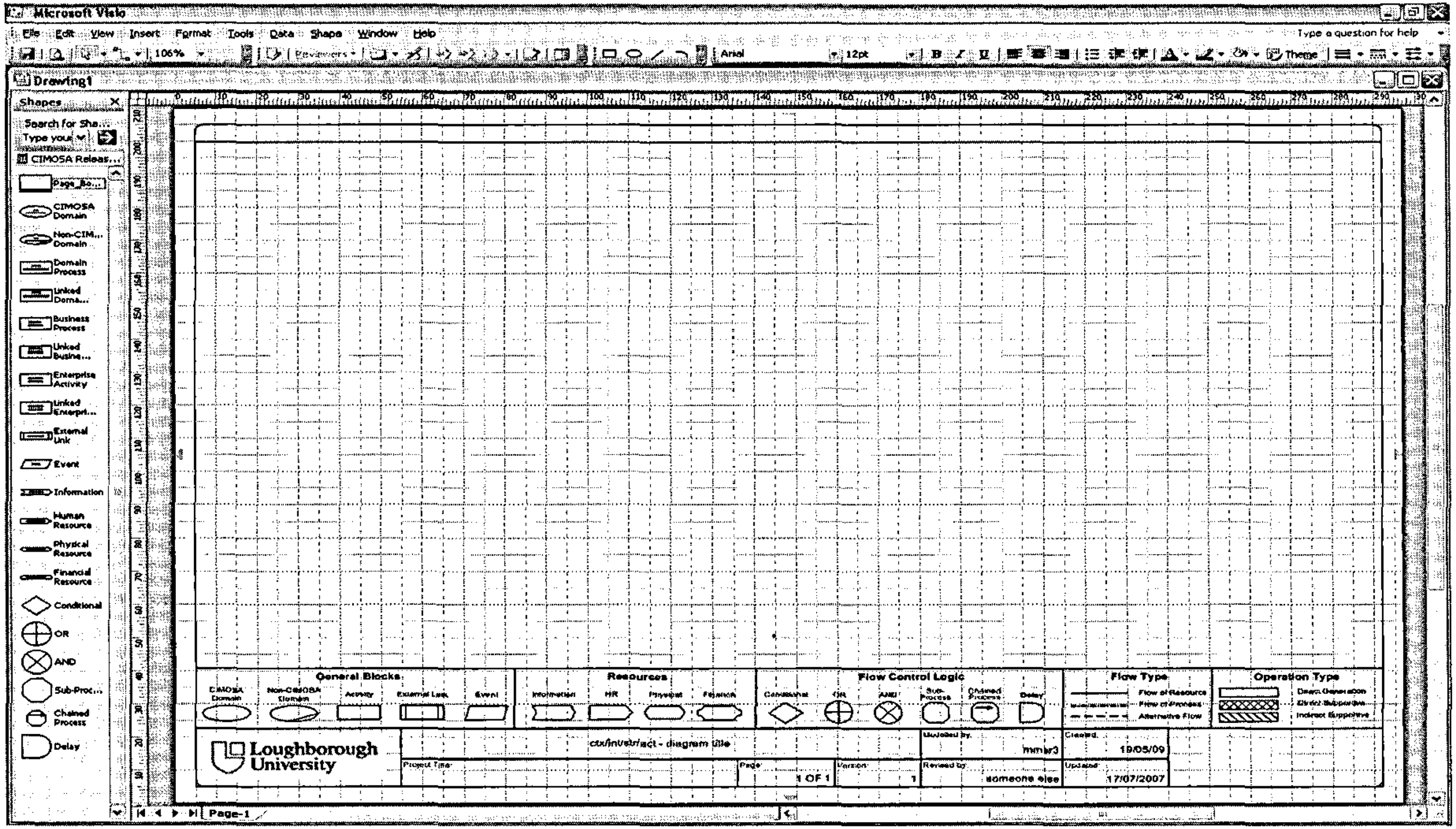

Figure 6.6 MS Visio-MSI tool for drafting enterprise models.

6.3.3 Data capturing tool to populate CIMOSA-MSI activity diagramming template and Simulation Modelling

A new tool was developed at MSI colleagues to capture data elicited from structured interviews with knowledge holders, and observations made by modellers about business processes and enterprise activities, so as to facilitate the creation of activity diagrams and also to facilitate reuse of process structures and related data by populating simulation models with required information and data. This tool was developed and updated by the author to fit the purposes of this research. This tool will be referred to in this thesis as a template for the "Collective capture of data for Activity level modelling" (see figure 6.7). This data capture tool is created based on use of MS Excel. The developed tool was designed to contain information and data about: the name of the modeller (or observer); the name of the owner of each business process; a description and identification of each business process captured, and their related enterprise activities, predecessor and successor of the business process; the initial triggers like an order; different resources required like information, material, human and machine/tool resources used to realise enterprise activities; the duration and frequency of each activity; end results, like order completion report and products delivered; and any comments. The data capture tool was expected to provide a structured approach with advantages relative to the use of a plain paper because: i) unlike a plain sheet of paper, the developed tool can include all the required parameters for which information and data can be collected in a structured way, ii) unlike a plain sheet of paper, in the developed data capture tool, information and data can be stored, retrieved and reused conveniently. To implement the data capture tool, each sheet needs to be filled in by the modeller, for each business process, by observing and recording all the enterprise activities and related entities listed in the forgoing.

Collective capture of data for Activity level modelling											
Process name				BP ID					Modeller		
Previous process				Next process					Process In-		
		Input							Output		
Activity	EA ID.	Info/Data	Material resource	Number of human resource	Machines	Tools	Activity Repetition (a)once/activity (b)once/batch (c)once/shift	Operation time (minutes)	Output info/Data	components	Comments

Figure 6.7 Collective capture of data for Activity level modelling.

6.4 Novelty and potential benefits expected from deploying M2

The integrated deployment of EM, CLD, SM and product classifications, in support of the analytical design of complex supply chains constitutes a new idea. Its novelty can primarily be associated with its new way of classifying products and quantitatively modelling various viewpoints, and therefore concerns, about process oriented flows in multi product supply chains. The related product classification technique was developed to break through the complexity introduced by product variance in any multi product supply chain. The reduced number of representative product classes can be managed conveniently. This simplification was expected to support the analytical design of multi product supply chains. To quantitatively analyse impacts of changed supply chain paradigms, structures and parameters, the behavioural aspects of flows associated with the developed product classes need to be computer simulated. This however was expected to be a much simpler task than trying to achieve the same goal, with all specific case of product types; because a significantly smaller number of process variables and scenarios should result, thereby much is reducing the complexity of the models and modelling experiments whilst still retaining sufficiently realistic modelling. Alternatively stated the approach was expected to handle much increased levels of product variance, and therefore should prove purposeful for a greater number of multi product supply chain types. The proposed integrated use of product classification, simulation modelling and enterprise modelling is new. Furthermore, a step by step approach was specified in this chapter to perform product classification. The product classification presented is expected to be a generic approach which can be used for product classification for most multi product supply chains, associated with different industry sectors. However, limitations of the proposed product classification ideas were expected, such as the development of the product classes was expected to make the application of M2 specific to the supply chain being studied. Also to realise product classification some historical data on product orders is used to provide the basis for specifying a vital few class(es) of products in the multi product supply chain being studied. So if the orders are significantly changed, the defined product classes may also need to be change accordingly.

Chapter 7: Use of Methodology M2 for Case Study 2: Static Modelling of a Point of Purchase (POP) Equipment Manufacturing Enterprise

The purpose of this chapter is to use M2 in respect of case study 2 and to assess its usefulness. Case study 2 is the case of a Point of Purchase (POP) equipment manufacturing company namely Artform International Limited, UK. An enterprise model of Artform was created to explicitly capture a big picture of the process network which constitutes its supply chain. The developed EM was then used in conjunction with a populated domain table to explicitly identify problem issues within Artform. An important issue of product changeover at assembly cells is selected for further investigation. The EM was then developed to detail the current process used in Artform assembly cells to achieve product changeovers. Single Minute Exchange of Dye (SMED), a well known lean technique for quick changeover was then used to improve the product changeover process; and then the EM was further developed to document recommended change process improvements. The combined use of the EM and domain table was then analysed with reference to the specific process improvements costs.

7.1 Case Company and Case Study Introduction

In 1968 Artform International Ltd. was founded initially as a small scale 'moulded-parts manufacturing' company. It has currently grown to become specialist in the design and manufacture of high quality, three dimensional point-of-purchase (POP) shop equipments, with a major manufacturing base located in Loughborough, UK. Artform products have widespread application so that day almost 50% of their finished products are exported to about 40 countries across the globe with their major clients being Boots and Superdrug Ltd. The company deals primarily in cosmetic and beauty care, consumer electronics and tobacco business sectors. Artform products support the point of purchase sale of global brands like Nike, L'Oreal, Rimmel, No.7, Maybelline, MaxFactor, Vodafone, T-mobile and

Gallaher. Their major local competitor is the Diam Company Ltd. which is also located in Loughborough, UK. However, there are also other major competitors overseas.

Artform is a £40 million company with an average of £2.2 million held in work in process (WIP) inventory. This is a huge amount tied up and the Artform management believe it could be utilised for better purposes. It has 400 permanent employees but a significant number of daily wage workers are acquired as per production requirements change. For the last couple of years, it has been owned by IMI plc and since that time it has undergone many organizational changes. The overall change can be characterised as being a paradigm shift from push type batch build to pull and lean manufacturing; with an effort to create sustainable flows through use of Artform's multi product supply chain. In this regards, a lean project was started in mid 2007. The project was supervised by a group of external consultants assisted by an internal cross functional team of well experienced staff. The project duration was for 1 year and the main objective of the project was to replace batch built product assembly system with a new "U-shaped" lean cell assembly system. However, other objectives were to implement lean methods like 5S; process mapping and value stream mapping; use of a super market inventory system; and Just in Time (JIT) and Kanban production.

The supply chain of Artform can be categorised as being a combined external and internal supply chain (see figure 7.1). The Supply Chain Operations Reference (SCOR) model is used to illustrate Artform's internal and external supply chain processes. . In general, all five supply chain processes (namely plan, source, make, deliver and return) form part of the internal supply chain of Artform. Hence it was decided that M2 would be used to model four of these internal processes in detail for the internal supply chain of Artform. Whereas the internal return process was not modelled to limit the study scope. Also some important characteristics of the external supply chain are observed and described.

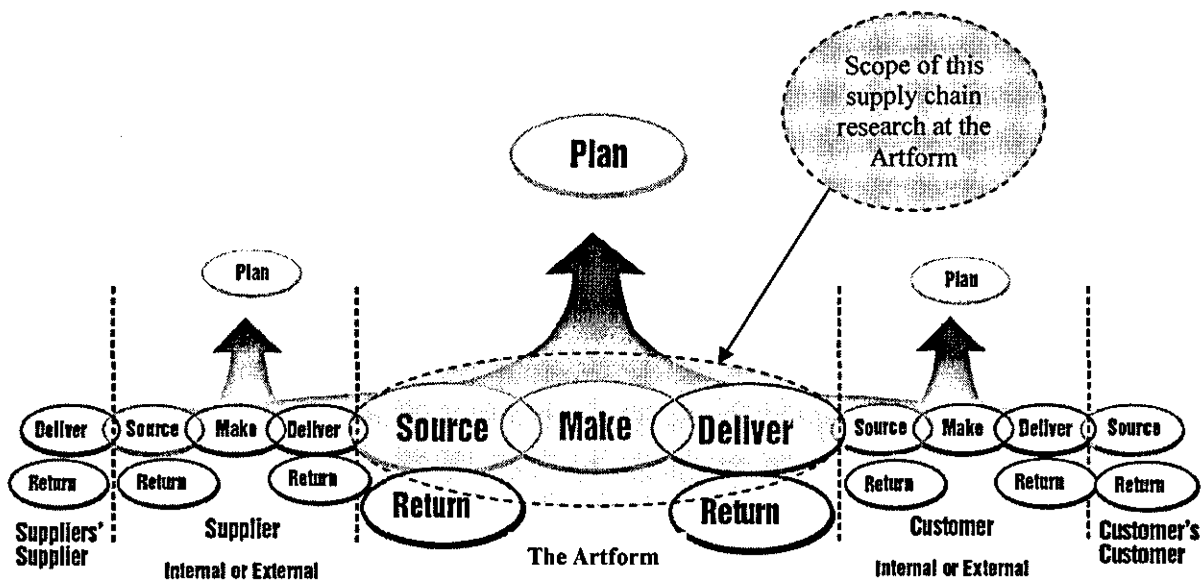

Figure 7.1 SCOR model to illustrate scope of supply chain research project at the Artform.

Figure 7.1 therefore illustrates the scope of supply chain research conducted at Artform (encompassed by a dotted bubble). The prime reasons for not including the research of external supply chain were: (1) time constraint for PhD completion, (2) access to supplier and market facility data, (3) the main interest of Artform management was on internal supply chain improvement, and (4) too many internal supply chain issues were observed to exist within Artform as illustrated by troublesome inventory levels.

The primary external supply chain of Artform is related to the supply of sub contracted components and standard items from overseas and UK subcontractors and suppliers. It also includes the supply of finished goods from Artform to its global and UK customers. The internal supply chain is concerned with the flow of materials, sub contracted items and standard parts inside Artform; through its different stores and work in process inventories and production departments and dispatch areas. Additionally Artform's both internal and external supply chains also realise information and cash flows.

The overseas supply of components and standard items is managed in such a way that overseas sub-contractors and suppliers commit to provide the required components to the end point required by Artform. Therefore those sub-contractors and suppliers are responsible for transportation to Artform UK. Mostly the DHL courier service is used for transportation. The Artform dispatch department then clears the consignment from the relevant UK dock. There are some risks involved in this dispatching process which are difficult to avoid. Although DHL is a leading courier company in the world it introduces uncertain delays which impact on delivery dates of overseas items. A common reason for this is that delivery dates are subject to the availability of space in the vessel of the ship on the dock. When there is not enough space in the vessel and no other ship is scheduled between the source and UK destination this can delay the delivery remarkably.

7.2 Creating Enterprise Models of the Artform Supply chain

The purpose of conducting enterprise modelling of the Artform supply chain was to enable related strategic, tactical and operational decision making. The scope of enterprise modelling was constrained via focusing on the capture process network associated with source, make and deliver processes for the internal supply chain of Artform. Some of the populated diagramming templates comprising of the big picture EM of Artform are presented in appendix 1. All EM diagrams were created using the Microsoft Visio-MSI software tool which proved an efficient tool for sketching enterprise models using a computer.

The CIMOSA EM of Artform was therefore created using four types of graphical modelling template namely 'Context Diagram', 'Interaction Diagram', 'Structure Diagram' and 'Activity Diagram'. By filling in these templates with specific Artform process data, a holistic (but static) model of ABC's different working domains and their decomposition into Domain Processes (DPs), Business Processes (BPs) and finally in to Enterprise Activities (EAs), was achieved. The developed EM documents relatively enduring aspects of interactions between DP's, BP's and EA's in the form of transfers of physical, information, human or financial resources. Careful construction of these diagrams led to the creation of an 'As-Is' big picture of Artform business processes associated with supply chain view point which can lead to benefit the analytical design of the Artform's supply chains.

For instance, process data used to create the context diagram was elicited by conducting semi structured and focused group interviews with relevant personnel. The main objective of these interviews was to understand and explicitly describe a relatively enduring characterization of selected supply chain process domains (internal supply chain of the Artform) related to the scope of this research project i.e., "Manage, make and deliver products to meet customer orders". The focused group interviews held with ABC managers fleshed out agreed understandings about nine process domains. Three of the domains were CIMOSA conformant domains which were modelled in detail (see figure 7.2).

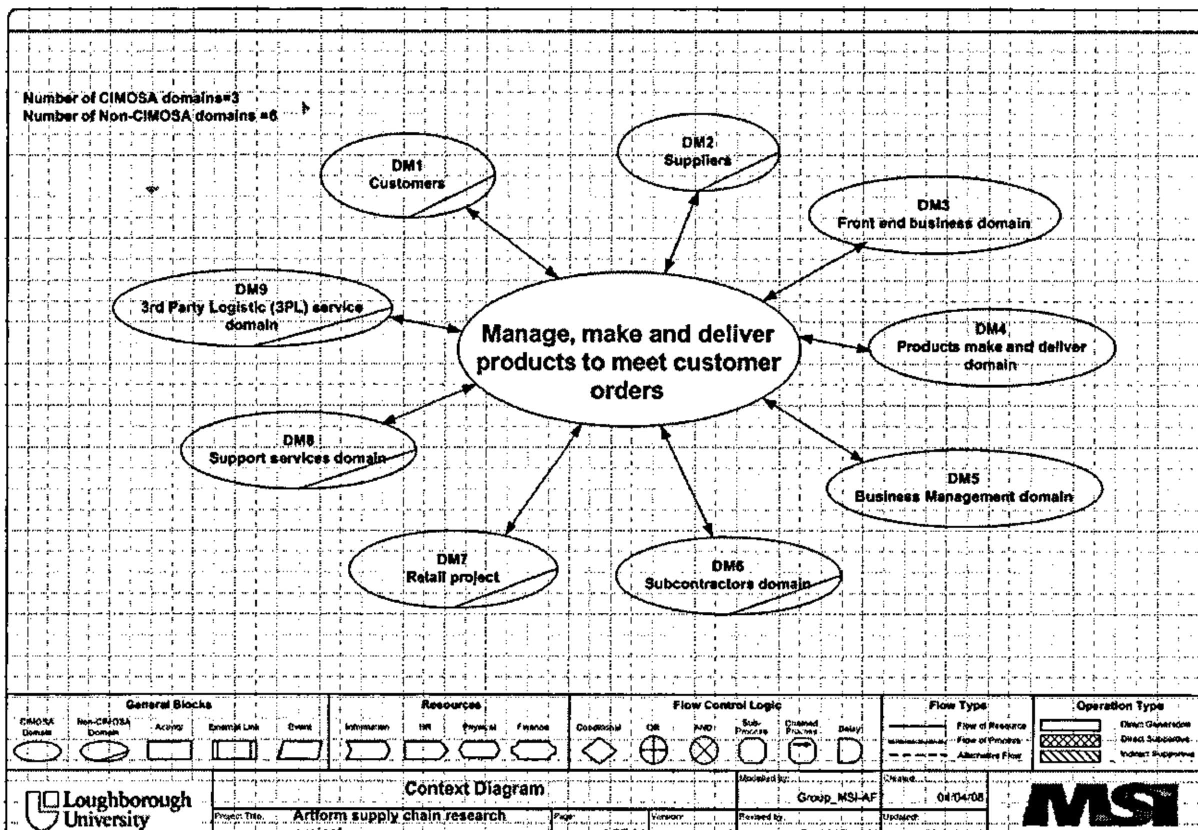

Figure 7.2 Context diagram for Artform supply chain research project.

The front end business domain (DM3), the products make and deliver domain (DM4), and the business management domain (DM5) were selected for detailed study and investigation. This was because the three domains contribute to key aspects of internal supply chain of Artform. DM3 was observed to include customer relationship management and customer order processing, along with the design and development and BOM generation of products. DM4 includes all physical activities required to: convert raw material into components and sub assemblies; deliver components; assemble components into final products; and deliver products as per customer order instructions. DM5 includes processes like supplier management, purchase management, inventory management, production planning, human resource management, finance management and delivery management.

All of the nine process domains presented in figure 7.2 interact with each other in terms of information, physical resource, human resource, and financial transfers. A top level interaction diagram is presented in figure 7.3 which shows interactions among all the domains.

