A DATA AND MODELLING FRAMEWORK FOR STRATEGIC SUPPLY CHAIN DECISION-MAKING IN THE PETRO-CHEMICAL INDUSTRY

by

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Declaration

I, the undersigned, hereby declare that the work contained in this thesis is my own original work and that I have not previously in its entirety or in part submitted it at any university for a degree.

30 November 2006

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Signature	***Date***

Summary

The research was initiated by an opportunity within the petro-chemical company Sasol to explore, improve and integrate various analytical techniques used in the modelling, design and optimisation of supply chains. Although there is already a strong focus on the use of analytical applications in this environment, the lack of both modelling integration and analytical data availability has led to less than optimal results.

This document presents an exploration into the supply chain planning landscape, and in particular strategic planning in the petro-chemical environment. Various modelling methodologies and techniques that support strategic supply chain decision-making are identified, followed by an in-depth analysis of the data requirements for effectively constructing each of these models.

Perhaps the biggest hurdle in the continual use of modelling techniques that support strategic supply chain decision-making, remains the extent of the data gathering phase in any such project. Supply chain models are usually developed on an *ad hoc* project basis, each time requiring extensive data gathering and analysis from transactional data systems. The reason for this is twofold: 1) transactional data are not configured to meet the analytical data requirements of supply chain models, and 2) projects are often done in isolation, resulting in supply chain data that end up in spreadsheets and point solutions.

This research proposes an integrated data and modelling framework, that aspires to the sustainable use of supply chain data, and continual use of modelling techniques to support strategic supply chain decision-making. The intent of the framework is twofold: 1) to enable the design of new supply chains, and 2) to ensure a structured approach for capturing historical supply chain activities for continued review and optimisation.

At the heart of the framework is the supply chain analytical data repository (SCADR), a database that maintains supply chain structural and managerial information in a controlled data model. The motivation behind developing a database structure for storing supply chain data is that a standard encoding method encourages data sharing among different modelling applications and analysts.

In the globalised environment of the 21st century, companies can no longer ensure its market position solely by its own functional excellence...in the new economy, whole business

ecosystems compete against each other for global survival (Moore, 1996). This motivates the ever-increasing importance of supply chain management, which necessitates the use of advanced analytical tools to assist business leaders in making ever more complex supply chain decisions.

It is believed that the integration of information requirements for multiple optimisation/ modelling initiatives in a structured framework (as presented in this research) will enable sustainability and improved strategic decision-making for the petro-chemical supply chain.

Opsomming

Hierdie navorsing het ontstaan uit die geleentheid binne die petro-chemiese maatskappy Sasol, om die gebruik van verskeie analitiese tegnieke in die modellering, ontwerp en optimisering van voorsienings-kettings te ondersoek, te verbeter en te integreer. Alhoewel daar reeds 'n sterk fokus is op die gebruik van analitiese toepassings in hierdie omgewing, lei die gebrek aan modellerings integrasie en die onbeskikbaarheid van analitiese data, tot sub-optimale resultate.

Hierdie dokument ondersoek die geleenthede en uitdagings van beplanning in voorsienings-ketting bestuur, en fokus spesifiek op strategiese beplanning in die petro-chemiese omgewing. Verskeie modellerings metodologieë en tegnieke word ondersoek, gevolg deur 'n in-diepte analise van die data behoeftes vir effektiewe gebruik van elk van hierdie modelle.

Moontlik die grootste uitdaging vir die volhoubare gebruik van modellerings tegnieke om strategiese voorsienings-ketting besluitneming te ondersteun, is die omvang van die data versameling fase in enige só projek. Voorsienings-ketting modelle word gewoonlik op 'n *ad hoc* projek basis ontwikkel, wat telkens 'n intensiewe data versameling en analise van transaksionele stelsels vereis. Die rede hiervoor is tweevoudig: 1) transaksionele stelsels word nie gekonfigureer om die analitiese data behoeftes van voorsienings-ketting modelle aan te spreek nie, en 2) projekte word dikwels in isolasie gedoen, wat tot gevolg het dat voorsienings-ketting inligting in sprei-bladsye en punt oplossings verlore raak.

Hierdie navorsing stel 'n geïntegreerde data en modellerings raamwerk voor, wat streef na die volhoubare gebruik van voorsienings-ketting inligting, en die volgehoue toepassing van modellerings tegnieke om strategiese besluitneming te ondersteun. Die bedoeling is tweeledig: 1) om die ontwerp van nuwe voorsienings-kettings moontlik te maak, en 2) om 'n gestruktureerde manier daar te stel vir die stoor van historiese voorsienings-ketting aktiwiteite, wat gebruik kan word vir voortdurende hersiening en optimering.

In die hart van die raamwerk lê die voorsienings-ketting analitiese databasis (SCADR), 'n databasis wat strukturele- en bestuurs- inliging van die maatskappy se voorsienings-kettings bevat in 'n gekontroleerde data model. Die motivering vir die ontwerp van hierdie databasis struktuur is dat 'n standaard manier van data enkodering die deel van data tussen verskillende modellerings toepassings en analiste aanmoedig.

In die era van globalisering waarin ons tans leef, kan maatskappye nie meer hul mark posisie verseker deur slegs op hul eie funksionele uitnemendheid staat te maak nie...in die nuwe ekonomie gaan besigheids-ekosisteme met mekaar meeding vir globale oorlewing (Moore, 1996). Dít motiveer die belangrikheid van voorsienings-ketting bestuur, wat die gebruik van gevorderde analitiese- en modellerings tegnieke impliseer. Die voordeel wat hierdie tegnieke bied is dat dit besigheidsleiers help om steeds meer komplekse voorsienings-ketting besluite te neem.

Die student glo dat die integrasie van inligtings behoeftes vir verskeie optimiserings / modellerings inisiatiewe, in 'n gestruktureerde raamwerk soos aangebied in hierdie navorsing, volhoubaarheid en verbeterde strategiese besluitneming in die petro-chemiese voorsienings-ketting sal verseker.

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List of Abbreviations

AB	Agent - based
ABC	Activity Based Costing
AHP	Analytical Hierarchy Process
APS	Advanced Planning System
BSC	Balanced Scorecard
CEO	Chief Executive Officer
DEDS	Discrete-event Dynamic System
DRP	Distribution Resource Planning
DSS	Decision Support System
EAI	Enterprise Application Integration
EDI	Electronic Data Interchange
EOQ	Economic Order Quantity
ERD	Entity Relationship Diagram
ERP	Enterprise Resource Planning
ETL	Extraction, Transformation & Loading
FFM	Financial Flow Model
GA	Genetic Algorithm
GAMS	General Algebraic Modelling System
GIS	Geographic Information Systems
GP	Goal Programming
GTL	Gas-to-Liquids
GUI	Graphical User Interface
IS	Information Systems
IT	Information Technology
KPI	Key Performance Indicator
LP	Linear Programming
MDM	Master Data Management
MILP	Mixed Integer Linear Programming
MIP	Mixed Integer Programming
MPS	Master Production Scheduling
MRP	Material Resource Planning

MSCDM	Master Supply Chain Data Management
NLP	Non-linear programming
PVC	Poly Vinyl Chloride
ROI	Return on Investment
SA	Simulated Annealing
SCADR	Supply Chain Analytical Data Repository
SCDD	Supply Chain Decision Database
SCM	Supply Chain Management
SCME	Supply Chain Modelling Editor
SCO	Supply Chain Optimisation
SCOR	Supply Chain Operations Reference
SCP	Supply Chain Planning
SD	System Dynamics
SKU	Stock Keeping Unit
SSPD	Sasol Slurry Phase Distillate
TCO	Total Cost of Ownership
TS	Tabu Search
VCA	Value Chain Analysis

Chapter 1

Introduction

The aim of this introductory chapter is to define the intent and context of the research, the methodology followed, and the deliverables expected. An overview of the structure of the document will help the reader navigate through the research space.