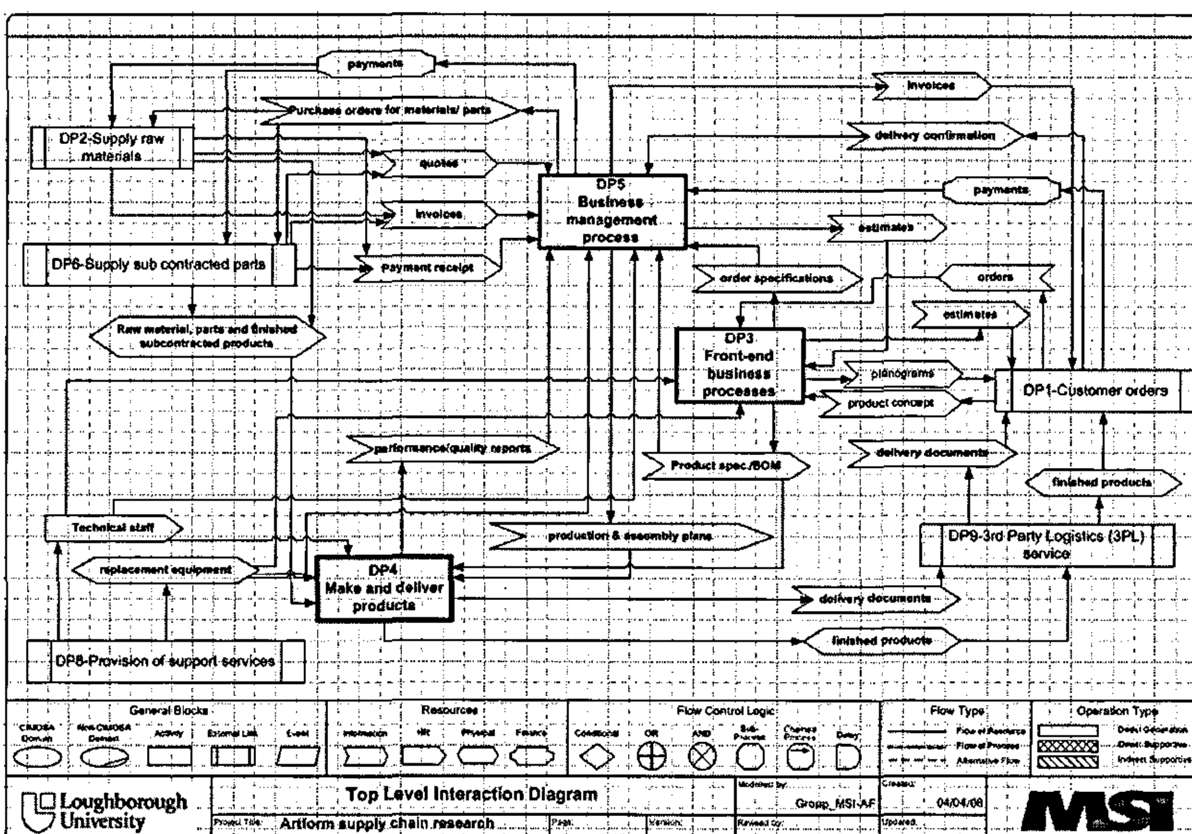

Figure 7.3 Top level interaction diagram.

The top level interaction diagram (figure 7.3) explicitly presents interactions among nine domain processes (DPs') of Artform. The three CIMOSA conformant domains DP3, DP4 and DP5 are shown as rectangular boxes while the non CIMOSA conformant domains are shown as external links. Generally customers provide a product concept to DP3 (front end business process) which is used by an Artform design team (DP3) to develop different planograms for customers to approve. According to the approved planogram and order requirements, estimates are generated by DP5 and forwarded to customers through DP3. The customers place an order which is input to DP3 which converts orders into product specifications and BOMs. The design spec./BOM information are provided to the DP4 (make and deliver products) and DP5 (manage business processes). DP5 also releases purchase orders for material/parts to DP2 (supply raw materials) and DP6 (supply subcontracted parts). The required raw materials and parts are provided to DP4 (make and deliver products). Project plans (a brief schedule for each order) and assembly plans are generated at DP5 and this is forwarded to DP4 for use. In DP4, as per the project plan and design specs/BOM, raw materials are converted into components and sub assemblies which are then assembled and packed. Packed products along with delivery documents are then delivered to different customers via DP9 (3rd party logistic service). Delivery confirmation is provided by the customers via DP5 through DP3. Invoices are prepared by DP5 and forwarded to customers and payments are debited as per agreed methods.

The top level interaction diagram (figure 7.3) presents interactions between different process domains (both CIMOSA and Non CIMOSA). However, it does not present the sequential flow of enterprise processes and enterprise activities through the supply chain.

Structure diagrams were constructed to explicitly describe the structural decomposition of different domain processes into their constituent business processes and enterprise activities. This diagram type presents business processes needed for realizing objectives of the domain. The structure diagram for DP4 is presented in figure 7.4.

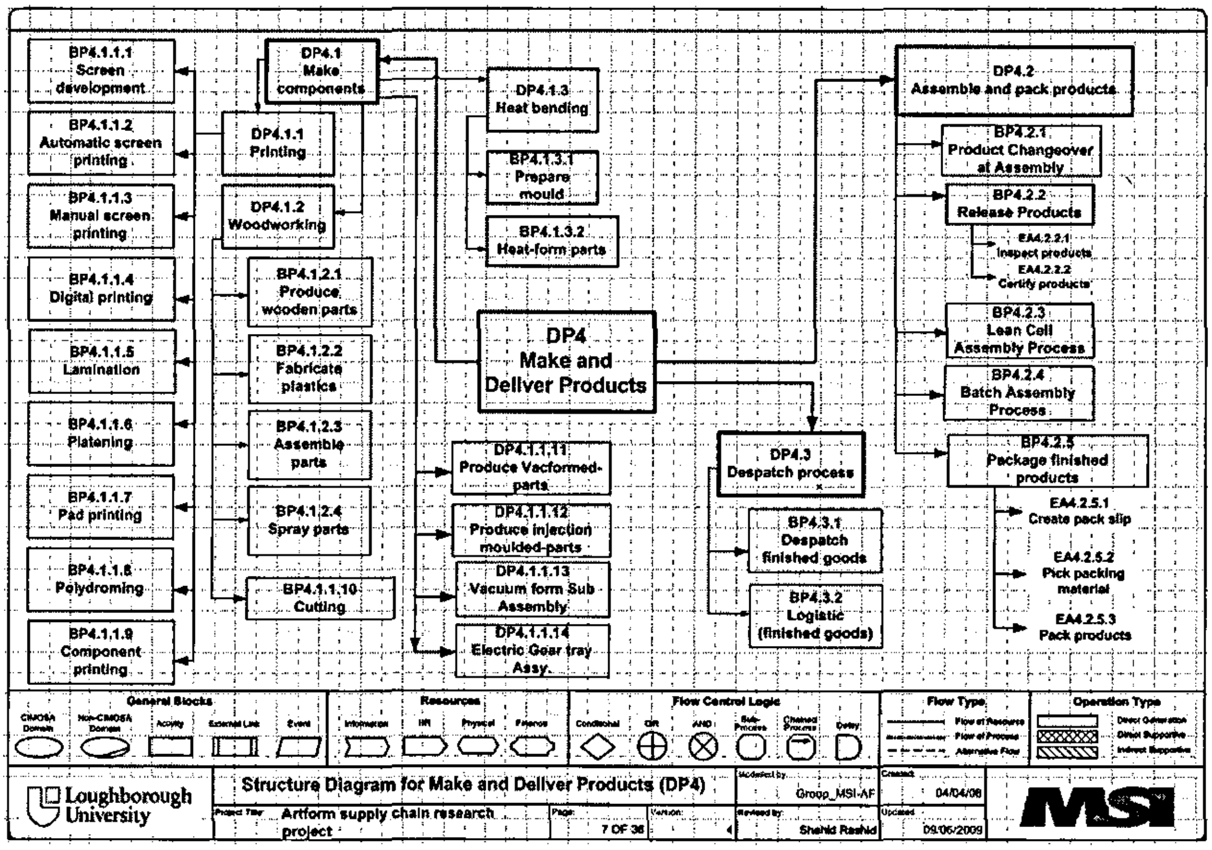

Figure 7.4 Structure diagram for make and deliver products (DP4).

This shows how DP4 (make and deliver products) is decomposed into sub DPs, BPs and EAs. DP4 is decomposed into three sub domain processes namely make components (DP4.1), assemble and pack products (DP4.2) and dispatch process (DP4.3). Each of the three sub domain processes are further decomposed into business processes and enterprise activities to fulfil the need of the make and deliver products process (DP4).

The structure diagram, shown in (figure 7.4) and the top level interaction diagram, shown in figure 7.3 are used as inputs to create the activity diagram. The activity diagram is the most detailed level of enterprise modelling used to represent business process requirements of MEs. Detailed process information was gathered to develop activity diagram based on structured interviewing and participant observations for the required BP's. These information and data were recorded and maintained via the MS Excel spread sheet tool namely the collective capture of data for activity level modelling. The corresponding data spread sheet, populated with relevant data, is presented in appendix 2 for reference. An activity diagram was created for the Artform manage, make and deliver processes to realise customer requirements (see figure 7.5). This activity diagram includes processes carried out in Artform, after the release of design and BOM and product orders. This activity diagram mainly shows flows of information, material and physical resources through necessary activities.

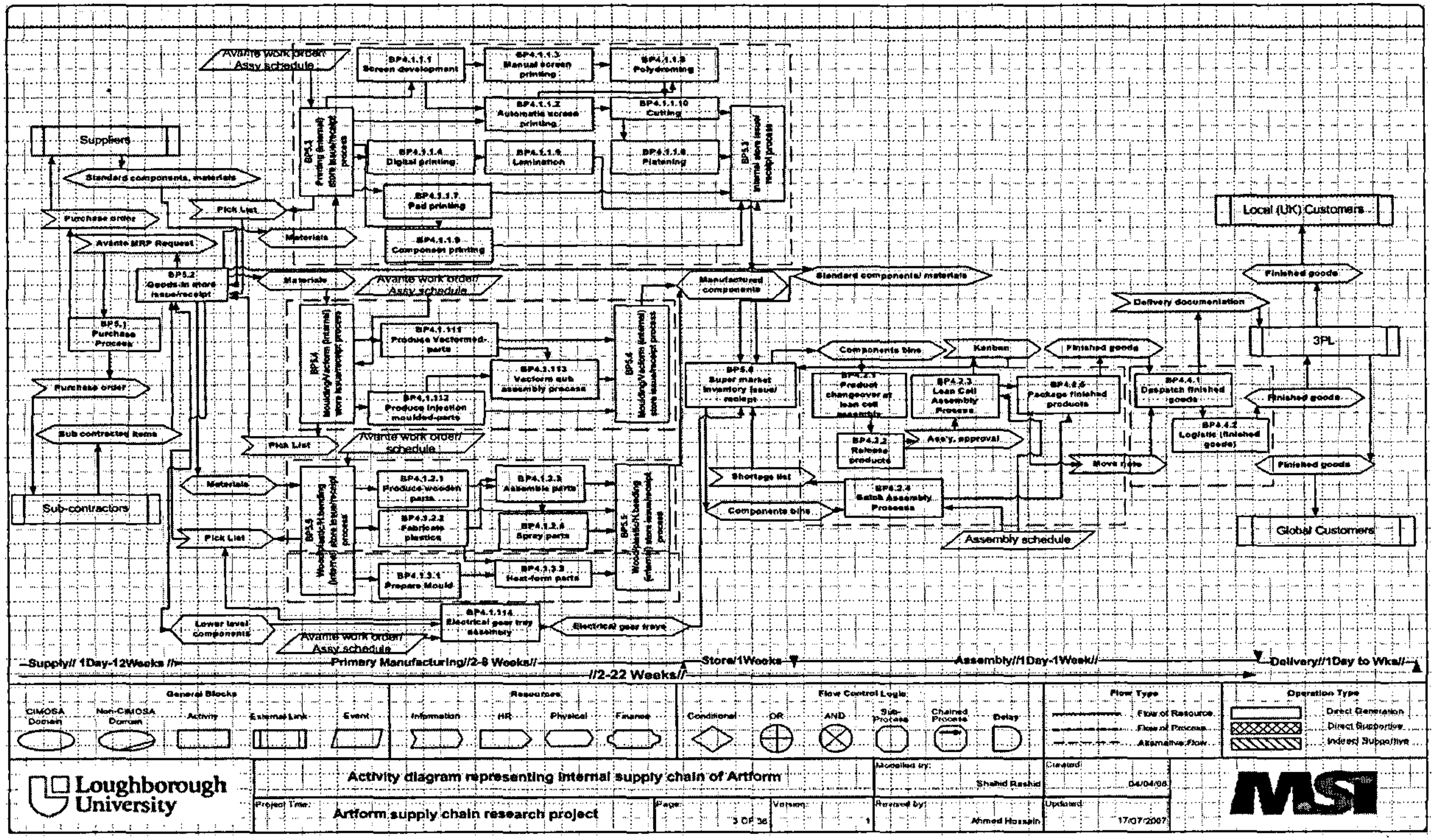

Figure 7.5 Activity diagram representing internal supply chain of the Artform.

Figure 7.5 depicts internal supply chain operations carried out in Artform. Artform planning is partly based on use of a commercial ERP software tool namely Avante. The supply chain operates in such a way that as soon as BOMs are up loaded on to the Avante software it releases a works order to produce the product. In figure 7.5 this is shown as an event "Avante work order/ assembly schedule". This event triggers requirement for raw material, components and sub assemblies at all the production domains; namely printing, injection moulding and vacuum forming, wood working and heat bending. The Avante MRP module automatically generates pick lists for all the materials and components. Purchasing is done by arranging the pick list items into purchase orders for different raw material suppliers and customised components sub contractors. The range of supply lead time is 1 day to 12 weeks. Generally for standard raw material supplied by local suppliers takes 1 day, while for long lead time customised items like metallic carcasses supplied by overseas suppliers takes a maximum of 12 weeks. The supplied raw material and components are booked in the goods in store after inspection and then handed over to the relevant production stores.

Different production processes are performed to convert raw material into components and sub assemblies as per product requirements (see figure 7.5). The range in production cycle times is 2 to 8 weeks, depending on the volume and complexity of the work to be realised. Almost all the manufactured items are packed in reusable storage and transportation bins. The component bins are booked on Avante in internal stores for each production department. These bins are then pushed to a central "super market inventory" as early as 7 days before the planned assembly start date for the product. In the super market inventory these component bins are arranged separately for each works order for products. The management of Artform decided that components should reach 7 days before the planned assembly start time; therefore, for the designed wait time of components for each works order is 1 week.

In figure 7.5, two types of assembly system used by Artform are shown; namely batch build and cell assembly (one piece of product flowing at a time through assembly process).

Artform is using both types of assembly systems to cover the variety of products they realise. The event "assembly start" triggers the assembly process, either batch or cell assembly, whichever is scheduled for the product. Batch assembly pulls component bins from the super market inventory using a shortage list; while cell assembly uses Kanban cards to pull component bins as per production requirements. Batch assembly can be started even if all of the required components are not yet available, but for cell assembly all components must be available to start assembly processing To initiate every new or changed product assembly at the assembly cell a product changeover is required. The first product assembled at the assembly cell needs to be approved and released as meeting its quality requirements. The released product then initiate repeats of the assembly process for the products to be assembled. Each assembled product is quality tested and then packed. The variation on assembly cycle time is 1 day to 1 week depending on size of the batch and size of the product.

The packed products are delivered to finished goods store along with a move note which provide product order and delivery information (see figure 7.5). Dispatch process is arranged and realises all the delivery requirements of the product while logistics process is used to realise safe loading of the 3rd party vehicle for dispatch to UK and global customers. The delivery lead time can be a day for UK deliveries and can be few weeks for overseas deliveries.

Figure 7.5 shows how more than 30 different business processes need to be realised by Artform and these 30 business processes constitute the internal supply chain of Artform. In this case study the business processes related to assembly processes were selected for further investigation. This choice was made to reflect the current interests of Artform management and to analyse impacts of change as Artform's' internal 'lean team' sort to replace some of the companies batch build assembly lines with lean assembly cells. The selected "assemble and pack product" domain process (DP4.2) has four business processes, namely product changeover at lean cell assembly (BP4.2.1), release products

(BP4.2.2), lean cell assembly process (BP4.2.3) and batch assembly process (BP4.2.4). The issues of concern related to DP4.2. were tabulated into a domain table (see table 7.1).

Table 7-1 Domain table for Domain Process DP4.2.

Domain Table for CIMOSA Domain Process – DP4.2 (Assembly and Pack Products)				
Domain Processes	**Domain issues related to different CIMOSA perspectives**			
	Information	**Physical**	**Human**	**Financial**
Product Changeover at Lean Cell Assembly – BP4.2.1	1) Late arrival of product specifications/BOM. 2) Incomplete products specifications/BOM. 3) Late changes in products specifications/BOM. 4) Improvement potentials to standardise line balancing process and make use of previous line balancing experience.	1) Un availability of product components to be assembled. 2) Delays in replenishment of components inventory at lean cells. 3) Some delays in availability of assembly/fitting tools at lean cells.	1) No communication between assembly supervisor and designer to discuss product specifications before actual start of product change over for the product assembly. 2) Line balancing staff (lean assembly supervisor) not trained to use advance and alternative methods to balance line optimally and quickly. 3) Lean assembly supervisors not trained to develop and balance an assembly line for different brands of products of cosmetics.	-------
Release Products – BP4.2.2	1) Incomplete (reference) information to inspect product for assembly release. 2) Certification signature missed.	1) Quality of reference Graphics used for visually inspection of product is not appropriate.	1) Product release officer not trained for in depth product inspection for all the product varieties at Artform.	------
Lean Cell Assembly Process – BP4.2.3	1) Incomplete Product Specification / BOM. 2) Non standard method for assembly line balancing at Cell. 3) Un tested rules for daily inventory replenishment.	1) In efficient product change-over in terms of replenish cell inventory for next product. 2) Un tested location of tools and inventory in terms of better work place design. 3) Quality is observed at the last station of the assembly cell which in case of non	1) Training shortfall regarding supervision of cell assembly for team leaders experienced in working in batch build environment. The training short fall areas are assembly line balancing, on job operators training for the new	--------

Domain Table for CIMOSA Domain Process – DP4.2 (Assembly and Pack Products)				
Domain Processes	**Domain issues related to different CIMOSA perspectives**			
	Information	**Physical**	**Human**	**Financial**
		conformity can stop the cell assembly. 4) Un availability of product components to be assembled. 5) Quality issues for incoming components either internally produced by the Artform or externally supplied by the sub contractors.	product, effective implementation of 5S and Health and safety training. 2) All types of related training shortfall for assembly operators.	
Batch Assembly Process – BP4.2.4	1) Incomplete Product Specification / BOM. 2) Lack for clear information about the expected time of arrival of short components for assembly.	1) In efficient product change-over in terms of replenish components inventory for next batch. 2) In efficient utilization of batch build space in terms of space allocation for components inventory, product build area, tools location and finished goods location. 3) Quality issues for incoming components either internally produced by the Artform or externally supplied by the sub contractors. 4) Non availability of all the components at the start of batch build assembly causes delays in over all batch assembly (build) time. 5) Effective implementation of 5S is difficult due to a very busy assembly floor with static batch of product placed for assembly and assembly operators/team leader in motion to grab components and tools.	1) Training shortfall regarding for team leaders regarding on job operators training for the new product, effective implementation of 5S and Health and safety training. 2) All types of related training shortfall for assembly operators. 3) Very low utilization of human resource due to un standard method of assembly driven by the available component and experience of the team leader.	--------

Domain table 7.1 shows different issues of concern that are organised in terms of CIMOSA perspectives of information, physical, human and finance. One common issue which is related to both cell assembly and batch built assembly processes is the unavailability of some components for assembly. This significantly delays the assembly process. Another important issue observed was product changeover at the lean assembly cells, which is currently a very time consuming process at Artform. Both of these important issues were selected for further investigation. The issue of product changeover at assembly cells is presented in this chapter. Whereas an investigation into the causes and effect of unavailability of components for assembly is mainly related to dynamic behaviours therefore this is presented in chapter 8 (dynamic modelling for Artform).

7.3 Quick change over of products at the assembly cells

It was observed that change over (or setup) has two elements namely internal change over and external change over. Internal change over consume capacity of the system by making the system down, and this therefore affects output. To reduce the effective change over time, it is required to either eliminate the need for the set-up entirely (e.g. by using dedicated machines) or to shift from internal to external set-ups (Burcher et al., 1996).