1.1 Research problem

The research was initiated by an opportunity within Sasol to explore, improve and integrate various analytical techniques used in the modelling, design and optimisation of supply chains. Although there is already a strong focus on the use of analytical applications in this environment, improvement opportunities were identified, which include:

- exploring new methods and tools to use in the design and optimisation of supply chains;
- an integrated supply chain modelling and optimisation framework;
- rapid modelling development;
- a sustainable supply chain data repository, enabling multiple uses of the same supply chain-related information for different modelling initiatives;
- increased use of analytical tools that are quick to build and to use for decision-support;
- improved supply chain knowledge sharing;
- a global and integrated view of different supply chains, corridors, *etc.* across multiple business units;
- visualisation of supply chain information;
- a tool to assist in the mapping of supply chain networks;
- a framework for supply chain scenario planning;
- trend and performance analysis on existing supply chains;
- supply chain infrastructure analysis; and
- identification of synergies between different Sasol business units and products.

The research will focus on ways to solve these issues by developing an integrated modelling framework for ***strategic*** supply chain decision support, supported by a sustainable supply chain data repository.

1.2 Research methodology

A comprehensive literature review will aim to contextualise this research in the petro-chemical supply chain planning landscape. The research problem will be addressed through the design of an integrated modelling framework, with emphasis placed on the exploration and evaluation of modelling/optimisation elements relevant to the supply chain environment. The decision-making information needs required within the organisation will be analysed to design a supply chain information system to facilitate the application of the modelling framework.

1.3 Research context

The research will be conducted within the proudly South African petro-chemical company, Sasol, and applies to ***strategic*** supply chain decision-making.

1.4 Research objectives

The aim of this research is not to develop a lot of software, but rather to conceptually design an integrated space in which modelling and optimisation enablers can complement each other to facilitate superior strategic supply chain decision-making. Main deliverables include:

- a review of the strategic supply chain problem space;
- a literature review of various supply chain modelling methodologies and tools;
- an analytical analysis of the data requirements for the various modelling techniques;
- an integrated modelling framework;
- a supply chain data model and information system; and
- a supply chain editor tool as user interface with the repository.

1.5 Research contribution

The integration of information requirements for multiple optimisation/modelling initiatives in a structured framework will enable sustainability and improved strategic decision-making in the petro-chemical supply chain.

1.6 Document structure

The first part of the document will contextualise the research by discussing a number of supply chain related concepts. The management of the global supply chain is introduced in Chapter 2. A discussion of the petro-chemical industry and its specific supply chain challenges and opportunities (Chapter 3) will be followed by a description of the company relevant to the research (Chapter 4).

The second part of the document focuses on modelling and optimisation techniques related to strategic supply chain decision-making (Chapter 5). Chapter 6 will extend the context to discuss supply chain information systems and information technology.

Chapters 7 and 8 involve the design phase of the research project. A detailed analytical analysis of the data requirements for the various modelling techniques (Chapter 7) will be followed by the design of the integrated supply chain data and modelling framework in Chapter 8.

Finally, chapter 9 concludes the research document by recommending next steps and future research focus.

Chapter 2

Introduction to managing the global supply chain

This chapter introduces the supply chain and the management thereof by describing the concepts, participants and processes involved. It aims to contextualise the benefits and importance of strategic supply chain management in the globalised economy of the 21st century.

2.1 Evolution of supply chain management to a strategic priority

Supply chain management (SCM) is no longer a foreign concept to most businesses. In fact, it has become such a buzzword that many people in business today use it cheaply, not always grasping the extent of the seemingly simple three words. This can be partly attributed to the evolution of the concept of supply chain management over the past two decades. The focus has shifted from merely integrating logistics and lowering cost, to recognising the supply chain as a strategic driver of business strategy (Evans & Danks, 1998:18). A short summary follows to provide insight into the progression of supply chain thinking (*Table 1*).

Table 1: Supply chain progression

DECADE	SUPPLY CHAIN FOCUS
1970's	Primarily known as "distribution". Focus on the integration of warehousing and transportation within the firm, and in cutting cost by lowering inventory.
1980's	Focus on the re-engineering of supply chain cost structures. Efforts were directed at the integration of supply chain processes in order to lower supply chain operating costs and the reduction of supply chain assets. The end of the 1980's saw the start of a shift in focus from cost reduction to improved customer service.
1990's	Improved customer service and growth becomes the priority of supply chain initiatives. Companies start to realise that a good supply chain can become a competitive advantage, and can boost growth.
2000's	The emerging view on supply chain management is that it can drive and enable a firm's strategy, rather than the traditional view of only forming part of the operational strategy.

The value forthcoming from the alignment of business strategy with supply chain strategy has been proven by the success of some of today's major global companies. Coca-Cola and Dell Computers have both outperformed their competitors in terms of shareholder growth, and this is largely attributed to their strong focus on the strategic alignment of their supply chains. ***Coca-Cola*** has gained substantial distribution advantage as a result of their global supply chain distribution configuration. ***Dell*** has redefined the way of making and selling computers with their direct sales approach. Because Dell is in direct contact with its customers, it has been able to better understand and forecast the needs of its different market segments. It has dramatically reduced inventory holding cost, by carrying only about 10 days' worth of inventory, in contrast with competition (selling through retailers) carrying in the vicinity of 80 to 100 days. For some products, such as monitors manufactured by Sony, Dell maintains no inventory. The transportation company simply picks up the appropriate number of computers from Dell's plant, and monitors from Sony's factory, matches them by customer order, and delivers them to the customer.

The success of the Dell supply chain is facilitated by sophisticated information exchange. Dell provides real-time data to suppliers on the current state of demand. Suppliers are able to access their components' inventory levels at the factories along with daily production requirements. Dell has created customised web pages so that its major suppliers can view demand forecasts and other customer-sensitive information, thus helping suppliers to get a better idea of customer demand and better match their production schedules to that of Dell. Their innovative supply chain approach has rewarded them with hefty growth figures in the past few years.

These are examples of companies that unlocked significant shareholder value as a direct result of strategic supply chain thinking. AMR Research ranked Dell the top supply chain of 2005 (AMR Research, 2005) in the Top 25 supply chains for 2005, with Coca-Cola at number 25.

2.2 Supply chain management defined

With this new strategic focus established, supply chain management is defined as follows:

> *"Supply chain management enables maximum* ***customer benefit*** *through an* ***integrative and strategic approach*** *to* ***managing*** *the entire* ***supply process****."*

To elaborate on the definition:

- As established before, ***customer benefit*** and satisfaction is the primary focus of business success. There is more to customer satisfaction than just cheap prices. A good supply chain can result in superior product availability, flexibility, and reliability, all of which can be a major competitive advantage in its own right.
- An ***integrative approach*** forms a vital ingredient in supply chain thinking. Linkages between the participants of a firm's supply chain (traditionally in functional silos), is key to establish the common focus of the supply process. This integration also extends across organisational boundaries.
- The ***strategic*** intent of supply chain management elevates the topic as a business driver or enabler, rather than keeping to the traditional focus on operational strategy.
- Not only is supply chain management involved with the physical flow of material, but also with ***managing*** the process of decision-making and taking actions to direct the activities of people within the organisation, and between organisations.
- The ***supply process*** constitutes the entire process for providing goods/services to customers. Membership of the supply process includes all parties, from initial supplier to final user. The process extends across organisational boundaries to include planning and control across different organisational units. Coordination and collaboration is encouraged between different supply chain partners.

A more ambitious definition of the supply chain is that of Cooper *et al.* (1997). They advocate a broader supply chain perspective, defining the scope of supply chain as *"dirt to dirt"*. This consists of all material flow activities from the sourcing of raw materials (from nature) to the final consumption and then to the recycling or return of used material (to nature). Their vision implies the joint responsibility of the entire supply chain for the sustainability of nature's precious (and scarce) resources, and will become an ever increasing global priority in the 21st century. This visionary approach has also become known as *"cradle to grave"*, and implies enormous responsibility for all parties in the supply chain network. Its realisation is however still a far way down the road, considering the lack of supply chain maturity in many organisations today.

2.3 Supply chain versus logistics

As a result of the evolution of the ***supply chain*** concept from the ***logistics*** function, and the continued interchangeable use of the two terms in business, the actual difference between the two concepts is not always clear. In essence, the term logistics falls under the umbrella of supply chain management. The Council of Logistics Management defines logistics as follows:

> *"Logistics is that part of supply chain management that plans, implements and controls the efficient, effective forward and reverse flow and storage of goods, services and related information between the point of origin and the point of consumption in order to meet the customers' requirements."*

Logistics therefore comprises the smaller functional links within the supply chain. These links will include managing the flow of raw materials from supplier to storage and the flow of finished product from production to storage to customer. Although logistics interacts with different functional links within the organisation, the main focus is neither on the cross-boundary, integrated supply chain in the organisation itself, nor on the interaction of product and information flow between different organisations (*Figure 1*).

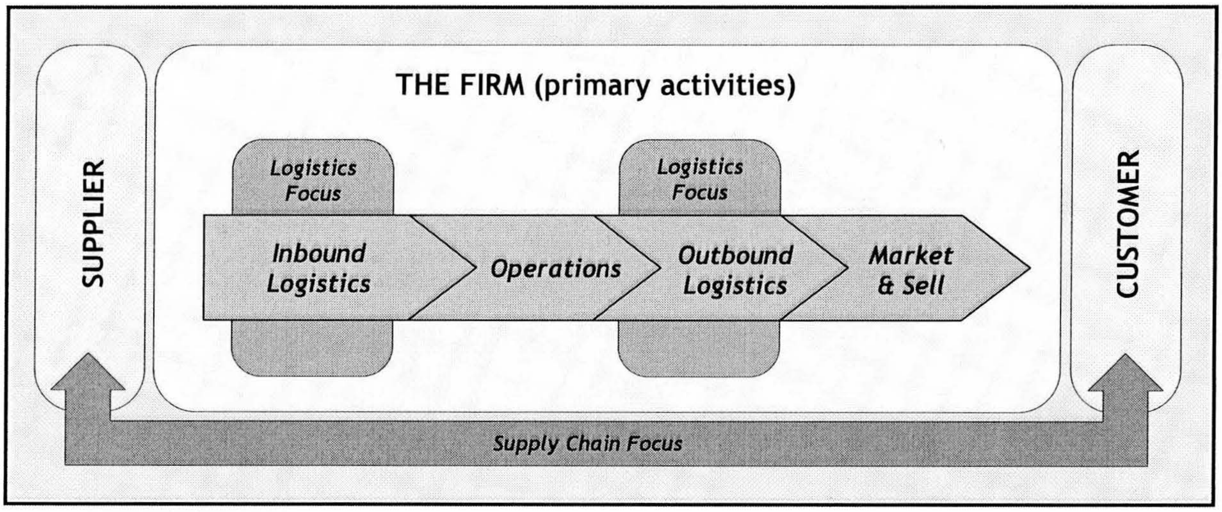

Figure 1: Logistics versus supply chain

2.4 Supply chain understanding

The supply chain is a complex ***system*** with many distinct but interrelated activities and processes (Schary & Skjott-Larsen, 2001:33). These activities and processes rely on different functional organisational resources (both inside and outside of company boundaries) to enable the ultimate goal of customer delight to be achieved. From a systems perspective, the true leverage lies not in the mastering of these activities individually, but in bringing these elements together in a coordinated ***system***. With this view comes the obvious challenge of managing the relationships between both traditionally separated organisational silos and different businesses.

The holistic intent of supply chain management further supports the synergistic view of a system as a whole rather than separate individual members. The influence of members on each other may not always be clear and apparent, but in a complex system like the supply chain, the effects of actions in one part of the system will manifest in some way or another in other parts in the system. A good example of this is what has come to be known as the ***bullwhip effect***. A small fluctuation of final customer demand is augmented upstream as the result of a lack of visibility, long lead times and poor demand forecasting (*Figure 2*). Overcompensation by the supply chain parties upstream results in an unbalanced supply chain with stock building at different tiers.

[**Source**: Schary & Skjott-Larsen (2001:496)]

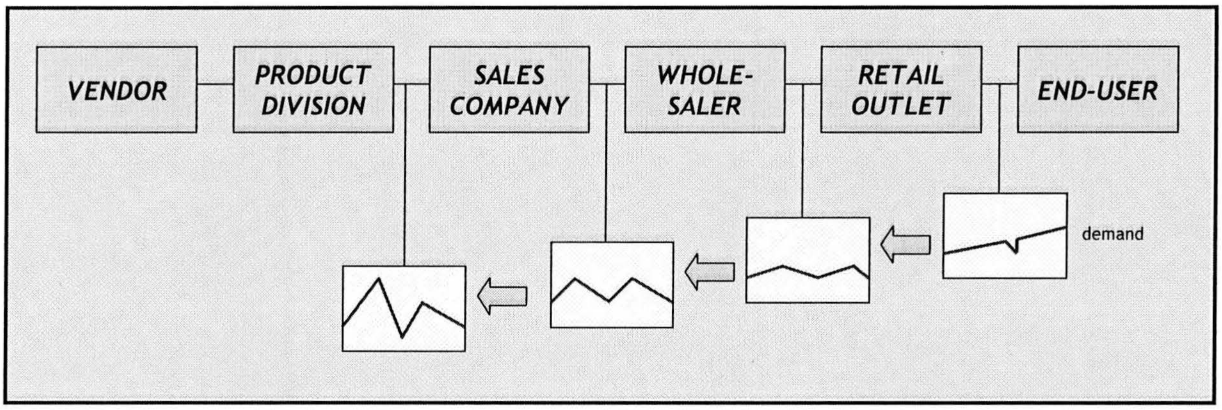

Figure 2: The bullwhip effect

Figure 3 illustrates a model of the supply chain (adapted from Schary & Skjott-Larsen, 2001:39). The supply chain starts with the customer, who is the initiator of supply activity. This customer-centered approach implies a pull system, where all activities should ultimately focus on customer delight. Supply decisions flow from the customer through all of the partners, towards the basic material supplier. Products and materials flow towards the customer, and after consumption, product recycling becomes a material flow backwards, to the place of re-use or renovation. Information flows in both directions: order transactions move towards the point of supply, while product movement transactions move towards the customer. Funds flow from the customer to the source of supply. Transportation supplies the physical links between supply chain participants in the form of logistics service providers.

[**Source:** Adapted from Schary & Skjott-Larsen (2001:39)]

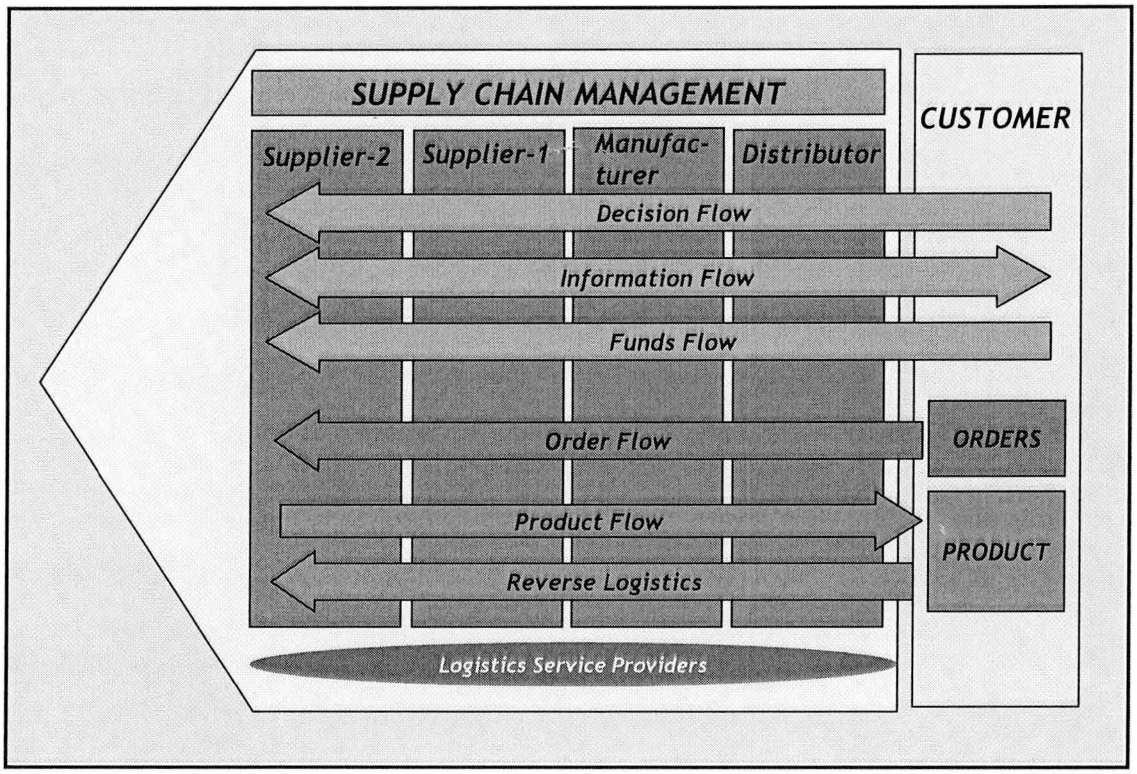

Figure 3: Supply chain model

2.5 A process view of business

Supply chain management is essentially about a ***process view*** of the business. It includes the entire collection of activities by which a company plans, produces, and distributes products to customers (Louw, 2004). The challenge has been, and remains to be, the streamlining of a firm's processes to ensure holistic rather than silo thinking.