Set-up times have a great impact on the way in which a business behaves in terms of inventory holding and manufacturing flexibility (Ritzman et al., 1984) and is one of the key elements in the just-in-time (JIT) approach. Single Minute Exchange of Dye (SMED) is a famous manufacturing setup and/or changeover reduction technique (Patel et al., 2001). The SMED three step process includes; i) identify internal and external changeover activities, where this means separating out non production stopping preparation activities from others, ii) shift activities from internal to external, thus eliminating the production down time by externalizing changeover activities and iii) streamlining the remaining internal activities, by means of improving fasteners and other internal adjustments. The SMED three step approach is illustrated conceptually in figure 7.6.

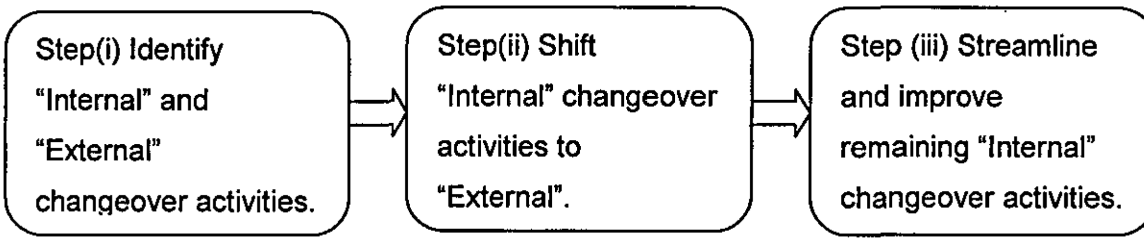

Figure 7.6 SMED changeover approach.

At Artform, changeover at assembly cells includes 6 activities namely, 1) availability and understanding of the next job order, 2) cell inventory ("2 bins" of component) changeover, 3) consumable (nut-bolts) replenishment and changeover, 4) assembly tools and equipment availability and changeover, 5) assembly cell (line) balancing and 6) staff training. The current state changeover process was then modelled using a CIMOSA-MSI activity diagram; and this is presented in figure 7.7 (CIMOSA, 1996).

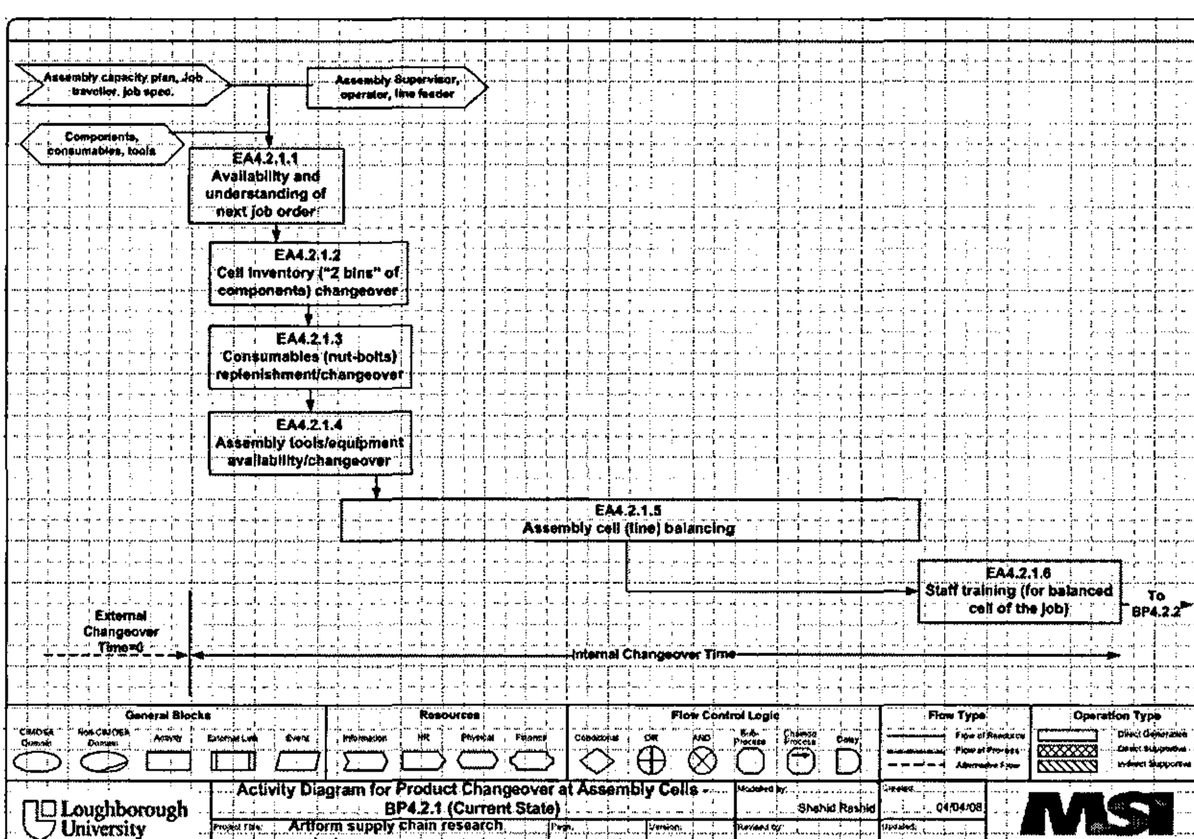

Figure 7.7 Activity diagram for product changeover at assembly cells-BP4.2.1 (Current State).

Figure 7.7 shows the start to end logical flow of all of the six changeover activities (presented as 'a' to 'f' above) that constitutes the job changeover process at any lean assembly cell at Artform. In the as-Is state all of these activities are internal changeover activities and there is no external changeover activity in the current state of the changeover process. So all of the six internal changeover activities cause production down time. The time span (horizontal length of bar) for the six activities were observed for current assembly cells and the results are presented in figure 7.7

Using the SMED concept, a three step changeover was followed and initially the six activities presented in the "As-Is" model were analysed with a view to externalizing them. The finding of this analysis was presented in a proposed "To-Be" future state model shown in figure 7.8.

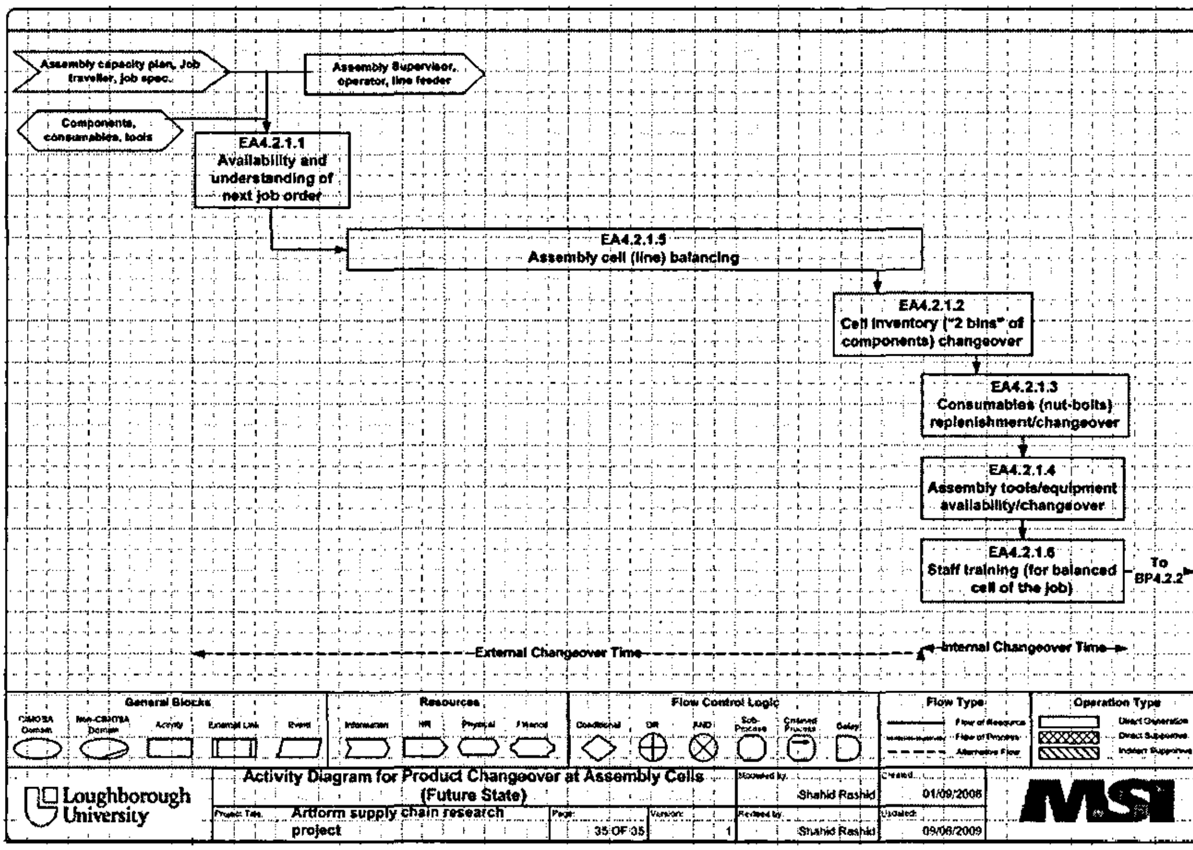

Figure 7.8 Activity diagram for product changeover at assembly cells-BP4.2.1 (Future State).

The To-Be model shows that changeover activities EA4.6.1 (availability and understanding of next job order) and EA4.6.5 (assembly cell (line) balancing) can be completely externalised, whereas 50% of the activity EA4.6.2 (cell inventory ("2 bins" of components) changeover) can be externalised. To externalise EA4.6.1 the Cell Assembly Supervisor needs to receive the next job order and specification and understand it before completion of any current job. EA4.6.5 can be externalised by performing a cell balancing time study (if required for new jobs) off the assembly cell without causing the assembly cell to be down. EA4.6.2 can be externalised 50% by start to change the 1 used/empty bin of components after half of the shift and to replace it with the bin of components for the next job. Figure 7.8 shows that about 70% of job changeover time can be reduced by externalizing and rearranging sequencing of the six activities.

To improve the realisation of individual enterprise activities shown in Figure 7.9, some additional suggestions were deduced which were considered.

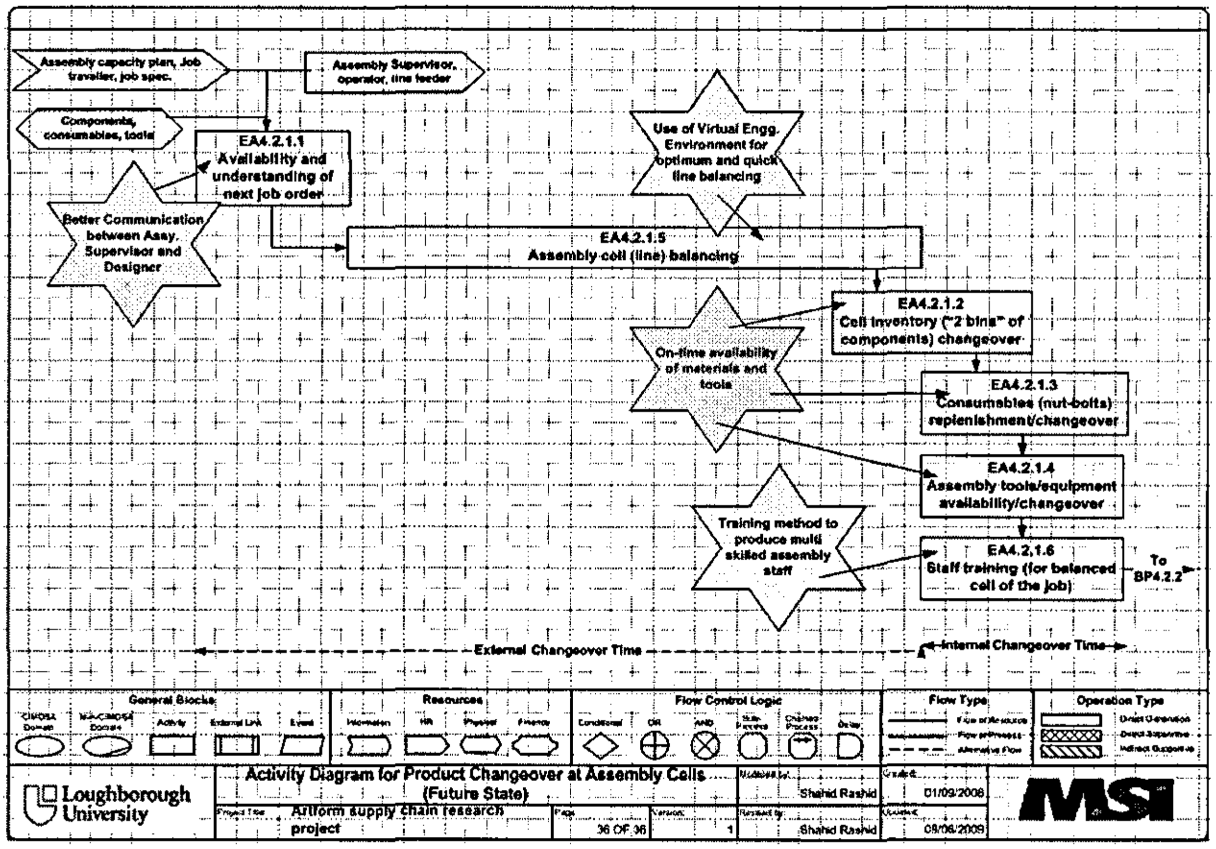

Figure 7.9 Future state activity diagram to illustrate improvement potentials for individual activities.

Figure 7.9 illustrates some improvement potential for individual activities of the changeover process at assembly cells. This is discussed as follows.

- Better communication between assembly supervisor and the designer is likely to result in the assembly supervisor having a much clearer understanding about the product specification and BOM before it is actually used for a changeover of product.
- A virtual environment can be developed by using public domain computer software tools like Timer Pro (Timer Pro, 2008) and Simul8 so that the performance of a balanced line can be tested on the software before the actual process is run. Also

maintaining a record of line balancing can enable reuse in future line balancing for similar products.

- Methods are required to ensure the time availability of components, materials and assembly tools and resources.

- A well designed training method is required to produce multi skilled trained staff which can perform all the assembly activities. This will add flexibility to the assembly cells.

7.4 Usefulness of enterprise modelling for the Artform

This chapter reports on the developmental and use of enterprise models created for Artform. These models used the four CIMOSA-MSI graphical templates which represented a big picture of processes used by Artform from a supply chain view point. The enterprise models depicted different actors and stake holders involved in the realisation of the selected context of the enterprise modelling i.e., manage, make and deliver products to fulfil customer orders. These enterprise models also documented relatively enduring aspects of interaction between DP's, BP's and EA's in the form of transfers of physical, information, human or financial resources. A detailed CIMOSA-MSI activity diagram was created to present process flows in process segments of concern to Artform managers, along with detailed depiction of transfers of information, materials, human and cash among the processes. This activity presented explicitly presented a process based picture of the internal supply chain of Artform. This process oriented enterprise model represents the internal supply chain, and as such it was used in different ways. Also the developed enterprise model depicted several issues related to the internal supply chain of Artform and this was subsequently re-represented in a structured way using the domain table. Furthermore, enterprise modelling was used to investigate a selected issue of product changeover at assembly cells by creating a current state activity diagram to explicitly describe requirements of the product changeover process for assembly cells. A well known quick changeover technique called

SMED was then used. This enabled the design of a significant improvement in the changeover process at assembly cells used by Artform. Enterprise modelling provided a suitable strength to demonstrate the improvement via the development of a future state activity diagram for a significantly improved changeover process at assembly cells.

Chapter 8: Use of methodology M2 for case study 2: Product classification and dynamic modelling of a point of purchase (POP) equipment manufacturing enterprise

The purpose of this chapter is to use product classification, causal loop diagramming (CLD) and simulation modelling (SM) techniques of M2 in the Artform case study (case study 2) and to assess its usefulness. In this chapter the issue of unavailability of components at the assembly cells is investigated in detail. Product classification is conducted to break down the complexity associated with high product variance in Artform's multi product supply chain for which the issue of component unavailability is generating significant problems. CLD is used to explore cause and effects impacts related to the issue of unavailability of components at assembly cells. In this regards, a detailed causal loop model was created to understand different dynamic factors effecting materials/components supply. This causal loop model helped identify key issues and key performance indicators which later can be used during simulation modelling. Simulation modelling was used to quantify impacts of issues of unavailability of components at the assembly cells. Due to the nature of case 2 which need abstract level complex investigation, a continuous simulation modelling tool (namely Stella) is used. The simulation model created encodes process, resource and workflow aspects of Artform's internal supply chain to enable simulation and quantification of behavioural aspects of its assembly cells when alternative component supplies are fed into the cells. Different what-if scenarios were tested to simulate and quantify the impact of the unavailability of components with reference to selected KPI's. In this way different possible futures are predicted. In the last section of this Chapter the usefulness of the product classification, and CLD's and SM are considered in respect of the Artform case.

8.1 Classifying Artform products

Artform realises a wide range of products in a variety of quantities. It mainly deals in the cosmetic and beauty care, consumer electronics and tobacco business sectors. Some of the features of Artform's product variance are described below.

- Product quantities fulfilled; order quantities range is from 1 to 1000 products
- Product variety fulfilled; 3 different business sectors, 12 different brands in cosmetics and beauty care business sector, 7 product classes for each of the 12 brands
- Approximately 5 Bill of Materials (BOM) released per day for different products

The product variance of Artform imparts a lot on the complexity of its multi product supply chain. This product variance is converted into a work variance; which is associated with different processes and operation times of processes needed to realise the products. To manage this complexity, the proposed product classification technique (detailed in chapter 6, see figure 6.4) was used for case 2 as described below.

- Step 1: Clear definition of purpose/application of the product classification; the purpose of this product classification is to help *manage, make and deliver products to meet customers orders.*
- Step 2: Selection of appropriate factors/views to choose a Pareto vital-few product class; the appropriate view needed to support the objective of this product classification, namely *plant capacity utilization.*
- Step 3: Analysis of historical data of all the ordered products for a suitable period of time related to the selected factors/views to identify a vital-few product class; customers orders data for the period January 2007 to December 2007 (1 year) is analysed in terms of the assembly capacity utilised for the customers orders. In this way the vital product class identified was "cosmetics" which utilises more than 95% of Artform's assembly

capacity. The remaining product classes are "consumer electronics" and "tobacco" (see figure 8.1).

- Step 4: For the vital-few product class, a secondary product classification was made by identifying those products that require the same processes for their realisation. This was achieved by using process maps (generated in the form of activity diagrams) during enterprise modelling (EM). By studying the routes taken by products as they pass through Artform's process network (as explicitly modelled the EM) it proved possible to draw out similarities between products so as to designate them as belonging to product sub classes. In the Artform case *make and deliver processes* are the primary processes considered when deciding upon process similarity among products included into the vital few class of products. In this way five sub classes were identified namely: cosmetics unit, cosmetic kit, cosmetic new/bespoke unit, cosmetic refurbished units and cosmetics print only kit jobs. These five sub classes and the assembly capacity each sub class consumes are shown in figure 8.1.
- Step 5: Within each process-based similarity sub class, a third stage classification was made by identifying products consuming more processing time than others, so as to form a tertiary processing time based sub classification of Artform products . Tertiary classification was made by analyzing historical process data, also collected for enterprise modelling (EM); with in two of the secondary sub classes, namely cosmetics unit and cosmetics kit, tertiary classification was made into *small cosmetics units, large cosmetics units, and small cosmetics kit and large cosmetics kit* (see figure 8.1).