2.5.1 Supply chain management process categories

AMR Research defines the generic supply chain management processes to include 5 major categories (Louw, 2004):

1) supply chain planning;
2) supply chain execution;

3) supply chain event management;
4) supply chain performance management; and
5) reverse logistics.

1) Supply chain planning

Supply chain planning processes incorporate planning decisions on strategic, tactical and operational levels. Typical processes/activities include supply chain network design, demand planning & forecasting, supply chain collaboration, distribution planning, manufacturing planning and production scheduling.

2) Supply chain execution

The focus of supply chain execution processes is on the day-to-day operational activities of the supply chain. These include order management, inventory management, transportation management and warehouse management.

3) Supply chain event management

A good plan is however not a guarantee for supply chain performance. A good supply chain is a robust supply chain – one that can absorb variability and hiccups from the various links in the supply chain. To enable supply chain performance, the monitoring, notification, simulation, control and measurement of supply chain events (on an operational level) are crucial.

4) Supply chain performance management

Supply chain performance management refers to clearly defined performance goals for all parties in the supply chain, with the aligned objective of customer delight. Performance management processes need to be in place across the whole supply chain to make sure that this alignment is clearly understood and pursued by all.

5) Reverse logistics / returns management

Reverse logistics processes are often underestimated, especially in the design of new supply chains. Part of a responsible supply chain is making sure that the firm is able to handle returns in the event of product non-conformance. This is enabled with the implementation of clearly defined reverse logistics processes.

2.5.2 SCOR methodology

Another definition of supply chain processes is found in the ***supply chain operations reference*** (SCOR) model, developed by the Supply Chain Council as a global methodology for the description/configuration of supply chains and their related processes[1]. The model is based on the following 6 distinct business processes that encompass all of the generic supply chain process categories discussed above: plan, source, make, deliver, return, and enable.

These processes are linked together across multiple functional units and organisations (*Figure 4*) to form the global supply chain.

[**Source:** Supply Chain Council (2005)]

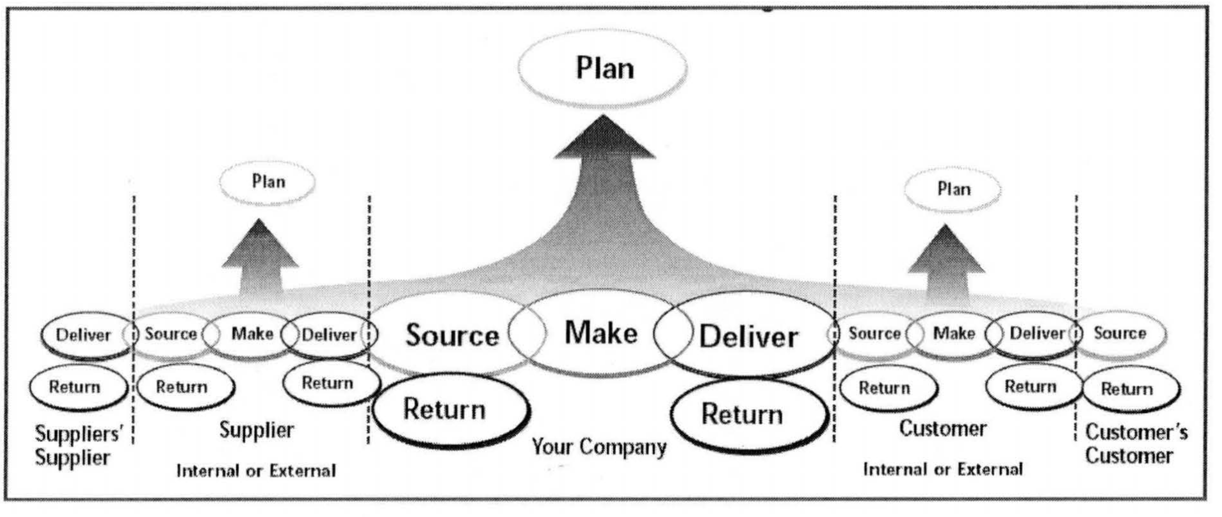

Figure 4: SCOR supply chain description

2.6 Going global

David Whitman, the CEO if Whirlpool Corporation, made the following statement in 1994, emphasising the importance of holistic business thinking (Schary & Skjott-Larsen, 2001:21):

"The only way to gain lasting competitive advantage is to leverage your capabilities around the world so that the company as a whole is greater than the sum of its parts. Being an international

[1] The SCOR framework will be discussed in more detail in Chapter 5.

company – selling globally, having global brands or operations in different countries isn't enough."

This implies that companies can no longer ensure its market position solely by its own functional excellence...in the new economy, whole business ecosystems compete against each other for global survival (Moore, 1996). Business ecosystems imply closely cooperative and coordinated networks, including multiple businesses and service providers across the entire supply chain. The relationship of these role players are that of partners with managed activities to achieve common goals. It is believed that this perspective is essential for the survival in the struggle for global markets.

2.7 Strategic alignment

This chapter was started by describing the evolution of supply chain management to a strategic priority that can improve shareholder value. Evans & Danks (1998:23) elaborate on the dimensions of a firm's supply chain strategy. They include the following aspects in establishing the supply chain strategy:

1) ***customer service strategy*** – how to respond to the needs and expectations of its customers;
2) ***demand flow strategy*** – the link between the customers and the product/service sources;
3) ***sourcing strategy*** – determines where and how products/services are produced; and
4) ***supply chain integration strategy*** – establishes the degree and type of integration between participants in the supply chain.

Evans & Danks (1998:23) identified some key elements to enable the formulation of effective supply chain strategies in each of these dimensions:

1) Customer service strategy

- ***Customer service segmentation*** – identify the unique segments of the customer base, and what service levels each of these segments expect.
- ***Cost to serve*** – analyse the customer service delivery cost structure of each customer segment, utilising activity based costing (ABC).
- ***Revenue management*** – determine the market share and price premium impact of the behavioural responses of customers to new levels of customer service.

2) Demand flow strategy

- ***Channel design*** – design the most profitable channel through which products will flow to customers, whether it is via retailers, wholesalers, dealers, distributors or direct.
- ***Demand planning*** – determine the level of production and inventory requirements to meet customer demand. Demand planning refers to the activities of forecasting, distribution resource planning (DRP), material resource planning (MRP) and inventory control.
- ***Supply chain configuration*** – determine the optimal number, location and role of each supply chain participant in the form of facilities, equipment and other assets.

3) Sourcing strategy

- ***Make or buy*** – decide whether to manufacture or purchase based on how it affects cost structure and risk exposure.
- ***Capacity management*** – determine where plants and suppliers should be geographically located and the level of capacity at each location.
- ***Manufacturing management*** – determine how production should be organised and managed.

4) Supply chain integration strategy

- ***Degree of supply chain*** integration – decide on the degree of integration between supply chain partners, a decision driven by the value creation opportunities that might result from such integration.
- ***Physical vs. virtual integration*** – decide on a physical or virtual supply chain integration approach.
- ***Type of supply chain integration*** – there are four forms of supply chain integration:
  - *information integration* – sharing of useful information;
  - *decision integration* – supports the planning and control functions across multiple firms;
  - *financial integration* – changes the terms and conditions of payment across the supply chain; and
  - *operational integration* – encompass the sharing of physical and human assets between participants in the supply chain.