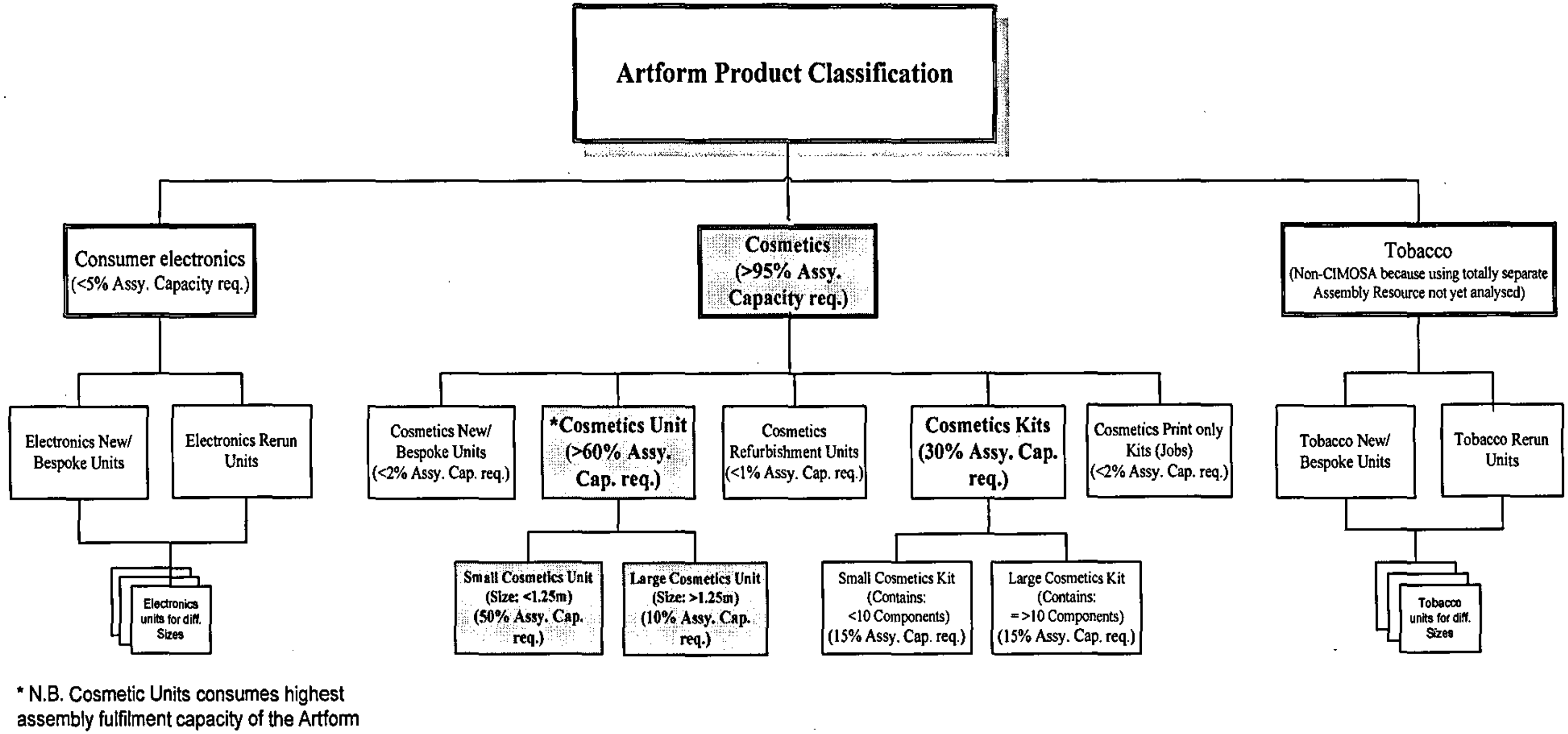

Figure 8.1 Product classification for the Artform products.

Cosmetic unit is the main class of Artform products from the viewpoint that this class utilised (in calendar year 2007) more than 60% of the Artform assembly capacity; out of which 50% is consumed for assembling small units, while remaining 10% is used to build large units.

8.2 Causal Loop Diagramming (CLD)

Causal loop diagramming was performed to study and explore the system dynamics associated with the issue of unavailability of components at cell assembly. In this regards a detailed causal loop model was created to understand the different dynamic factors effecting material supply disruption and delay into cell assembly. This is shown in figure 8.2. The diagram covers the important process domains associated with the observed issue of material supply. Those process domains are customers (DM1), suppliers (DM2), subcontractors (DM6), produce designs (BP3.2), purchase process (BP5.1), goods-in-store process (BP5.2), make components (DP4.1), super market inventory issue/receipt (BP5.6), assemble and pack products (DP4.2) and the dispatch process (DP4.3). All of those domains (DMs) (and their associated Domain Processes (DPs), Business Processes (BPs) shown in dotted blocks), and the descriptions associated with DM, DP or BP elements, are consistent with the attributed labelling of the enterprise model created for Artform (and presented in chapter 7).

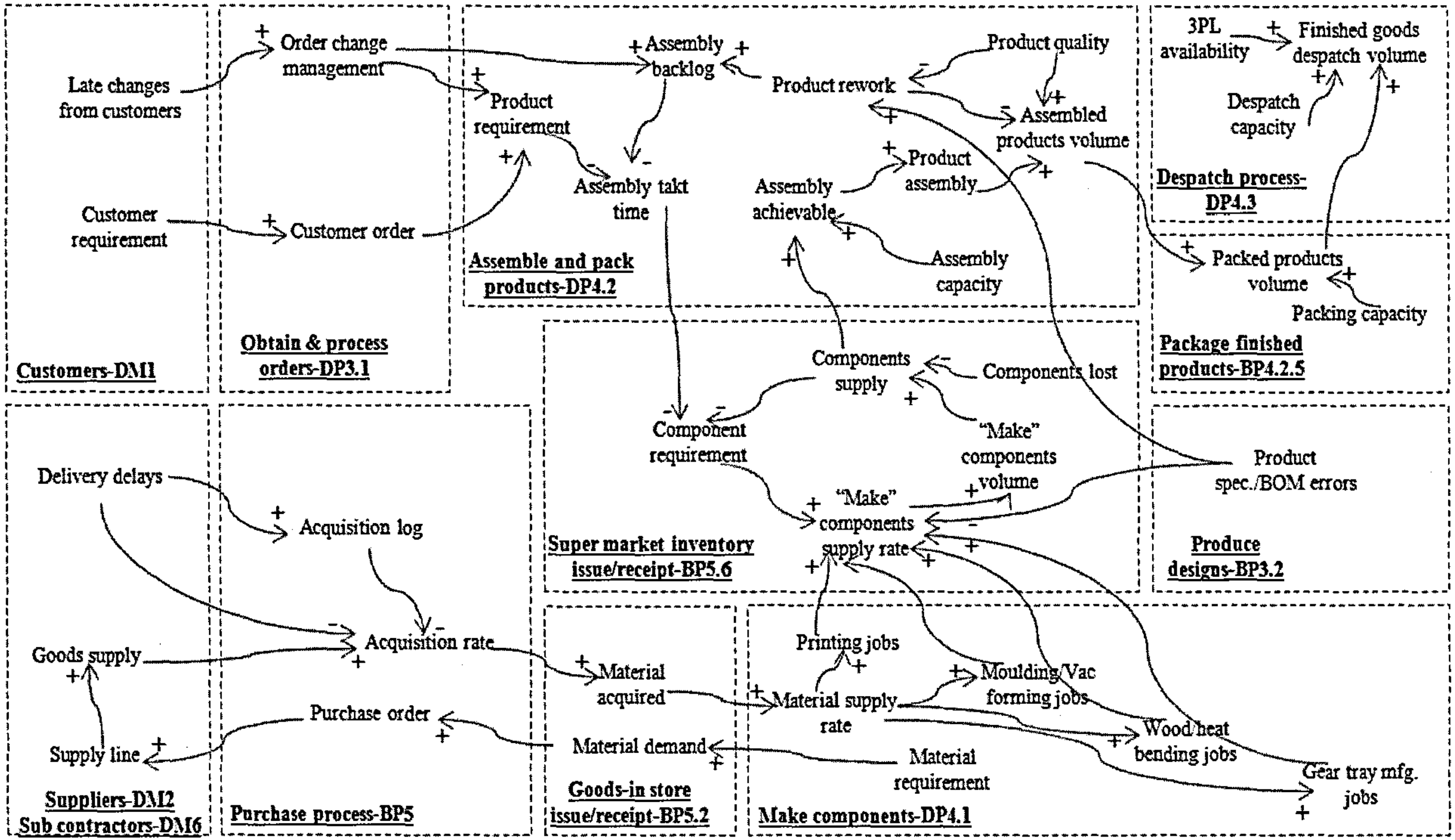

Figure 8.2 Causal loop diagram representing supply chain dynamics.

Figure 8.2 explores the causes and their effects associated with material availability issue at the assembly cells. It makes this exploration in a structured and integrated way by generating the causes and effects related to all the relevant and interacting processes. For instance, it can be seen in figure 8.2 that the issue of components unavailability is related to customer domain (DM1), due to late changes requested by the customer. The other cause is assigned by the produce design business process (BP3.2), where product specifications and BOMs have some errors causing delays in component production and their availability. There is some delivery delays associated with the supplier's domain (DM2) and sub contractor's domain (DM6), as well which causal delays in materials and out sourced component availability. There are some components lost in the super market inventory business process (BP5.6), during the associated issue and receipt process elements, which cause delay in components availability at the assembly cells.

The result of all of these supply chain issues presented in the above paragraph can be seen in terms of different variables or key performance indicators (KPIs) like super market stock , and product throughput rate at assembly cells. However the causal loop diagram can only depict qualitatively (i.e. an increasing or decreasing trend) that indicates how different cause and effect variables impact on the selected KPIs. Some of the outcomes deduced from the causal loop diagram are arranged into table 8.1.

Table 8-1 Cause and effect table for the components unavailability issue.

Supply chain KPIs / Supply chain Issues	Super market stock	Product through put rate at Assembly Cells
Late changes from customers	Increase	Decrease
Product spec/BOM errors	Increase	Decrease
Components lost	Increase	Decrease
Components quality	Increase	Decrease

Table 8.1 shows for example, that if the supply chain issue of late changes from the customer has an increase this would likely increase the super market stock and it would likely decrease the product through put rate at the assembly cells. Similar trends for other supply chain issues can be deduced for product spec./BOM errors, components lost and components quality problems, as presented in table 8.1.

8.3 Simulation modelling (SM) of Artform material supply issues

Simulation modelling was performed to quantify impacts of delivery delays of components at assembly cells and their impact on supply chain performance in terms of selected KPIs; namely super market stock and product throughput rate at assembly cells. Causal loop diagramming explored different causal variables impacting on the delivery of components at assembly cells. Continuous simulation modelling was used to model the Artform material supply chain in relation to the observed issue of delivery delays of components at the assembly cells. There were a few reasons for choosing to use a continuous simulation modelling to quantitatively model this situation namely ; i) continuous simulation modelling can naturally computer execute models of stocks and flows, which can be linked to the quantification of selected KPIs, which in case 2 were super market stock volume and product throughput rate at assembly cells, ii) several causes, and their causal effects, that delay the delivery of components at assembly cells can be readily and suitably modelled with continuous simulation modelling, iii) an abstract level analysis is required to quantify impacts of several causal variables on the selected KPIs; and the underlying multiple differential equation solving abilities of continuous simulation modelling suit this kind of high level abstract modelling . The computer software tool Stella was chosen and used to perform the required continuous simulation modelling. In the Stella software, stocks are represented via a rectangle, while a flow is shown as a double lined arrow with a valve in the centre of the arrow. Round shaped converters are used to input data so as to regulate flows, according to equations attributed to those converters. All the flows are required to be generated from a stock, i.e. a source, and are required to be absorbed by a stock, or sink. All the stocks and flows need to be connected as per relationships in the actual observed case. Also causal variables need to be connected with other connectors and related stocks and flows. The designed principle in the Stella is that a stock is regulated only by its incoming and outgoing flows and connectors can only use feedback from the stock but cannot input to a stock. However, connectors can regulate flows by providing inputs. A simulation model was created in Stella to model the Artform components supply chain (see figure 8.3). The stock and flow portion of the model is created by re-using structures and parameters previously encoded by the enterprise model created for the Artform supply chain (see chapter 7, figure 7.5). To develop this simulation model, different causal variables and KPIs were modelled by re-using structures and variables previously encoded by the causal loop diagram presented in figure 8.2. To input data related to multi products and work variance, outcomes from the product classification were re-used.

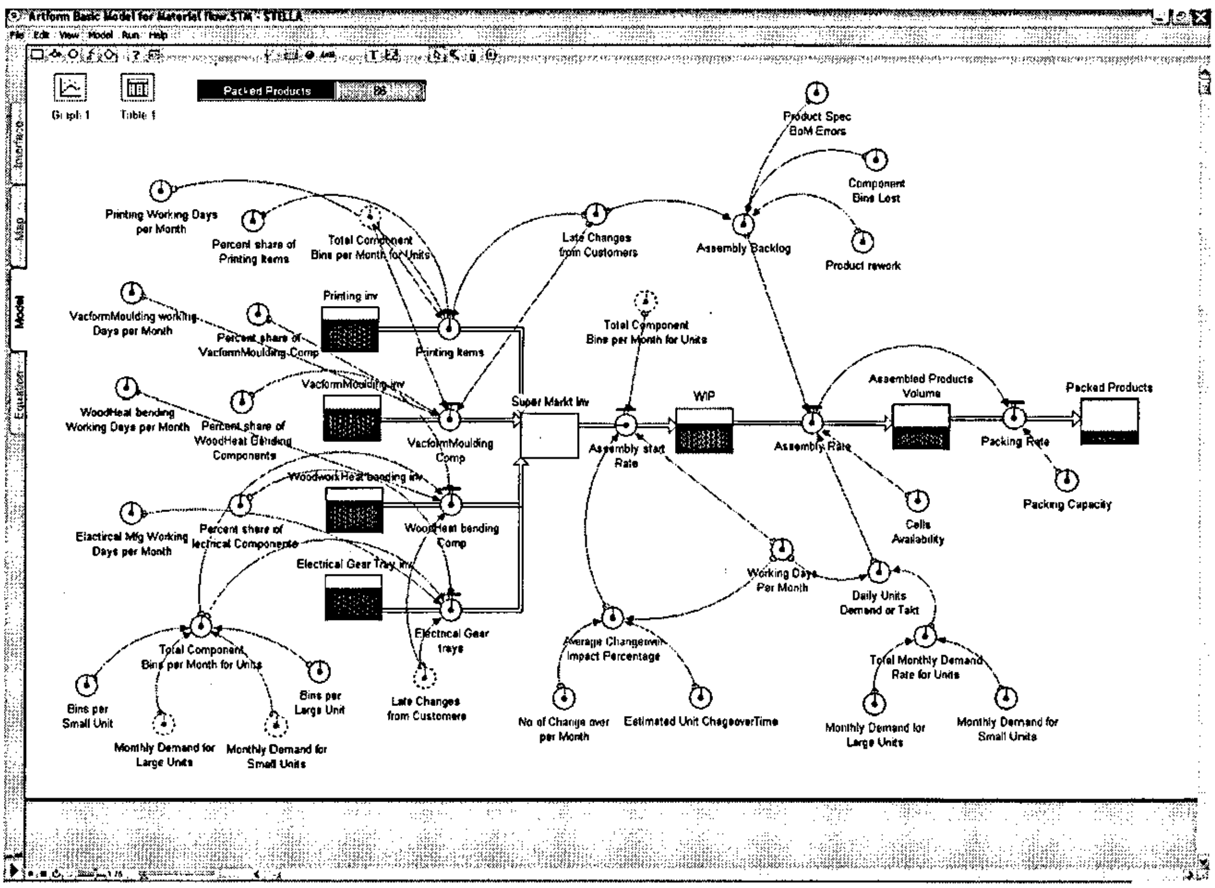

Figure 8.3 Simulation model for the components unavailability issue at assembly cells.

Figure 8.3 shows a screen snap shot of screen of the continuous simulation model created using Stella software included in the model are equations describing Artform's four component manufacturing departments that realise the components and push components into the super market inventory. The components are then pulled by the assembly cells as per customers demand rates. Assembly cells realise the assembled products which are then pushed into the packing process, then packed products are stored as stock. Some converters are then introduced to characterise stock and flows conditions as per real material flows. Additional converters were used to introduce the causal variables associated with the observed issue of delivery delay in components at assembly cells. Different values assigned to these variables were then simulated and the ensuing results were analysed with respect to the selected KPIs. The two tertiary product sub classes, namely small cosmetics unit and large cosmetics unit were selected as representative of the product flows through the cell assembly system, so as to manage complexity introduced by product variance at Artform.

There are some assumptions which were made to simplify the observed problem.

- It is assumed that all components are transferred from the manufacturing departments in component bins.
- Return supply chains and their component bins were not modelled and it was assumed that their bins are always available at their point of fill (i.e. at components manufacturing departments).
- It was also assumed that basic raw materials for primary manufacturing departments like synthetic granules, plastic, paper and ply wood sheets, printing inks, jigs and fixture and tools are readily available for use.
- A fixed percentage of the total number of bins are assumed to be provided by each primary manufacturing department for the product class modelled (i.e. cosmetics unit), up to a certain batch size.
- 1 week of safety stock of components was assumed to be stored as super market inventory.
- All 4 primary delay issues, namely "late changes from customers", Product spec./BOM error", "Components lost", and "Product quality", were assigned values in terms of their occurrence percentage.
- Proficient packing and delivery facilities are assumed.
- It is assumed that the assembly work for the selected product class “cosmetics unit” is realised via 7 assembly cells. This was analysed on the basis of share of assembly capacity utilised for the cosmetics units for the year 2007.

The model operation was verified for the above taken assumptions by using historical data and their results. Different scenarios were tested using the verified simulation model. The inputs and the results from the simulation experiments are shown in table 8.1. The simulation period selected for the simulation was 1 month which is considered to be a suitable duration in terms of material stocks at the super market inventory and for the assembly of the selected products (small and large cosmetics units) at the assembly cells.

Table 8-2 Simulation input and results.

Supply chain issues → / Supply chain inputs & results (KPIs) ↓		Late changes from customers (a)		Product specification/ BOM errors (b)		Components quality issues (c)		Cumulative Effect of (a), (b) and (c)	
		Current State	Ideal state	Current State	Ideal state	Current State	Ideal state	Worst case scenario	Ideal state
Inputs	Percent occurrence of SC issues (%)	4%	0%	5%	0%	5%	0%	(a=4% & b=5% & c=5%)	0%
	Average Customers demand rate of "cosmetics units" (units/day)	140 units/day							
Results	Throughput rate of "units" (units/day)	120	140	110	140	107	140	85	140
	Super market stock (no. of bins)	2710	2508	2980	2508	3010	2508	3745	2508

The simulation results presented in table 8.2 show that each of the selected supply chain issues (a), (b) and (c) can affect the required rate of assembled cosmetics units per day; which is 140. These 140 units are allocated 7 assembly cells for their daily fulfilment. Due to the supply chain issues (a-c), which cause a delay in the availability of component supply at the assembly cells, the actual throughput rate is less than that required. This often is known to create assembly cells scheduling problems, resulting in late deliveries to customers and backlog of assembly work, requiring extra shifts and over time to finish the job. This also increases components in stock bins in the super market inventory. The reason is that as assembly cells operate on the principle that all the components should be available before start of assembly process. Therefore, due to the unavailability of some components needed to assemble certain cosmetics units, the rest of the components have to remain in the super market inventory. A worst case scenario is simulated when all of the delay issues occur at the same time. The results for the worst case scenario predict a significantly slow throughput rate of 85 units/day and also that a super market inventory can build up to 3,745 bins, which might create a capacity constraint on the super market inventory as a whole.

8.4 Usefulness of the product classification, CLD models and SM for the Artform case study

This chapter report on the application of the product classification, causal loop diagramming and simulation modelling techniques used in an integrated way as part of methodology M2. The product classification was made using the defined step by step approach and as a result a vital product class "cosmetics" was identified. This class was sub-divided into five process based similarity sub classes; namely cosmetics unit, cosmetic kit, cosmetic new/bespoke unit, cosmetic refurbished units and cosmetics print only kit jobs, and then into tertiary processing duration based sub classes; namely small cosmetics units and large cosmetics units, and small cosmetics kits and large cosmetics kits. The secondary cosmetics unit sub class with its two tertiary sub classes, namely small cosmetics unit and large cosmetics unit, utilise the large majority of assembly capacity; therefore it was selected as a representative product class for further investigation. The same share of assembly resource was considered to realise the cosmetics unit product class (i.e., 7 assembly cells which constitute about 60% of assembly capacity while in the year 2007 the assembly capacity utilised by the cosmetics unit product class was 60%). The selected product classes small units and large units were therefore used in the simulation model with their related share of 7 assembly cell utilizations for assembly realisation. This approach to handling the complexity associated with high product variance at Artform helped later to much simplify the design of the simulation model yet allowed this model to provide very useful results related to a very significant portion of all products made by the case company. Causal loop diagramming was performed and a detailed causal loop model was created to explore causes and effects related to the issue of unavailability of components at Artform assembly cells. The causal loop model explicitly identified key issues and key performance indicators associated with the focused issue of components unavailability. These cause and effect variables, along with the identified KPI's, were used to design a simulation model using a continuous simulation modelling technique. The simulation model was created to model behaviours of the Artform internal supply chain. Resultant simulation modelling quantified impacts of the issue of unavailability of components at the assembly cells. Different what-if scenarios were simulated. Different possible futures were thus predicted. In summary, all of the three techniques (product classification, CLD and SM) that formed part of methodology M2 were used in the Artform case study and were found useful in terms of their desired functionality.

Chapter 9: Conclusions

The main aim of this research was to "to develop and test use of an integrated modelling methodology to support decision making about complex supply chains". To fulfil this aim, the following objectives were defined.

Objective 1. To study state of the art modelling techniques that have potential for the analytical design of complex supply chains.

Objective 2. To develop an integrated modelling methodology for the analytical design of complex supply chains.

Objective 3. To case test and update the integrated modelling methodology for the analytical design of complex supply chains.

The capabilities envisaged for the integrated methodology for the analytical design of complex supply chains were as follows:

- graphically represent and explicitly describe key characteristic properties of complex supply chains.
- analytically explore dynamic properties of complex supply chains, via the provision of analytic means of reasoning about impacts of uncertainty in complex supply chains, such as those introduced due to changes in demand, supply, make, delivery and return processes.
- predict possible futures of complex supply chains when certain types of uncertainties that may arise.
- quantify and predict behavioural aspects of complex supply chains when they are subjected to observed uncertainties or risks (potential uncertainties).

To fulfil the defined aim and design and build the modelling methodology to provide the required characteristics, a review of supply chain literature was carried out (see chapter 2).

The supply chain review included coverage of some basic concepts and described the historical evolution of supply chain theories. Different supply chains paradigms were reviewed and several important issues associated with supply chains were identified. The issues identified were presented in few main classes; namely demand, supply, make, and plan. Different existing modelling techniques were reviewed which have potential to support the analytical design of complex supply chains. In this regard, different modelling techniques namely enterprise modelling, causal loop diagramming and simulation modelling techniques were reviewed. Some existing methodologies were also reviewed that were designed to integrate the use different modelling techniques in a unified way, so as to analyse and solve manufacturing problems. Analysis of the reviewed work showed that there existed no integrated methodology in the existing research in the field of modelling supply chains which can fulfil the set of characteristics required to analytically design complex supply chains.

To choose the overall research approach for this research, general know how about different types of research was reviewed (see chapter 3). Keeping in view needs of this research, it was deduced that applied research, descriptive research and a combination of quantitative and qualitative research are the relevant research types to be undertaken. Some data collection methods were reviewed and it was concluded that this research required use of both primary and secondary data collection methods: including interviews and observations. Also different types of case company documents like process charts, value stream maps, sales data, quality records, inventory records, and design and BOM data would be required and used, as available. A general step by step research approach was presented to fulfil the research need of developing an integrated methodology for the analytical design of complex supply chains.

9.1 Design of an integrated methodology for the analytical design of complex supply chains and novelty of this research

In this research an integrated methodology for the analytical design of complex supply chains was conceived and developed (for details see chapter 4). Specified capabilities of the integrated methodology were required, as discussed in section 9.0. Different modelling techniques namely enterprise modelling (EM), causal loop diagramming (CLD) and simulation modelling (SM) were reviewed and analysed in this regard. It was observed that many researchers around the world, and extensively in MSI, have used EMs to capture big a picture of processes used by particular enterprises operating within a specific business context. Therefore, EM was chosen as a technique for graphically representation and explicit description of key relatively enduring characteristic properties of complex supply chains. It was observed that CLD is a widely used technique to capture mental models of different dynamic situations, presented in terms of causes and its effects. Due to this capability of CLD, it was selected to analytically explore dynamic properties of complex supply chains and provide analytic means of reasoning about impacts of uncertainty in complex supply chains, such as those introduced due to changes in demand, supply, make, delivery and return processes. Also CLD was chosen to predict possible futures of complex supply chains in which uncertainties can arise. It was observed that SM was used as a technology to simulate different what-if scenarios and numerically quantify different performance variables associated with different scenarios. Hence SM was selected to quantify and predict behavioural aspects of complex supply chains due to observed uncertainties or risks (potential uncertainties). By using the chosen modelling techniques systematic use of an integrated methodology was proposed (referred to in this thesis as M1). M1 was designed to support the analytical design of complex supply chains. The novelty associated with the proposed integrated methodology are; i) use of EM, CLD and SM in a unified way to support the analytical design of complex supply chains; this was a new concept and this kind of a methodology was not available in the supply chain literature prior to the author's study, and ii) development of a new domain table concept, to explicitly describe and present issues, bottlenecks and potential improvements in a structured way so as to support an improved integrated use of EM, CLD and SM.

9.2 Usefulness of methodology M1

The proposed methodology M1 was used in the case of a parking and valeting company (referred to as "ABC") (for details see chapter 5). In the ABC case the integrated methodology for the analytical design of complex supply chains was used and most of the characteristics of the M1 methodology were found to be useful in terms of satisfying the purpose for which they were selected. For instance, the CIMOSA based MSI EM templates were found to successfully represented, explicitly document and graphically describe a big picture of ABC's processes from a supply chain view point. The developed models captured and graphically presented different important perspectives about the ABC supply chain, like transfers of information, physical, finance and human entities. Also the EM identified some issues, bottlenecks and potential improvements areas in the ABC supply chain. The identified issues, bottlenecks and potential improvements were arranged in a structured way in the domain table. The arrangement was in four categories, namely: information, physical, finance and human aspects. Causal loop diagrams were created for a couple of selected issues namely information shortfall and training shortfall at ABC reception. The causal loop diagrams explored the system dynamics associated with the selected issues. Also causal loop diagrams analysed qualitatively dynamic behaviours of supply chain issues in cases of uncertainty or change introduced. Furthermore the causal loop diagrams helped to identify supply chain key performance indicators (KPI's) for the selected issues. Also SM was performed which usefully supported quantitative analysis of dynamic behaviours of the supply system associated with the selected issues. The simulation results were presented using the supply chain KPI's.

9.3 Enhancement of methodology M1

Case study 2 was the case of a point of purchase (POP) equipment manufacturing company, namely Artform International (Limited) UK. Unlike the ABC parking and valeting case study 1, Artform had to manufacture a wide variety of POP products demanded in different quantities by their large customer base. To realise this high product variance, complex supply chains were in place. To model the Artform supply chain with its high product variance enhancements were observed to be required to methodology M1. Therefore new product classification technique was introduced to break through the complexity. In this way an enhanced integrated methodology composed of EM, CLD, SM and product classification techniques was developed and proposed (referred to in the thesis as M2) (for details see chapter 6). M2 was considered to be an improved version of M1 as it had capabilities to support the analytical design of complex supply chains. The novelty of M2 was associated with a new way of classifying products and by integrating use of the product classifications with SM. Also use of a couple of drafting tools was adopted to improve the use of M2. The tools adopted were then used to improve; i) the efficiency of data collection when creating the EM and SMs and ii) to increase the speed and quality of drafting enterprise models onto computer to enable behavioural modelling.

9.4 Usefulness of the enhanced methodology M2

The proposed methodology M2 was used in the Artform case (for details see chapter 7). In Artform the enhanced integrated methodology for the analytical design of supply chains was used and the designed characteristics of the M2 methodology were found useful in terms of providing the purposes for which they were intended. For instance, the CIMOSA based MSI EM templates successfully represented and graphically documented the big picture of the Artform processes from a supply chain view point. The developed models captured and graphically presented different important perspectives of this supply chain, like transfer of information, physical, finance and human. Also the EM identified some key issues, bottlenecks and potential improvement areas. The identified issues, bottlenecks and potential improvements were arranged in a structured way in the domain table into its four categories namely information, physical, finance and human entity groupings. An important issue in the Artform complex supply chain concerned product changeover at assembly cells; so this issue was selected for further investigation for which activity diagrams from the Artform EM were re-used to represent current relatively enduring temporal flow of the process associated with the selected issue. A well known technique for quick changeover namely SMED was used in conjunction with the process map derived from the EM to determine which changeover activities could be externalised. The conceptual design generated in this way promised significant improvement to the product changeover process at Artform assembly cells. The new conceptual design and process improvement was then represented using a modified activity diagram as part of the Artform EM.

Another important supply chain issue concerned the unavailability of components at assembly cells and this was also selected as a subject for further analysis (for detail see chapter 8). A causal loop diagram was created for the selected issue. This causal loop diagram explored system dynamics associated with the whole Artform complex supply chain, and thereby characterised causal relationships between different causal and effected variables and their possible impacts on the unavailability of components at the assembly cells. Also this causal loop diagram analysed qualitatively dynamic behaviours of material supply system associated with the selected issues in the case of any uncertainty or change introduced to the supply chain system. Furthermore, the causal loop diagram help identify some KPI's as objective functions of the analysis. Product classification was performed and the complete range of Artform's customised products was classified into a few important and similar product classes; on the basis of their required resource utilization and their processing requirements. One of the most important product class was then selected as a subject of detailed SM. SM was performed for the selected product class to quantitatively analyse dynamic behaviours of the supply system associated with the unavailability of components at the assembly cells. The simulation results were presented in terms of the chosen supply chain KPI's.

In summary, all the four techniques of the M2 namely EM, CLD, SM and product classification complement each other and provided improved supply chain understandings and analysis capabilities in the manner expected during the design of M2. Therefore it is concluded that the usefulness of M2 in analyzing a specific complex supply chain, such as that used in the real Artform case was proven in case study 2.

9.5 Some research limitations and suggestions for future research

Some research limitations and suggestions for future research are organised into the following categories.

- **Research application**

This research developed an integrated methodology for the analytical design of complex supply chains. During the period of this PHD research the developed methodology was applied on two case studies; one of which was related to a service company and the second was a manufacturing company. These two case studies showed the usefulness of the developed methodology and also help identify reasons to enhance the methodology. In both the case studies, detailed data, and access via visits, was only available for the case companies and not for its suppliers and customers. Therefore, the developed methodology for the analytical design of complex supply chains was mainly tested in respect of the internal supply chains of the case companies.

In future the integrated methodology for analytical design of complex supply chains can be used for modelling and analyzing complete supply chains (including external supply chain segments) to observe the usefulness of the developed methodology.

- **Enterprise modelling (EM)**

EM showed its usefulness in both the case studies conducted in this research in terms of graphically representing processes, by formally decomposing the process-oriented context in which subject process segments of concern need to operate. In this way it explicitly describes key characteristic properties of the requirements of complex supply chains. However, it was observed that additional modelling concepts and therefore capabilities can be introduced into Ems, such as to explicitly represent ; i) max level of storage and work in process (WIP) inventory designed in the complex supply chains, and ii) detailed representation of standard times for end to end processes flows in the complex supply chains. Using (ii) it is expected that critical path(s) can be defined for each product to be realised by the complex supply chain.

- **Causal loop diagramming (CLD)**

CLDs also provide support towards the aim of this research; this being which evident in both case studies. However, further research could systemised and therefore improve the process of finding KPI's through using CLDs.

- **Simulation modelling (SM)**

SM showed its usefulness in both the case studies by quantifying dynamic behaviours of supply chains for different what if scenarios. Thereby it was proven to enable prediction of future behaviours of an observed system related to selected issues and objective functions. In both of the case studies the developed simulation models can readily be extended and re-used to perform supply chain wide simulations at a high level of abstraction; this facility could usefully support policy level decisions for complex supply chains, like: the selection of suitable paradigm in complex supply chains; size of inventory required (strategic stocks needed) in the case of a selected paradigm; and inventory turnover for a given selected paradigm etc.

- **Product classification**

The technique of product classification was used in the Artform case study. Product classification was design to simplify the design of and use of models whilst maintaining sufficient quality and clarity of model purpose. It did this by seeking to reduce the impacts of complexity introduced by the high product variance. Here many different products were consolidated into a few important product classes; which were believed to be representative of all members assigned to each class. The important product classes were then used as the subject of simulation experiments. The product classification technique developed was observed to simplify the simulation modelling of the Artform complex supply chain. However, further research needs to be conducted to systematically integrate the use of product classification with SM so as to enhance achieved analytical benefits.

Publications

1. RASHID, S., MASOOD, T. & WESTON, R. H. (2009) Unified modelling in support of organisation design and change. *Proc. IMechE Vol. 223 Part B: J. Engineering Manufacture, page 1-25.*

2. RASHID, S., KHALID, S. & WESTON, R. H. (2007) Model driven organization design and change. 4th Intl conference on Responsive Manufacturing (*ICRM07).* Nottingham university, UK. 17th -19th September, 2007.

3. RASHID, S., AGYAPONG-KODUA, K. AND WESTON, R. H. (2008) Business process value analysis using an analytical hierarchical process. 6th Intl. Conference on Mfg. research (ICMR08) Brunel University UK 6th -9th September, 2008.

4. KHALID, S., RASHID, S., AND WESTON, R.H. (2008) Productivity enhancement in a manufacturing enterprise by improving management processes. 6th Intl. Conference on Mfg. research (ICMR08) Brunel University UK 6th -9th September, 2008.