A firm's supply chain strategy can however not exist in isolation, and should be aligned with the firm's business strategy. Evans & Danks (1998:32) describe business strategy in the simplest form as addressing 3 fundamental questions:

- what products/services should the firm sell?
- what customer segments should the firm serve?
- in what geographic markets should the firm operate?

It is not difficult to see the inter-dependencies between the business strategy and the supply chain strategy. *Figure 5* illustrates this alignment.

[**Source:** Evans & Danks (1998:33)]

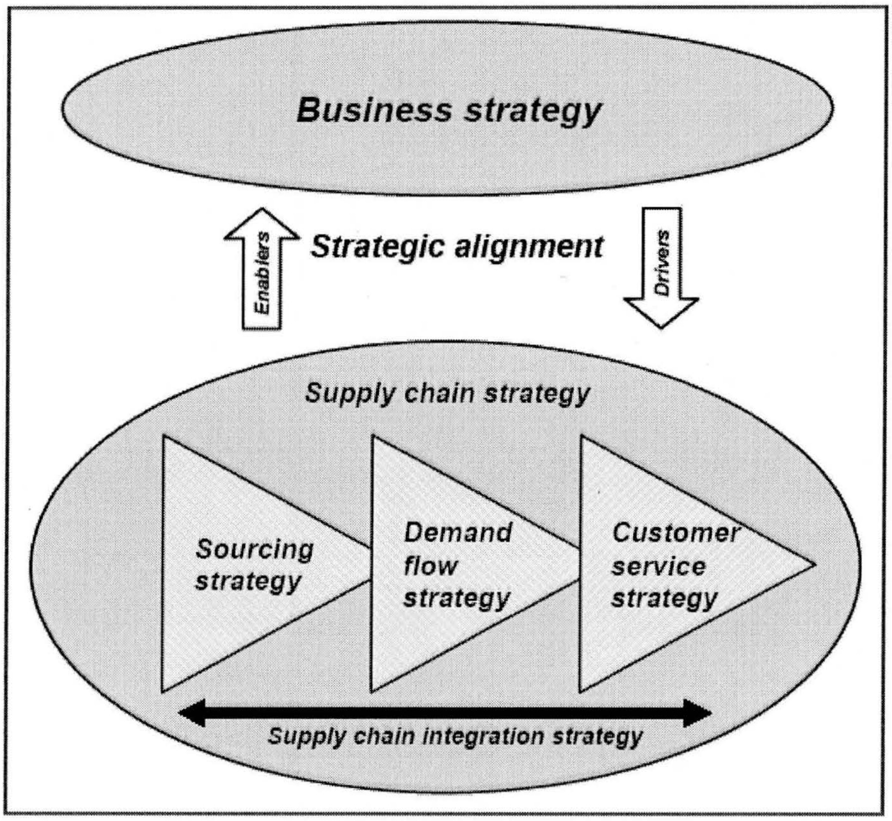

Figure 5: Alignment between supply chain strategy and business strategy

Establishing supply chain strategy and aligning it with business strategy involves many decisions. Most of these decisions can be supported by proven analytical decision-making methods, many of which will be described in the next chapters. It is envisaged that this research will make a significant contribution to the successful implementation of these methods to provide decision-support for supply chain strategists.

2.8 Supply chain benefits and challenges

Moore (1996) stated that companies will no longer ensure their market position solely by their own functional excellence...that in the new economy, whole business ecosystems will compete against each other for global survival. This poses an enormous challenge to companies on how they manage their global supply chains. A chemical industry executive recently said the following regarding the new global supply chain approach (Nix, 2001:63):

> *"Historically, what goes on between companies (in a supply chain) is aimed at how the pie will be divided among them. Nobody is focused on how to make the pie bigger. The purpose of supply chain management is for companies to work together to increase the size of the pie."*

It is believed that the size of the pie can only be increased by capitalising on the opportunities of advanced supply chain management and integration. Many companies are however still in their infancy when it comes to real supply chain maturity. Crossing functional silos within the company will be their first step towards supply chain adulthood.

The application of supply chain management (even if it is only across one business) offers improved visibility, alignment and synchronisation, that can lead to:

- improved customer service experience;
- reduced inventories;
- lower operating cost; and
- improved use of fixed assets.

All this can contribute to the ultimate objective of increasing the size of the supply chain pie.

2.9 Concluding chapter 2

In this chapter the supply chain and management thereof was introduced by describing the concepts, participants and processes involved. The relevance of integrated supply chain management in the 21st century global economy is that it has become a strategic driver for business success. The visionaries that can successfully implement innovative supply chain strategies will taste the benefits in the form of increased shareholder value.

To conclude this chapter a quotation from Owens (1998:xiii) about the future of global supply chain management can be cited, as it is particularly applicable to the objective of this research:

"Perhaps the biggest breakthrough in prospect lies in achieving truly integrated decision support systems that link all the parties along a particular supply chain. A comprehensive supply chain information system will make visible to managers all the opportunities to improve performance along the length and breadth of the network, ensuring that all parties improve their decision - making and their capacity to contribute to, and benefit from, the optimum supply chain."

Chapter 3

Supply chain management in the petro-chemical industry

The chapter starts with a definition of the process industry (in which the petro-chemical industry is categorised). It then focuses more specifically on the petro-chemical supply chain and its unique challenges, followed by current opportunities that support the relevance of, and potential in, this area.

3.1 Defining the process industry

The process industry represents one of the largest and most important sectors of the global economy. Encompassing an array of vertical markets - including oil and gas, petroleum, chemicals, food and beverages, pharmaceuticals, pulp and paper - these industries manufacture the products that are essential to everyday life (Aspen Technology, 2006).

The process industry involves continuous manufacturing, where raw materials are transformed by a series of processes (often chemical processes). *Figure 6* shows the basic choices when it comes to manufacturing processes, determined by the size of the production run, ranging from once-off project based, to large volume, continuous based.

Industries involving continuous processes (*i.e.* the process industry) are usually capital intensive and involve great financial risk. The petro-chemical industry falls in this category.

Process manufacturers differ fundamentally from their discrete counterparts. *Figure 7* illustrates some of these differences. It has obvious implications for the supply chains of process manufacturing industries. The same supply chain rules as those in discrete manufacturing supply chains do not necessarily apply.

[**Source:** Schary & Skjott-Larsen, 2001:159]

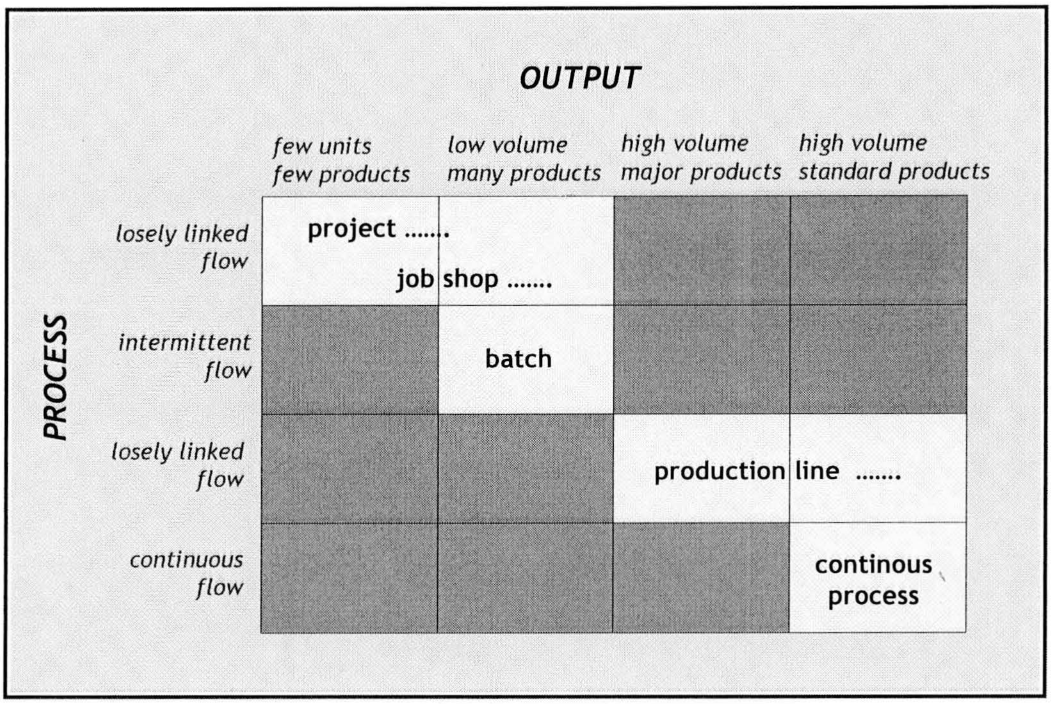

Figure 6: Manufacturing processes

[**Source:** Rossouw, 1994:26]