Appendix I Current state enterprise model for Artform

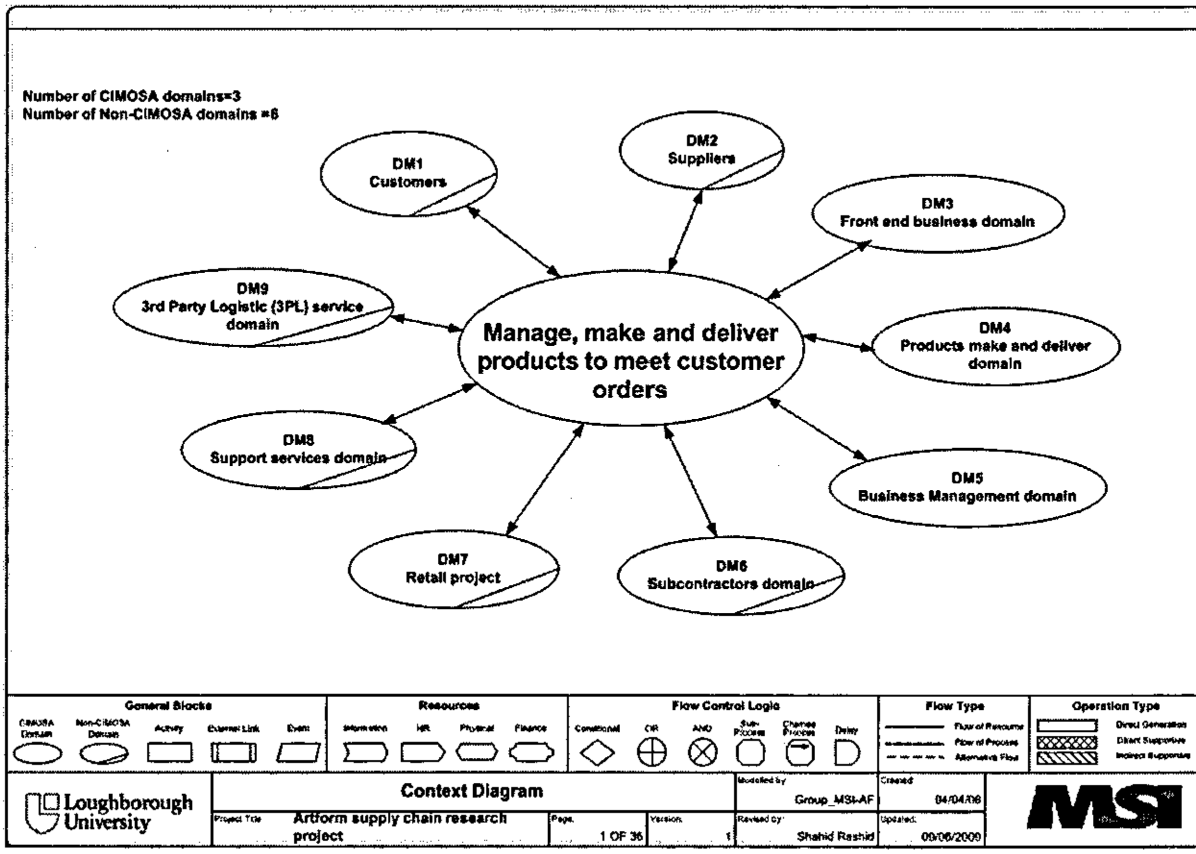

Figure 1: Top level context diagram

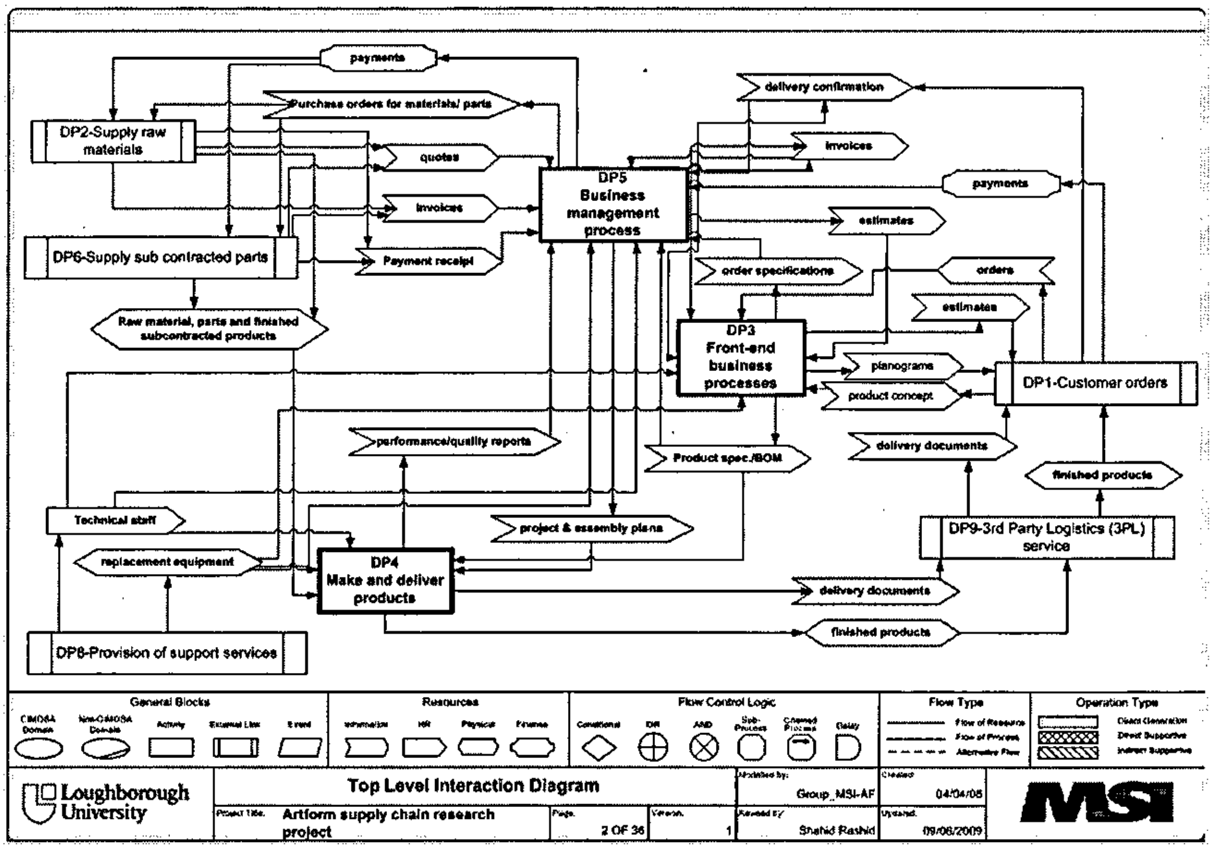

Figure 2: Top level interaction diagram

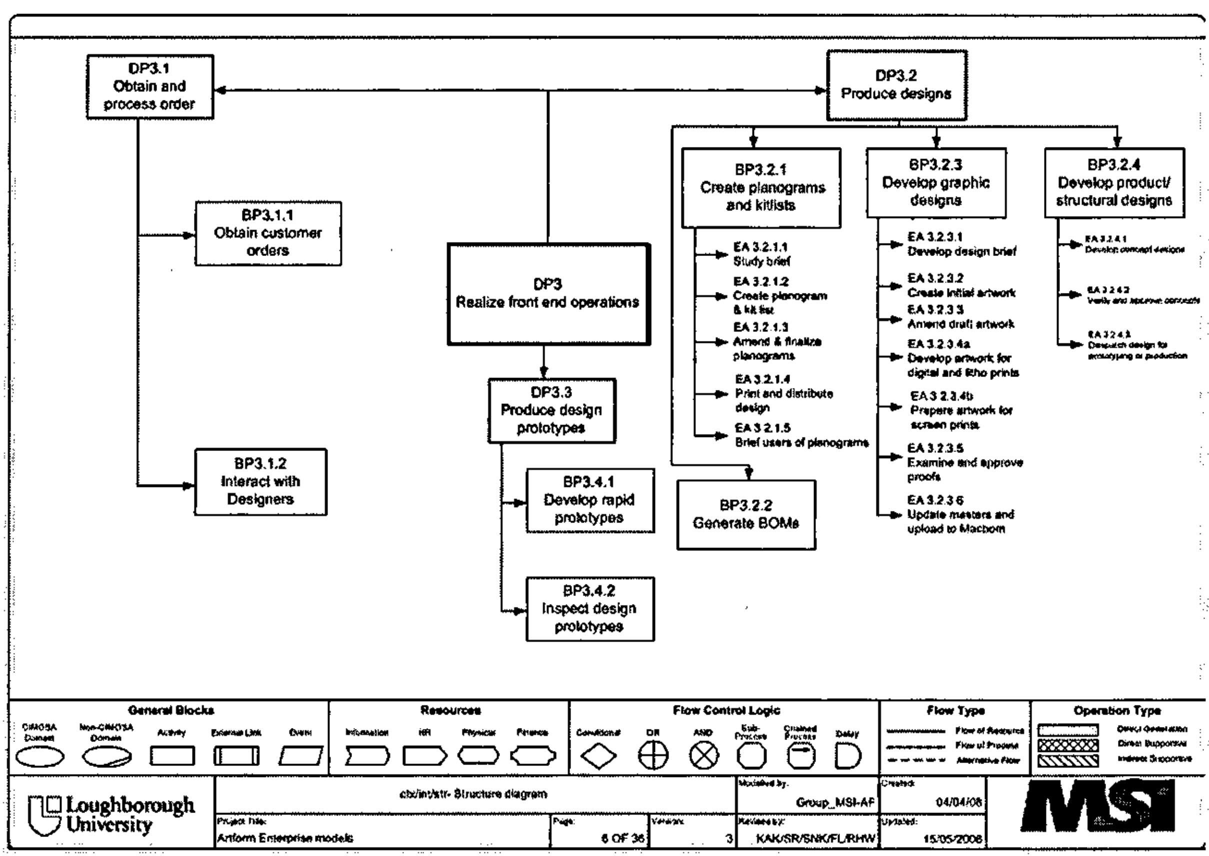

Figure 3: Structure diagram for DP3

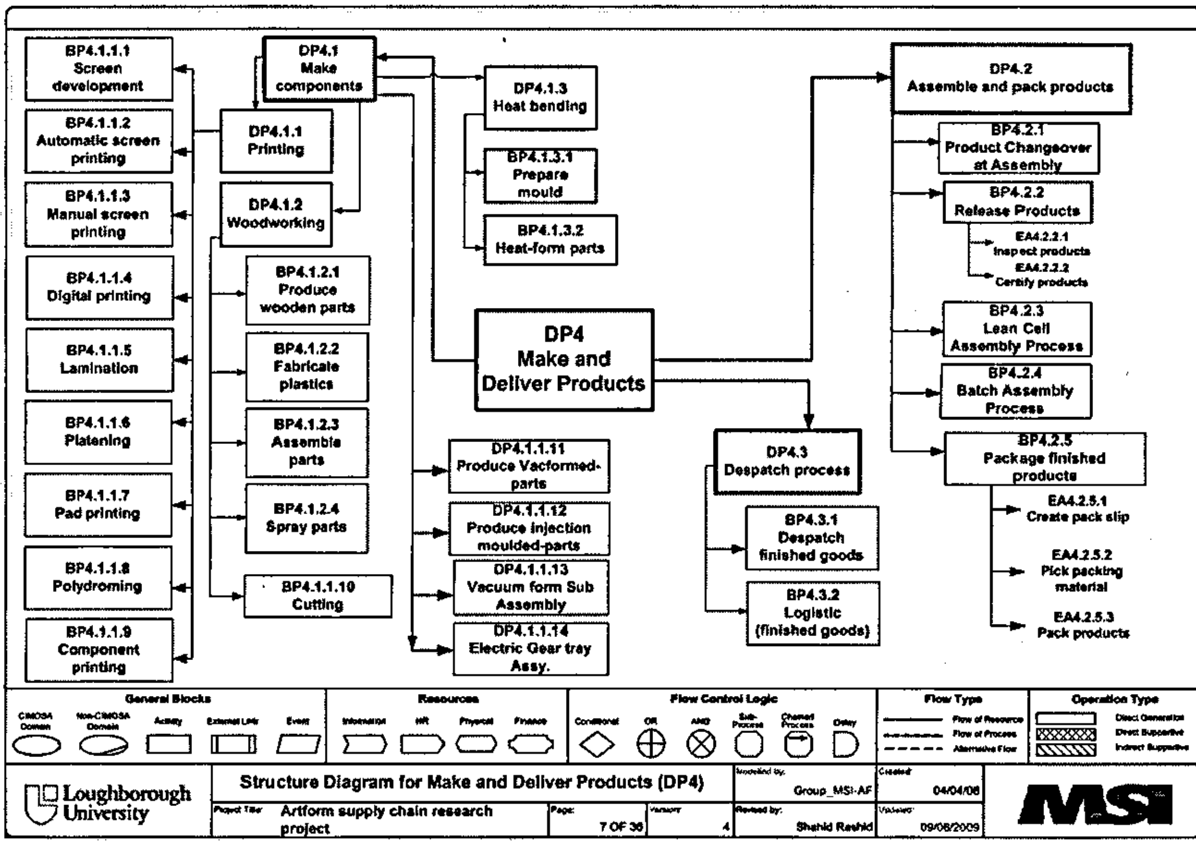

Figure 4: Structure diagram for DP4

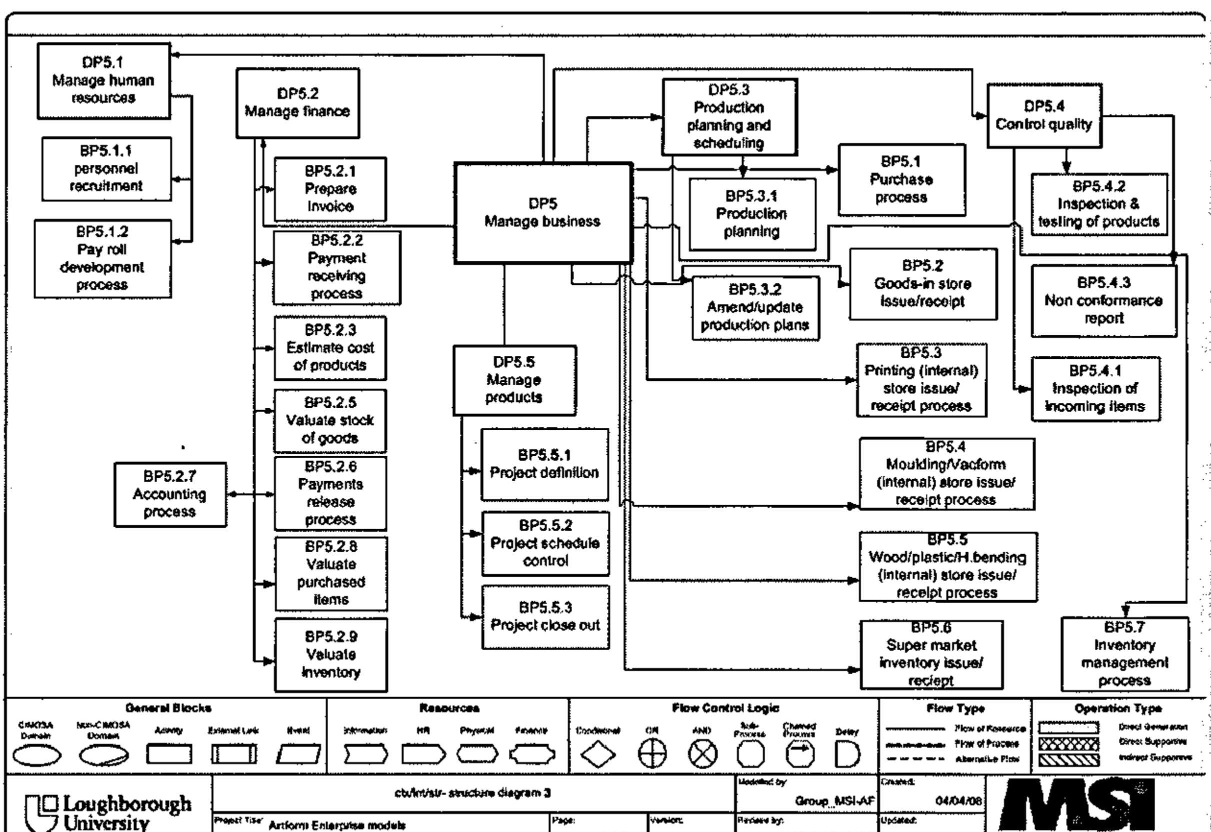

Figure 5: Structure diagram for DP5

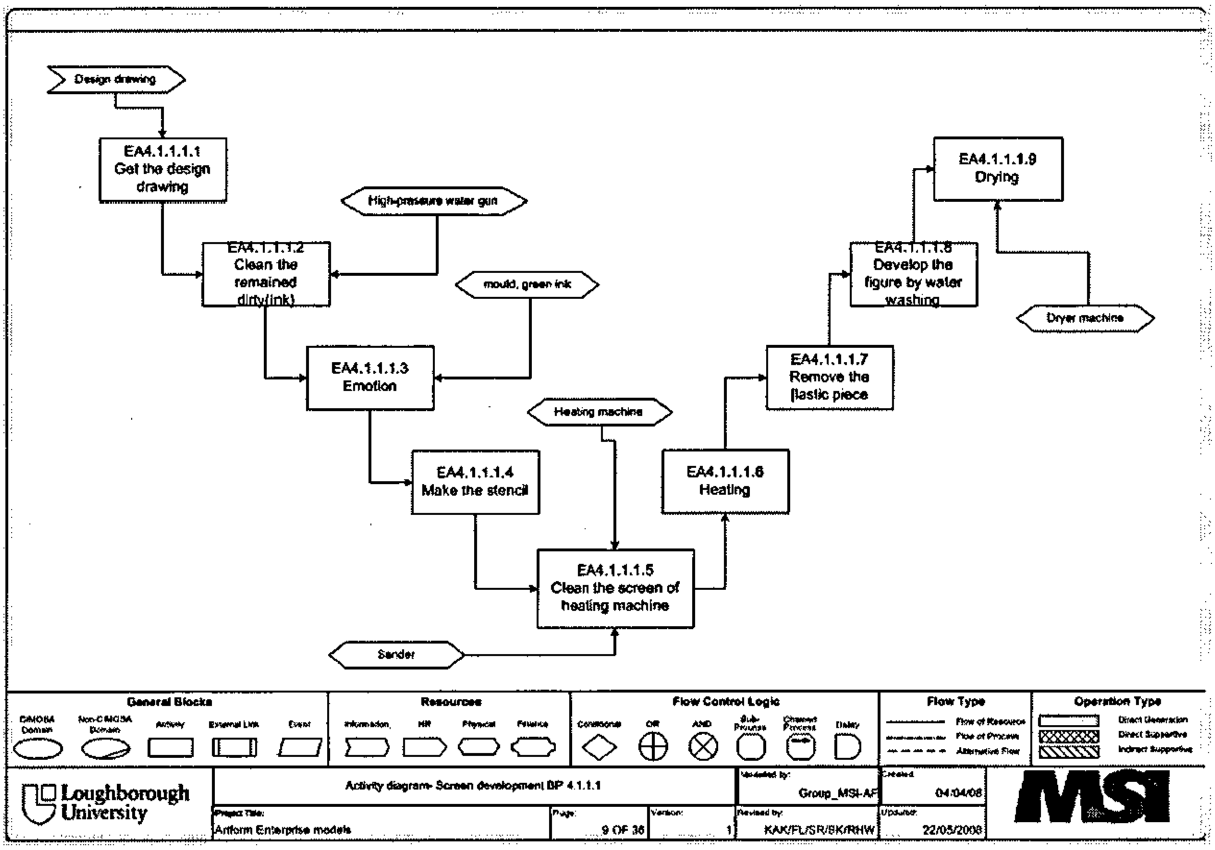

Figure 6: Activity diagram for BP4.1.1.1

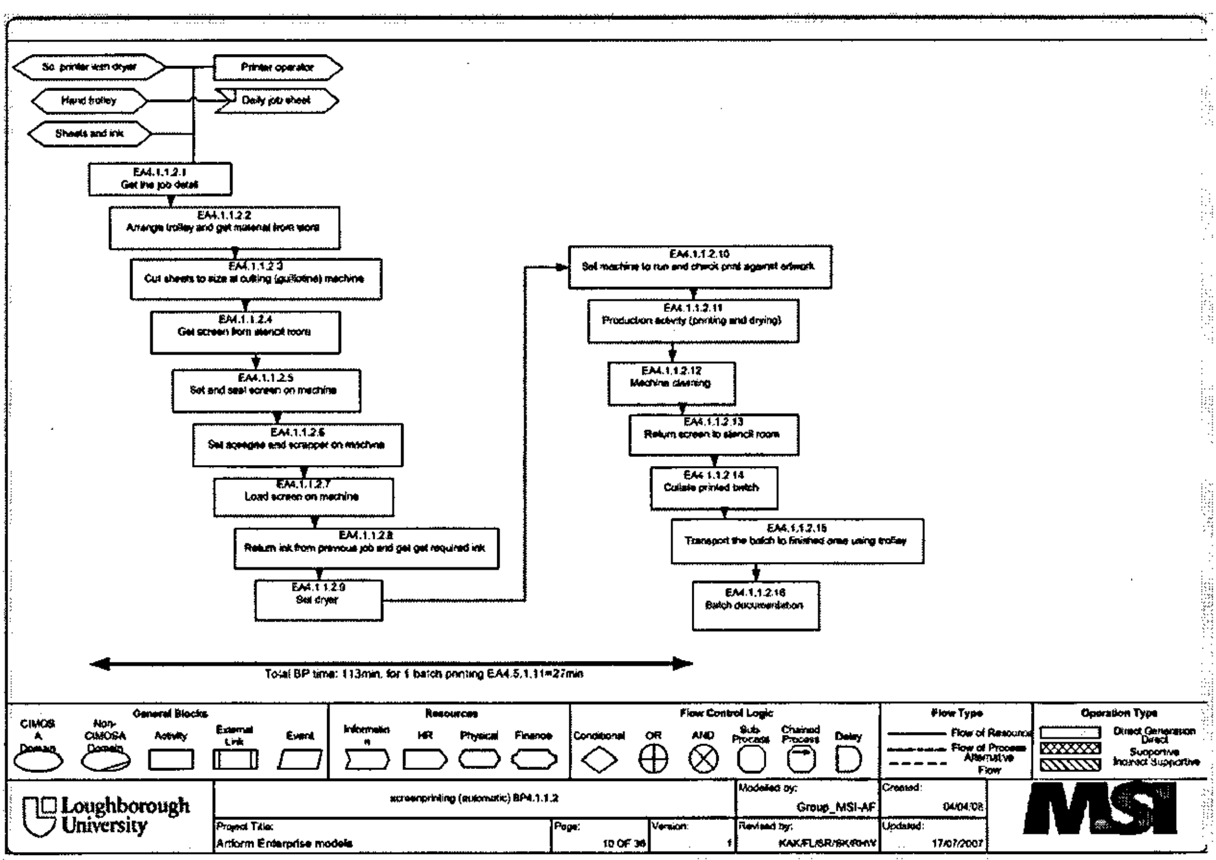

Figure 7: Activity diagram for BP4.1.1.2

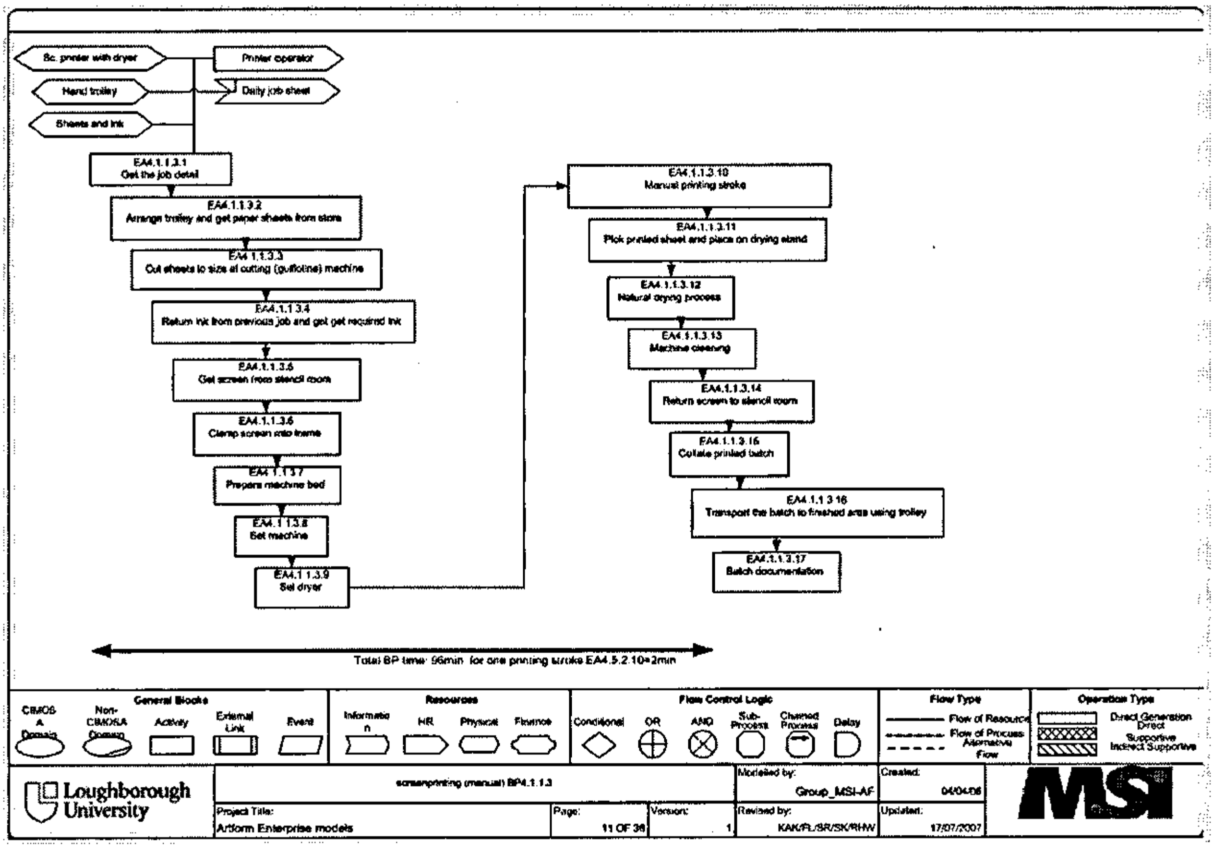

Figure 8: Activity diagram for BP4.1.1.3

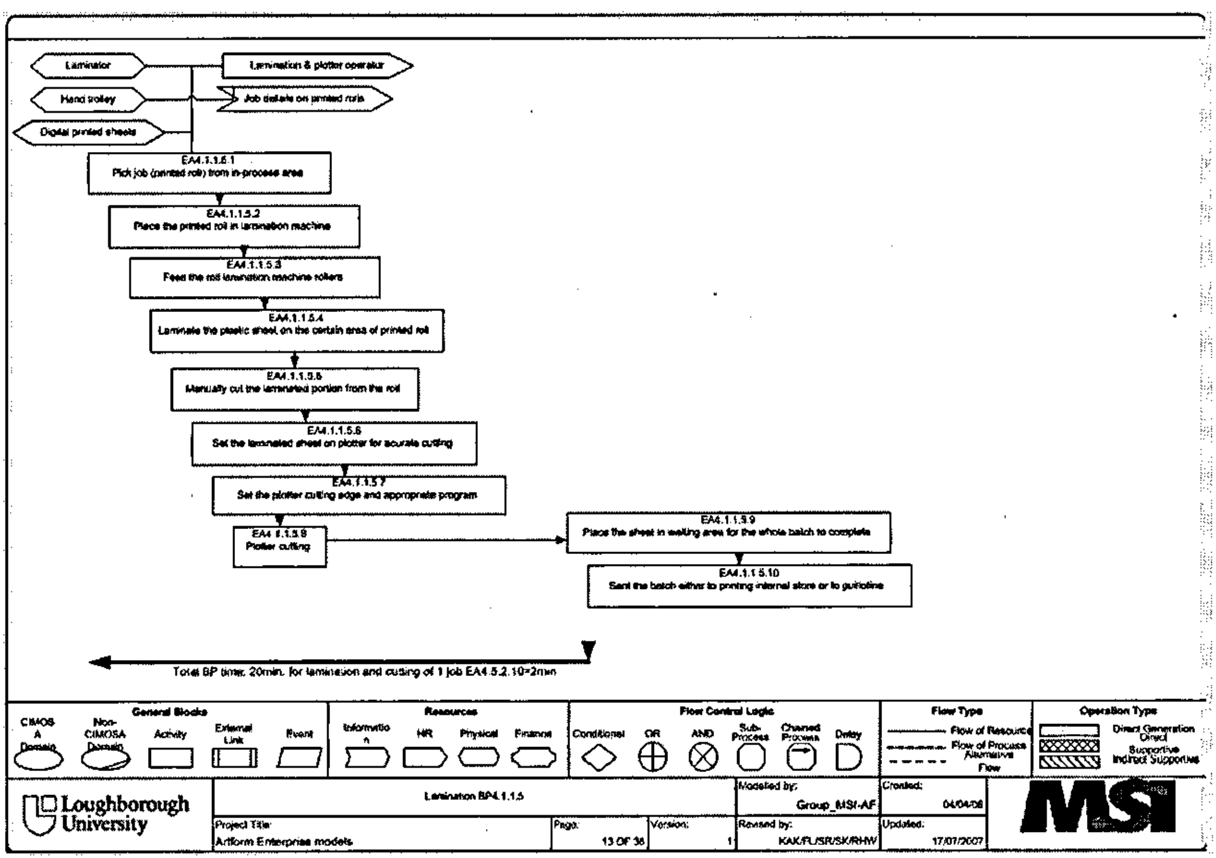

Figure 9: Activity diagram for BP4.1.1.5

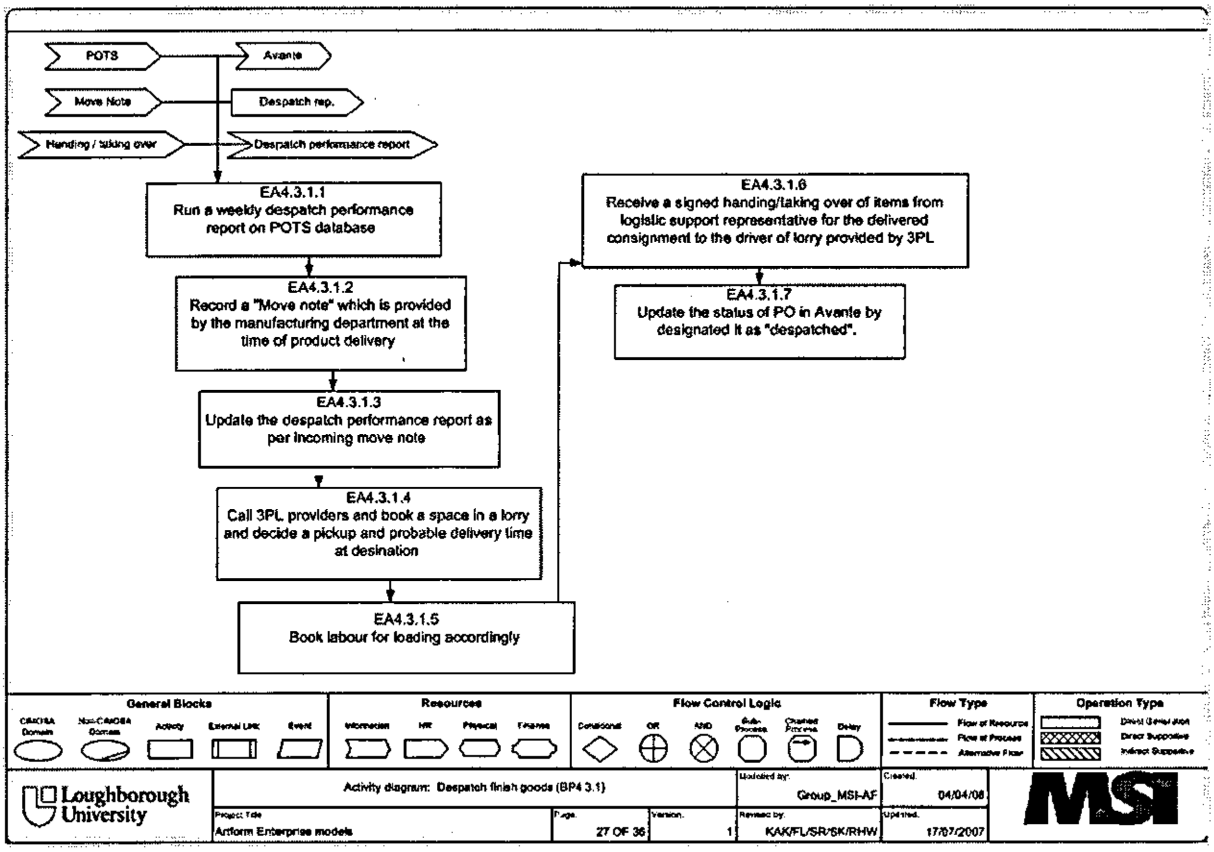

Figure 10: Activity diagram for BP4.3.1

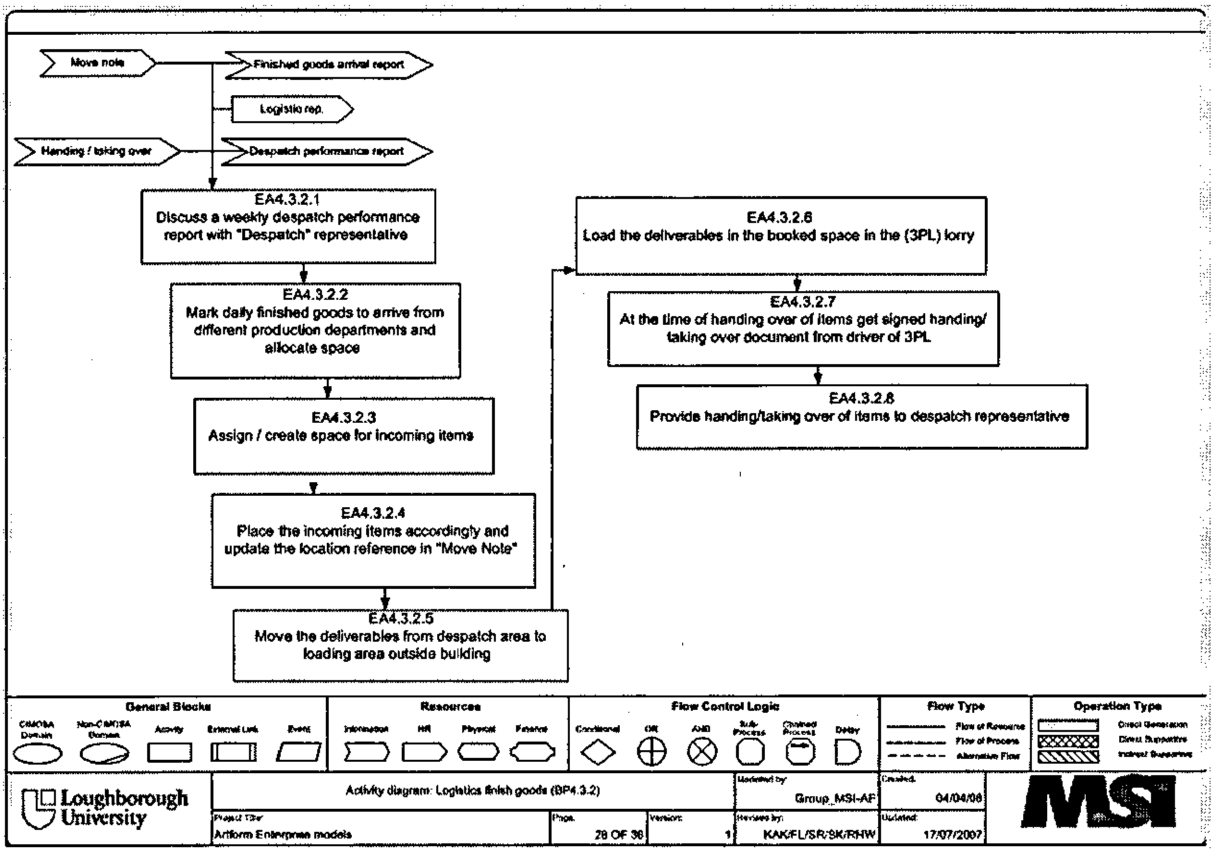

Figure 11: Activity diagram for BP4.3.2

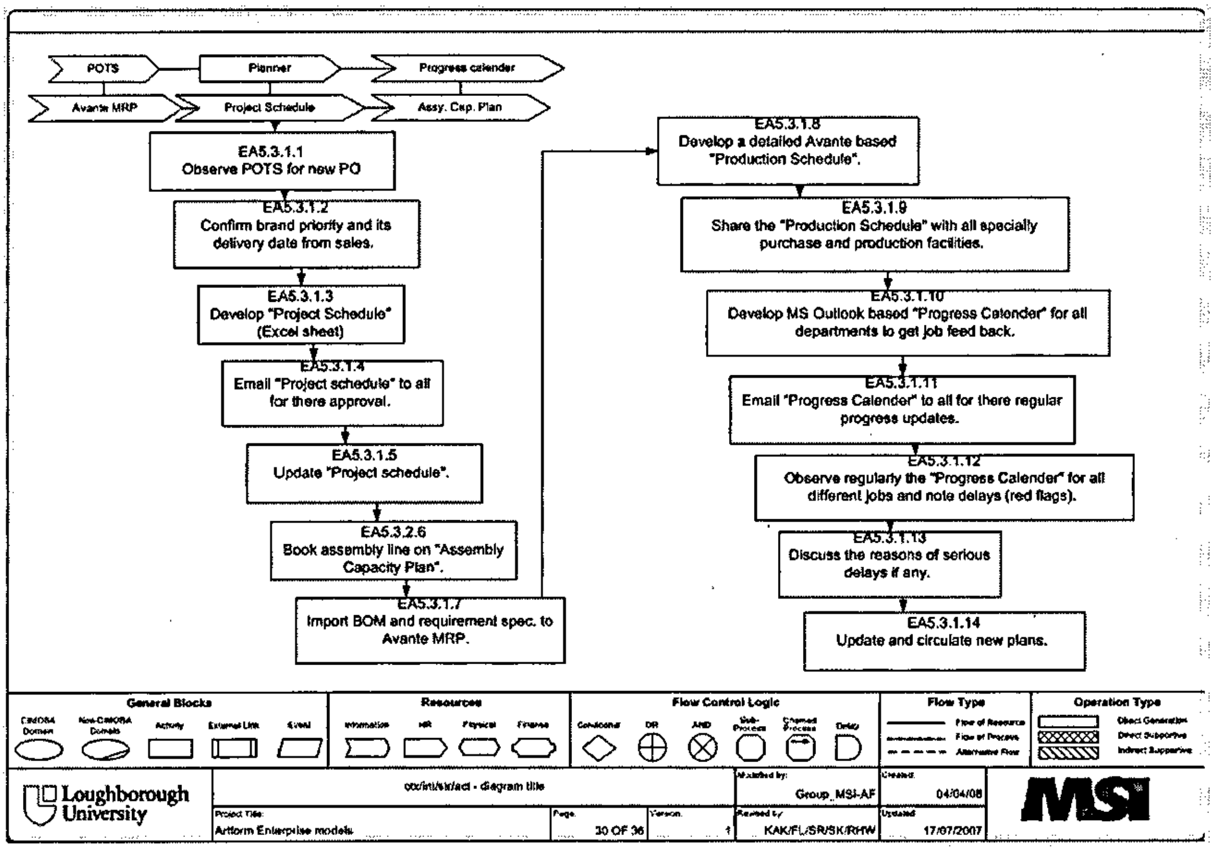

Figure 12: Activity diagram for BP5.3.1

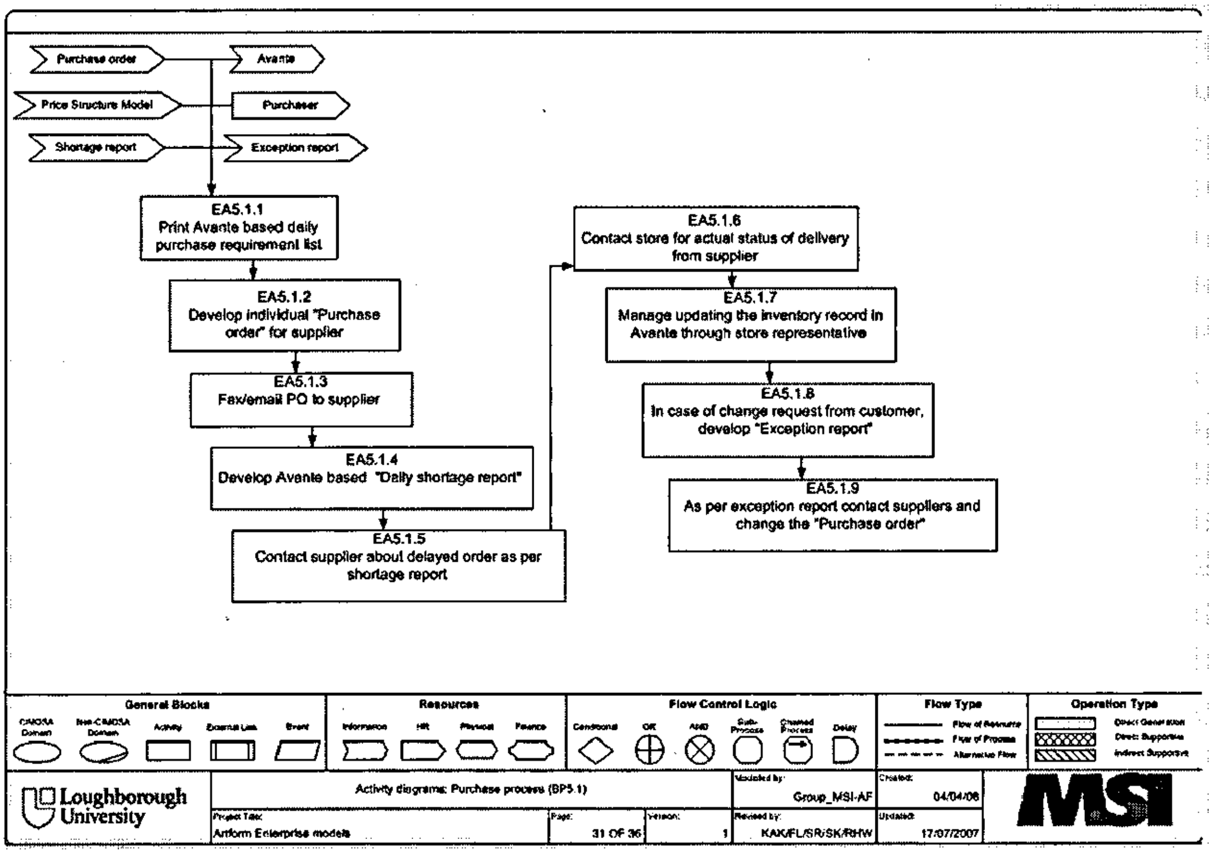

Figure 13: Activity diagram for BP5.1

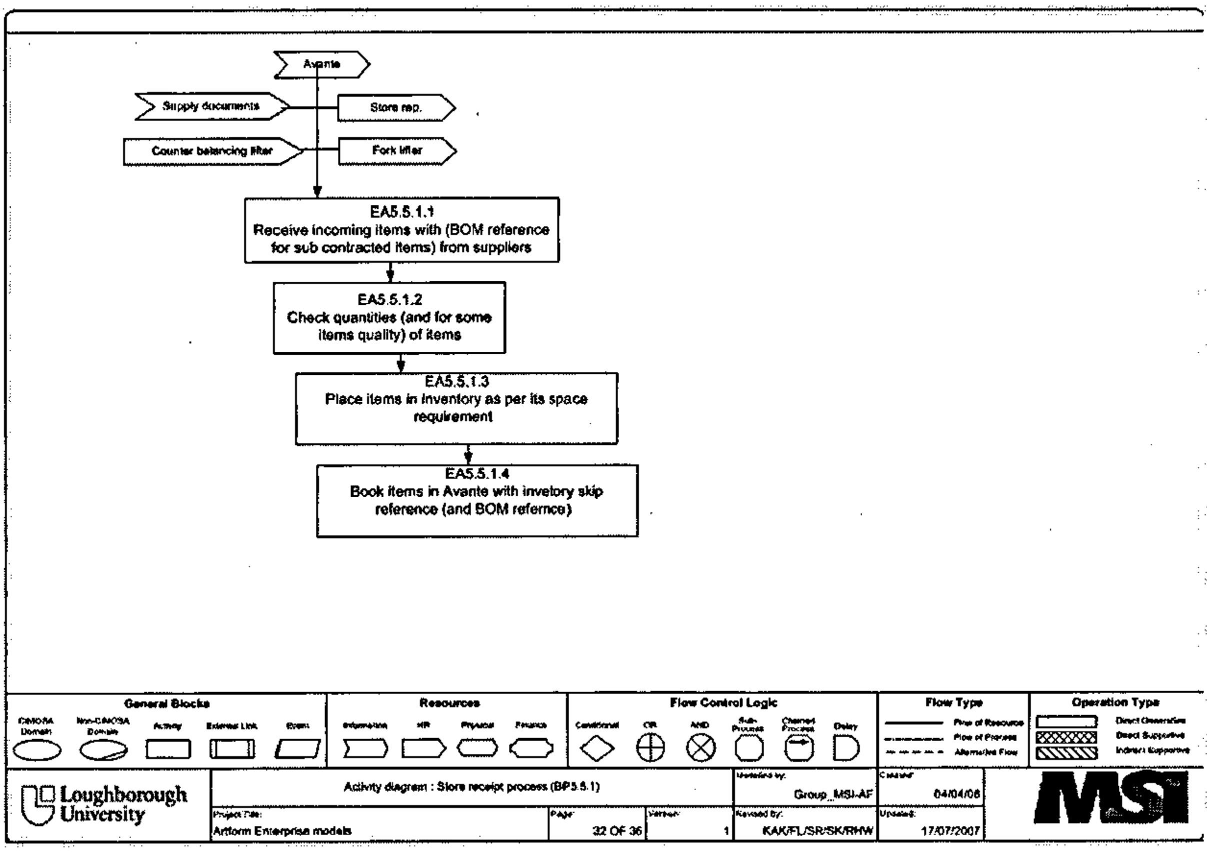

Figure 14: Activity diagram for BP 5.5.1

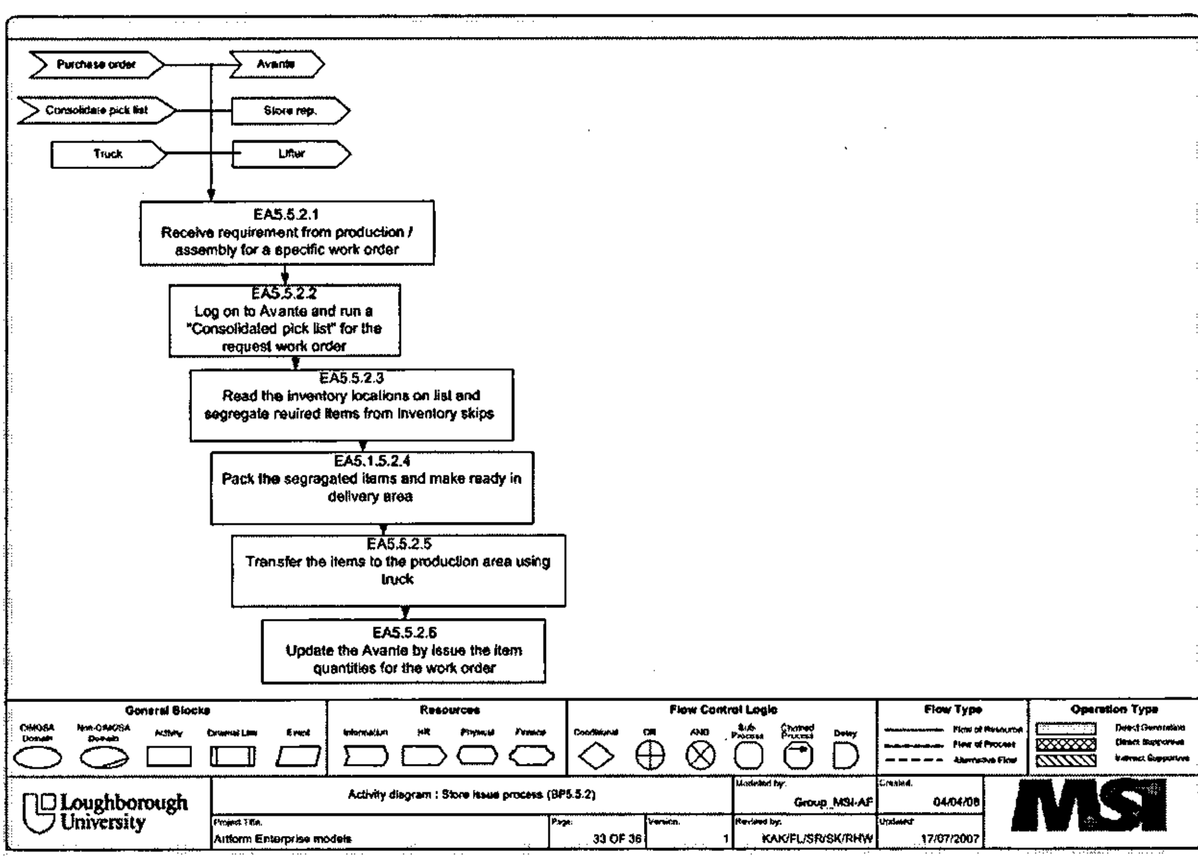

Figure 15: Activity diagram for BP5.5.2

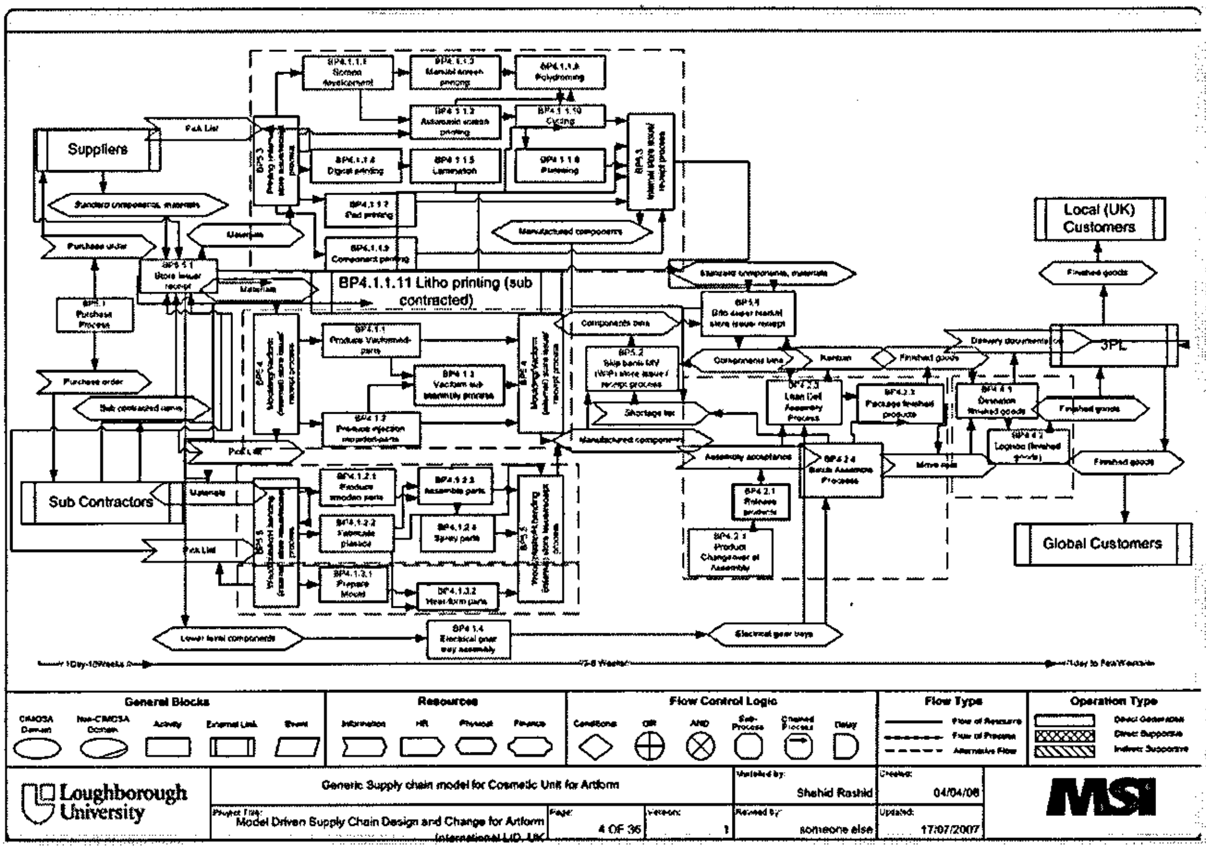

Figure 16: Activity diagram representing supply chain of Artform products

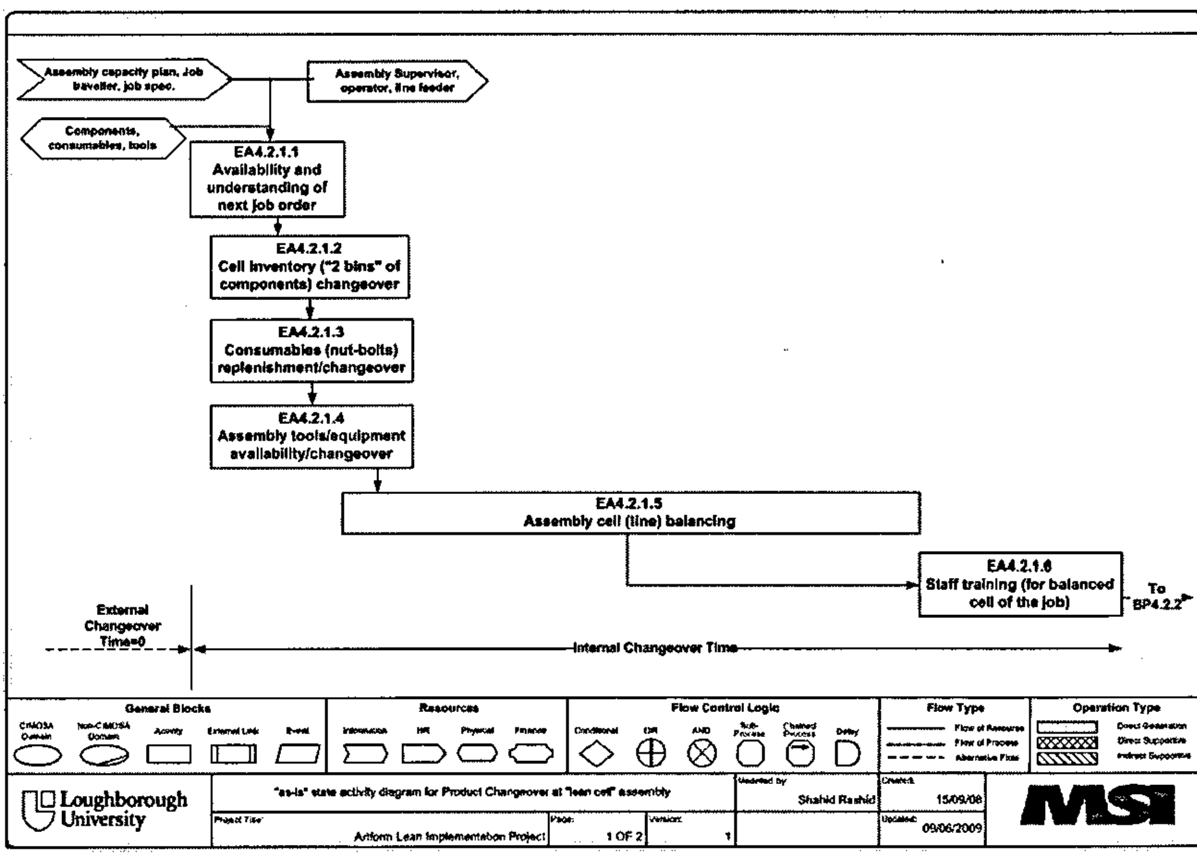

Figure 17: Activity diagram for BP4.2.1

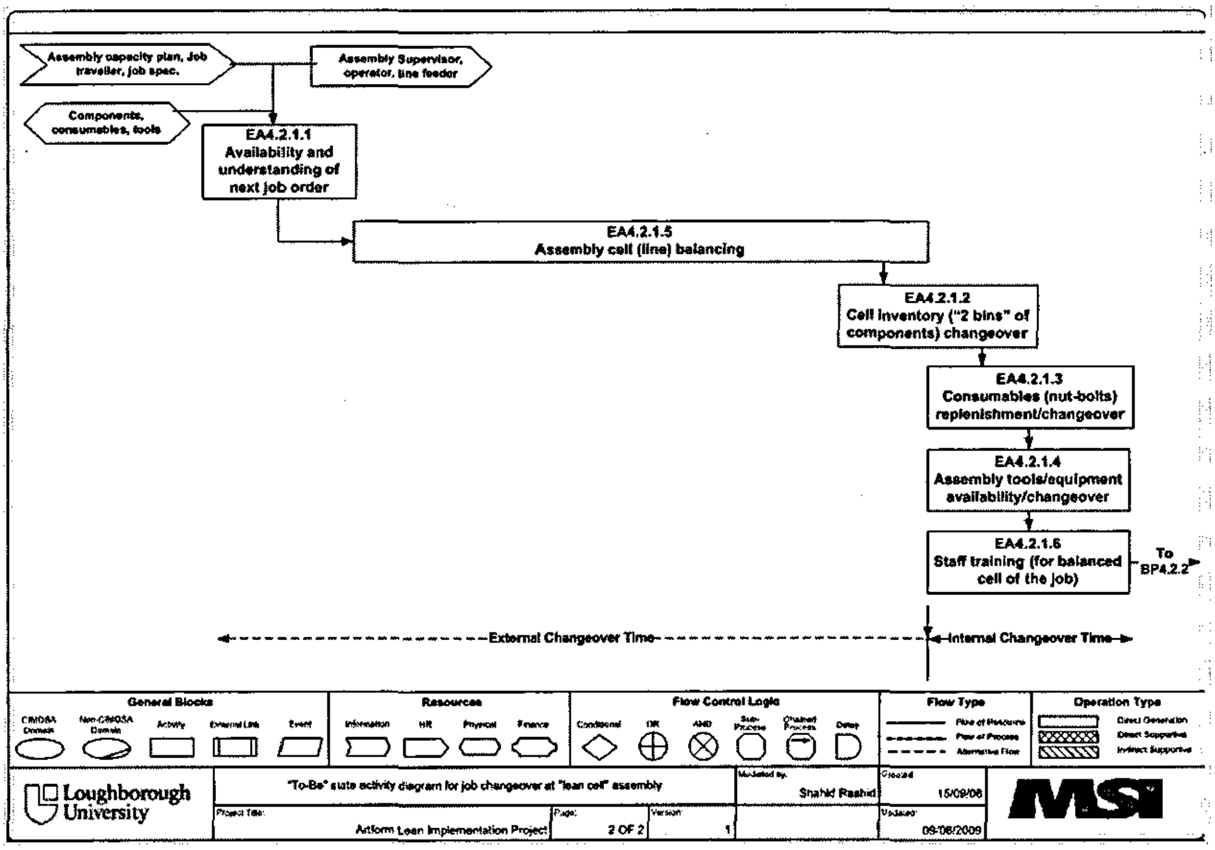

Figure 18: Activity diagram for BP4.2.1 (proposed future state)

Appendix II Data in support to develop EM and SM for Artform

Collective capture of data for Activity level modelling											
Process name	Screen Printing (automatic)			BP ID	BP4.5.1				Modeller	Shahid Rashid	
Previous process				Next process					Process In-charge		
		Input							Output		
Activity	EA ID.	Info/Data	Material resource	Number of human resource	Machines	Tools	Activity Repetition (a)once/activity (b)once/batch (c)once/shift	Operation time (minutes)	Output info/Data	components	Comments
Get the job detail	EA4.5.1.1	Job traveller?		1			(b)	10			
Arrange trolley and get material from store	EA4.5.1.2		paper sheets	1		hand trolley	(b)	7			
Cut sheets to size at cutting (guillotine) machine	EA4.5.1.3			2	Paper cutting	hand trolley	(b)	6			
Get screen from stencil room	EA4.5.1.4			1	printing&drying	screen	(b)	3			these activities are captured on "Svecia" printing machine 1 with "Abbess" dryer (warm air), while the only other similar machine is "Svecia" printing machine with "(Trumax) dryer(UV lamp). Both can use for printing nomal or special inks.
Set and seal screen on machine	EA4.5.1.5			1			(b)	14			
Load screen on machine	EA4.5.1.6			1			(b)	3			
Set sqeegee and scrapper on machine	EA4.5.1.7			1			(b)	3			
Return ink from previous job and get get required ink	EA4.5.1.8		ink	1			(b)	6			
Set dryer	EA4.5.1.9			1			(b)	1			
Set machine to run and check print against artwork	EA4.5.1.10			1			(b)	2			
Production activity (printing and drying)	EA4.5.1.11		paper and ink	1			(a)	27			
Machine cleaning	EA4.5.1.12			1			(b)	8			
Return screen to stencil room	EA4.5.1.13			1			(b)	3			
Collate printed batch	EA4.5.1.14			1			(b)	5			
Transport the batch to finished area using trolley	EA4.5.1.15			1		hand trolley	(b)	10		Printed batch	
Batch documentation	EA4.5.1.16			1			(b)	5	Batch completion sheet		
								113			

Table 1: Data capture template for BP4.5.1

Collective capture of data for Activity level modelling											
Process name	Purchase process			BP ID	BP5.4.1				Modeller	Shahid Rashid	
Previous process				Next process					Process In-charge	Ian Chambers	
Activity		Input							Output		Comments
	EA ID.	Info/Data	Material resource	Number of human resource	Machines	Tools	Activity Repetition (a)once/activity (b)once/batch (c)once/shift	Operation time (minutes)	Output info/Data	components	
Access Avante "Purchase bench" daily and take a print of the overall dialy purchase requirements due	EA5.4.1.1			1		PC	a	10			
Develop individual "Purchase order" including quote based on previous payment to suppliers	EA5.4.1.2			1		PC	a	10			
Fax/email the POs to respective suppliers as per approved suppliers list	EA5.4.1.3			1		PC/Fax	a	10			
Access Avante and develop a "Daily shortage report"	EA5.4.1.4			1		PC	a	5			
As per shortage report contact relevant suppliers for not provision of ordered items on time	EA5.4.1.5			1		Telephone	a	>10			
If items are delivered in the store but not booked in the store, contact store	EA5.4.1.6			1		Telephone	a	>10			
Manage updating the inventory record in Avante through store representative	EA5.4.1.7			1		PC	a	>10			
In case of change request from customer, develop "Exception report"	EA5.4.1.8			1		PC	a	10			
As per exception report contact suppliers and change the "Purchase order"	EA5.4.1.9			1		Telephone	a	>10			

Table 2: Data capture template for BP5.4.1

Collective capture of data for Activity level modelling											