Production method
Fundamental differences between discrete & process

Dimention	Discrete		Process
Examples	Ships	↔	Petroleum
Raw materials	Many	↔	Few
No of sub-parts	Many	↔	Few
Work in progress	Variable	↔	Constant
Finished products	Few	↔	Many
Production quantity/volume	Low	↔	High
Production lead time	Long	↔	Short
Production rate	Low	↔	High
Skill & experience level	Low	↔	High
Equipment and tooling	General	↔	Specific
Throughput constraints	Materials	↔	Capacity
Production control	Low	↔	High
Manufacturing cost (fixed)	Low	↔	High
Marketing cost	Low	↔	High
Value per mass	High	↔	Low
Process reversibility	High	↔	Low
Measurement	Unit	↔	Quantity
Manufactured / market unit	Same	↔	Varies
Facility expandability	Simple	↔	Complex

Figure 7: Differences between discrete and process manufacturing

3.2 The petro-chemical value chain

The petro-chemical industry, as the name implies, is a marriage of petroleum- and chemical production, and is referred to as such because of its inherent integrated nature. The petro-chemical value chain is divided into three key stages:

1) acquisition and production of ***raw materials*** (crude oil, gas and coal);

2) ***refining/synthesis*** to produce consumable petroleum products (diesel fuel, heating oil, paraffin, lubricants, gasoline, *etc.*) and chemical feedstock (propylene, ethylene, methane, benzene, toluene, xylenes); and

3) ***chemical processing*** to produce chemical derivatives (*e.g.* solvents, polymers, olefins, surfactants, *etc.*). These can be classified as bulk chemicals, fine chemicals and speciality chemicals.

Figure 8 indicates the relationships between petro-chemical feed streams and products.

[**Source:** Aspen Technology (2003)]

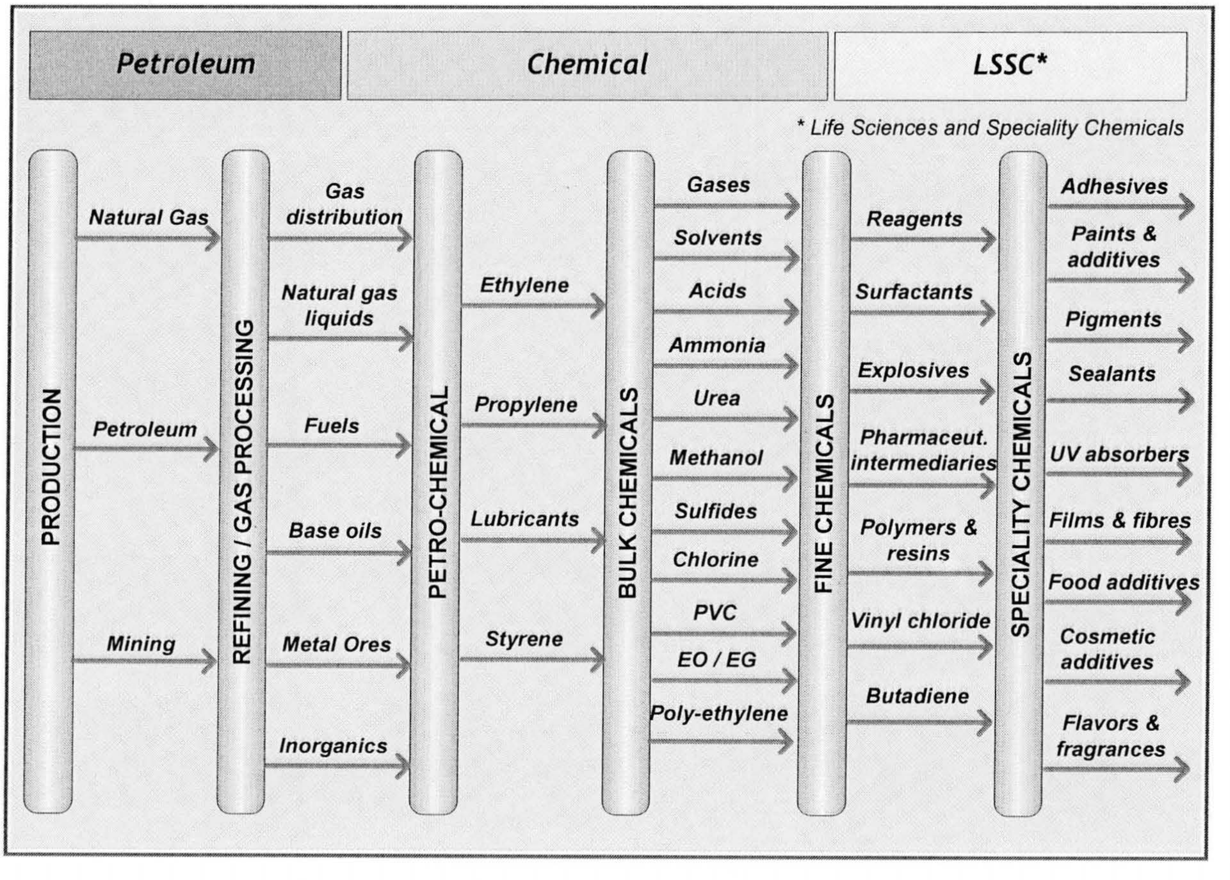

Figure 8: Typical stages of the petro-chemical value chain

The nature of the industry provides for numerous alternatives as to the use of chemical molecules, as illustrated in *Figure 9* (Redman, 2005). This implied flexibility with regards to the use of feedstock to manufacture different products is however limited when one considers the asset intensity of different chemical processes. The challenge in an integrated petro-chemical environment is to make informed decisions regarding the optimal use of molecules for maximum benefit. From a supply chain perspective, the industry is complicated. The industry is organised around highly specialised business processes (and business units) which encourage fragmentation (Louw, 2004). Creating a single supply chain focus for the whole petro-chemical value chain is still an ambitious goal. Sharman (2002: 78) states that supply chain management is a difficult challenge for complex chemical companies, where there typically exist a number of different business units with different sourcing and logistics agendas.

[**Source:** Adapted from Redman (2005)]

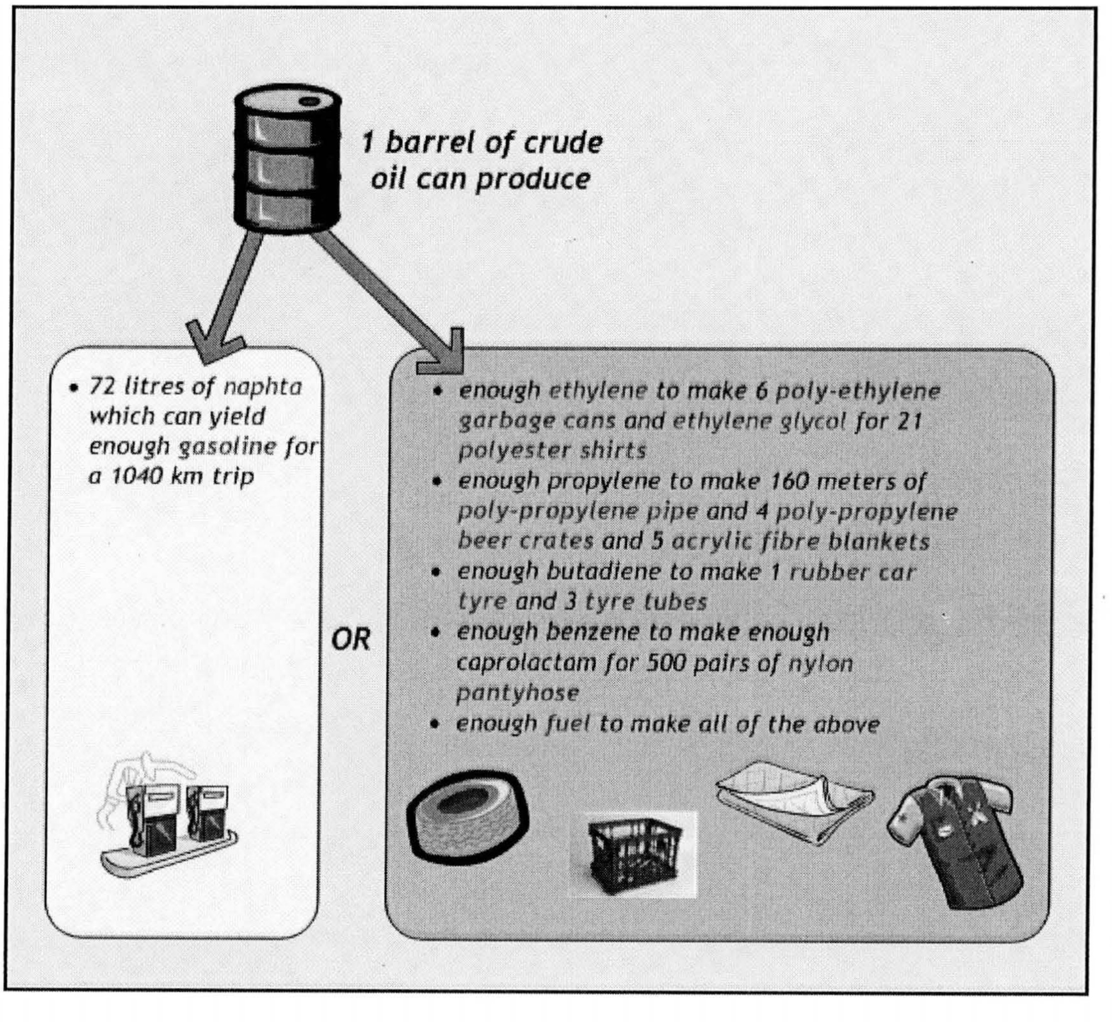

Figure 9: Molecule alternatives

3.3 Petro-chemical supply chain challenges and limitations

Shah (2005) suggests that process industry supply chain benchmarks do not measure up well in comparison with other sectors (*i.e.* discrete manufacturing). Examples include:

- stock levels in the whole chain can amount to a large percentage of annual demand;
- there are usually 4-24 weeks' of finished goods supply; and
- supply chain cycle times can be very long, with only a very small percentage involving value-adding operations.

Another benchmark where petro-chemicals lag behind other industries is when analysing the ratio of supply chain costs to value-add[2] (Braithwaite, 2002). They claim that petroleum and chemicals are the furthest behind when compared to all other industrial sectors.

The reason why the process industry is hampered in its quest for improved supply chain efficiency and responsiveness is a result of both intrinsic and technological factors (Shah, 2005). Intrinsic factors include the need to influence processes at molecular level and the distribution and associated cost of asset ages. Technological limitations include the limited availability of tools for process industry supply chain analysis.

Other factors limiting supply chain success for petro-chemical companies are suggested by Krenek (1997):

- the petro-chemical industry has a very conservative culture, where corporate mentality discourages risk-taking and speedy decision-making;
- direct competition for structural changes (mergers and acquisitions) strain an organisation's time and attention;
- lack of top level supply chain management champions;
- inadequate understanding of the importance of the supply chain as strategic imperative; and
- minimal attention to changed job requirements and responsibilities.

Louw (2004) identified some of the complexities challenging the optimisation of petro-chemical supply chains (more than other industries):

[2] Their definition of value-add is the costs and margin added by the company itself, excluding feedstock and material purchases.

- the industry combines supply push and demand pull, and this needs to be balanced for optimal results;
- transportation logistics are complex, with significant risks in the movement of hazardous bulk materials;
- strict requirements to comply with environmental legislation;
- economic impact of co- and by-products complicates production planning;
- high volumes with low margins;
- competitors may compete through exchange agreements;
- raw materials are often interchangeable;
- continuous production drives the supply chain; and
- order profitability is often dependent on the manufacturing sequence.

Whether or not supply chain excellence in the petro-chemical industry is complex and challenging, is no question. The challenge for practitioners and academics working in this field is to continually seek ways to provide improved and integrated supply chain decision-support on strategic-, tactical- and operational levels.

3.4 Relevance and opportunities

Braithwaite (2002) claims that the relevance of improved supply chain decision-making for petroleum and chemicals lie in the high ratio of supply chain costs to value-add. According to their research, petroleum (43%) and chemicals (37%) are on the top of the list when compared to all other industrial sectors. They pose the question that if the auto, retailing, high technology and food & beverage industries are paying great attention to their supply chains, this must be of critical importance to the petro-chemical industry too.

The global economy will put increasing pressure on companies to improve their supply chains for global competitiveness. This means lower costs, more flexibility, reliability, *etc.* Shah (2005) foresees new challenges for the process industry over the next 10 years:

- providing life-cycle solutions for customers (a move from a product-orientated business to a service-orientated business);
- more dynamic markets and greater global competition;
- more flexibility by means of shorter product life-cycles;
- mass customisation (producing speciality products at commodity costs);

- improved social and environmental impact management throughout the supply chain; and
- responsiveness with regards to regulation and compliance requirements (*e.g.* product recovery/recycling of consumer products).

3.5 A vision for world class petro-chemical supply chains

Given the complexities, relevance and opportunities discussed before, the question is: How does a world class petro-chemical supply chain look? Braithwaite (2002) suggests 8 core characteristics of a world class petro-chemical supply chain:

1) functional excellence
2) synchronised processes
3) visibility & accuracy of information
4) one number planning
5) segmentation
6) optimised network
7) time compression
8) aligned and relevant key performance indicators (KPIs)

The move towards a process orientation in supply chain management should not exclude the continued drive for ***functional excellence*** in petro-chemicals supply chains. Value lies in the combination of functional excellence and ***synchronised processes*** and flows, enabled by ***real-time visibility of highly accurate data***. The basis for synchronised flows is an agreed ***one-number plan*** (shared across the chain) and the ***segmentation*** of products and customers into realistic commercial commitments. An ***optimised network*** will be based on that segmentation and end-to-end visibility. Planning and fulfilment cycles will be increasingly frequent, reflecting the principle of ***time compression***. Finally, all functions and supply chain partners will be bound together with ***aligned and relevant KPIs.***

This research will endeavour to contribute to achieving this vision by providing a framework for improved decision-support through the use of scientific analytical methods, based on the availability of the appropriate supply chain information.

3.6 Concluding chapter 3

After defining the process- and petro-chemical industries, and stressing the differences with its discrete manufacturing counterpart, the chapter focussed on supply chain challenges in this industry. It also highlighted the relevance and opportunities of supply chain management in the petro-chemical environment, and concludes with a vision for a world class petro-chemical supply chain. In the next chapter, the focus will narrow to the company specifically targeted by this research: the proudly South African oil, gas and chemical company, Sasol.

Chapter 4

Supply chain management in Sasol

We have discussed the principles of supply chain management and the petro-chemical industry in general. In this chapter, the focus is more specific, i.e. on the organisation relevant to this research, and the status quo of its supply chain maturity.

4.1 Sasol at a glance

Sasol is an integrated oil and gas company with substantial chemical interests. In South Africa, these operations are supported by mining coal and converting it into synthetic fuels and chemicals through proprietary Fisher-Tropsch technologies. In March 2004, Sasol began to produce and pipe Mozambican natural gas, some of which is currently used as alternative feedstock to its fuel and chemical production in South Africa.

The company also has chemical manufacturing and marketing operations in Europe, Asia and the Americas. Sasol's larger chemical portfolios include polymers, solvents, surfactants and their intermediaries, waxes, phenolics and nitrogenous products.

The group refines international crude oil into liquid fuels in South Africa and retails liquid fuels and lubricants through a growing network of Sasol retail convenience centres.