Process name	Despatch Finished Goods			BP ID	BP4.3.1				Modeller	Shahid Rashid	
Previous process				Next process					Process In-charge	Neil Robson	
		Input							Output		
Activity	EA ID.	Info/Data	Material resource	Number of human resource	Machines	Tools	Activity Repetition (a)once/activity (b)once/batch (c)once/shift	Operation time (minutes)	Output info/Data	components	Comments
Run a weekly despatch performance report on POTS database	EA4.3.1.1			1		PC	a	10			
Record a "Move note" which is provided by the manufacturing department at the time of prod	EA4.3.1.2			1			a	5			
Update the despatch performance report as per incoming move note	EA4.3.1.3			1		PC	a	5			
Call 3PL providers and book a space in a lorry and decide a pickup and probable delivery tim	EA4.3.1.4			1		Telephone	a	30			
Book labour for loading accordingly	EA4.3.1.5			1		PC	a	10			
Receive a signed handing/taking over of items from logistic support representative for the deli	EA4.3.1.6			1			a	5			
Update the status of PO in Avante by designated it as "despatched".	EA4.3.1.7			1		PC	a	10			

Table 3: Data capture template for BP4.3.1

Collective capture of data for Activity level modelling											
Process name	Logistics (finished goods)			BP ID	BP4.3.2				Modeller	Shahid Rashid	
Previous process				Next process					Process In-charge	Neil Robson	
		Input							Output		
Activity	EA ID.	Info/Data	Material resource	Number of human resource	Machines	Tools	Activity Repetition (a)once/activity (b)once/batch (c)once/shift	Operation time (minutes)	Output info/Data	components	Comments
Discuss a weekly despatch performance report with "Despatch" representative	EA4.3.2.1			1		PC	a	20			
Mark daily finished goods to arrive from different production departments and allocate space	EA4.3.2.2			1		PC	a	15			
Assign / create space for incoming items	EA4.3.2.3			>1			a	>30			
Place the incoming items accordingly and update the location reference in "Move Note"	EA4.3.2.4			>1		Fork lifter	a	<>30			
Move the deliverables from despatch area to loading area outside building	EA4.3.2.5			>=1		Fork lifter	a	<>60			
Load the deliverables in the booked space in the (3PL) lorry	EA4.3.2.6			>=1		Fork lifter	a	<>60			
At the time of handing over of items get signed handing/taking over document from driver of 3PL	EA4.3.2.7			1			a	5			
Provide handing/taking over of items to despatch representative	EA4.3.2.8			1			a	5			

Table 4: Data capture template for BP4.3.2

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