Sasol is continuously expanding globally, with its most recent the development of two joint-venture gas-to-liquids (GTL) plants in Qatar and Nigeria. It will be based on Sasol's proprietary Sasol Slurry Phase Distillate™ (SSPD) process.

4.2 Sasol group of companies

The Sasol group comprises nine main subsidiary companies:

Sasol Mining (Pty) Ltd mines about 45 million tons per annum (tpa) of saleable coal in the Sasolburg and Secunda regions for the South African petro-chemical plants. It exports about 3,6 million tpa of this coal.

Sasol Synfuels (Pty) Ltd operates the world's only coal-based synfuels manufacturing facility in Secunda, South Africa. It produces synthesis gas through coal gasification and natural gas reforming, and uses proprietary Fischer-Tropsch technology to convert synthesis gas into synthetic fuel components, pipeline gas and chemical feedstock, including ethylene, propylene, ammonia and solvents.

Sasol's chemical businesses in South Africa and around the world produce commodity, intermediate and speciality chemicals, including alcohols, acids, ketones, surfactants, surfactant intermediates, inorganic speciality chemicals, monomers, polymers, alpha-olefin co monomers, inorganic compounds, phenolics and waxes, as well as chlor-alkali chemicals, mining reagents, fertilisers and commercial explosives.

Sasol Oil (Pty) Ltd also known as ***Sasol Liquid Fuels Business (LFB)*** manufactures and markets petrol, diesel and other liquid fuels derived from crude oil refining and from coal conversion, as well as industrial and automotive lubricants, fuel oils, recarburiser cokes, creosote and other tar-derivatives. It has established 370 service stations in South Africa since January 2005 and exports fuels to eight African countries.

Sasol Gas Ltd markets natural gas from Mozambique's Temane and Pande fields, as well as methane-rich gas produced by Sasol at Secunda, to industrial and commercial customers. It began supplying Mozambican natural gas to customers, in phases, during March 2004.

Sasol Petroleum International (Pty) Ltd develops and manages Sasol's oil and gas exploration and production interests in Gabon, Equatorial Guinea, Nigeria, Mozambique and South Africa.

Sasol Synfuels International (Pty) Ltd develops and manages Sasol's interests in international synfuel ventures incorporating its competitive Fischer-Tropsch technology. It has brought the world's first commertial scale gas-to-liquids (GTL) plant into production with Qatar Petroleum in 2006.

Sasol Technology (Pty) Ltd supports its fuel and chemical businesses in research and development, technology and innovation, business optimisation, new business development and in designing, constructing and commissioning new plants.

Sasol Financing (Pty) Ltd is responsible for group cash and liquidity management, in-house banking, domestic and international financing arrangements, foreign exchange management, treasury risk management and other general treasury matters.

4.3 Sasol products

Sasol's wide product range touches millions of lives daily; from the realms of travel and adventure to education, fashion, sport and health, and from music, reading, cooking and motoring to farming, mining and road building. A few of the uses of Sasol products are listed:

- ***Sasol solvents*** are used in many household and personal care products, including paint, varnishes, aftershave lotions, deodorants and perfumes;
- customers convert Sasol's ***polypropylene*** into automotive components, carpets, garden furniture, crates and kitchenware;
- ***poly vinyl chloride*** (PVC) is used for water and waste pipes, electric cable sheeting, footwear, flooring and bottles;
- many shampoos, soaps, detergents and disinfectants use Sasol's ***surfactants*** and other chemicals;
- ***ammonia*** is used to produce horticultural and agricultural fertilisers, as well as commercial explosives for mining, quarrying and civil engineering;
- ***petrol, diesel, jet fuel and lubricants*** enable millions of people to be transported to and from work and holiday destinations daily, as well as providing vital energy for many industries;
- Sasol's ***pipeline gas*** is used as an energy source for producing steel, bricks, ceramics, paper and pulp, and fertilisers;
- ***Sasol waxes*** are used for a number of personal and industrial applications, from candles to fruit coatings.

4.4 Sasol's global supply chains

4.4.1 Sasol's global footprint

The hundreds of fuel and chemical products that Sasol manufactures in Sasolburg and Secunda in South Africa, and at various locations in Europe, the Americas, the Middle East and Asia-Pacific, are sold to customers in almost 100 countries. This makes the management of supply to customers both complex and challenging. *Figures 10* and *11* illustrate Sasol's global footprint.

[**Source:** Sasol Facts 2006]

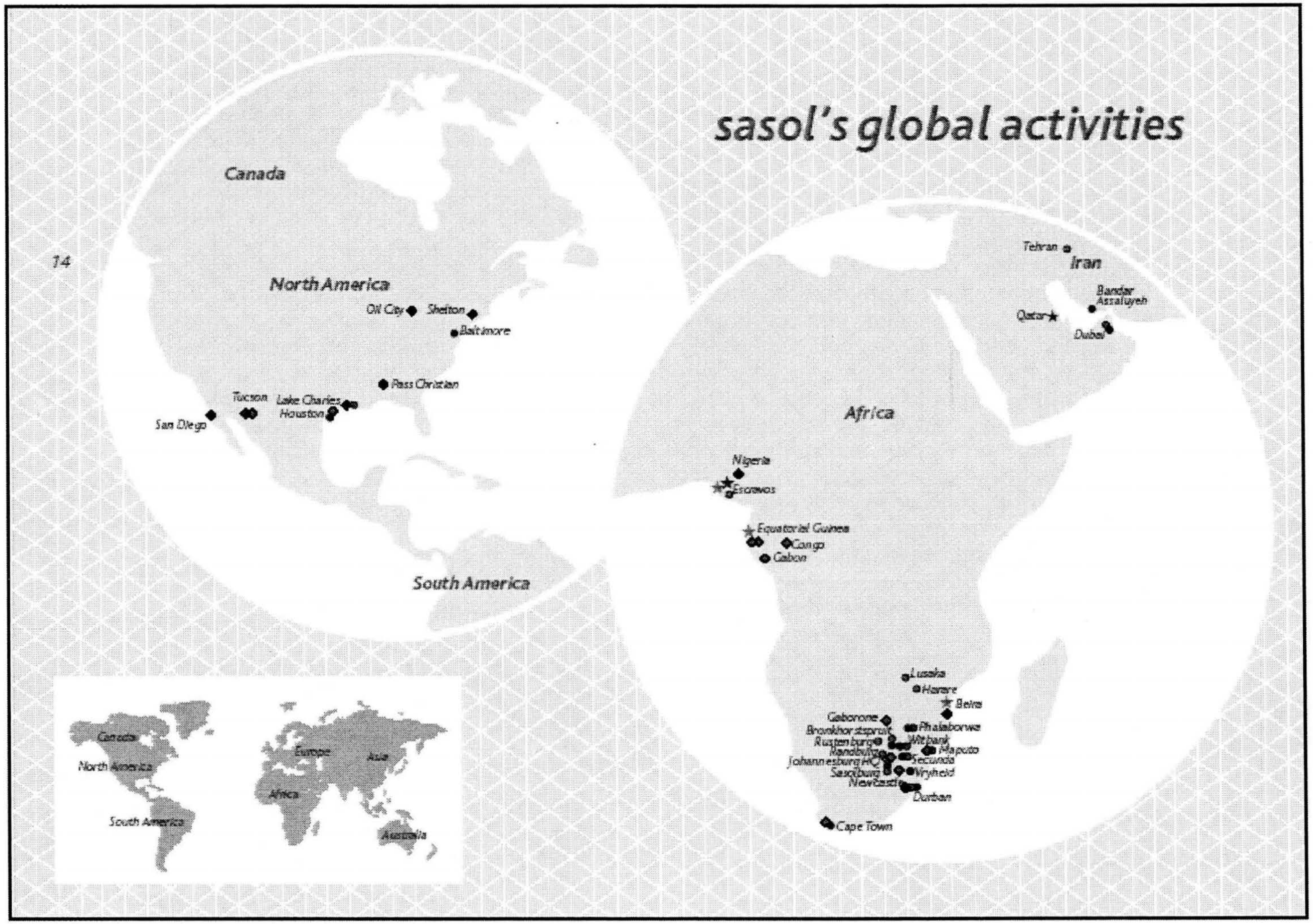

Figure 10: Sasol's global footprint (1)

[**Source:** Sasol Facts 2006]

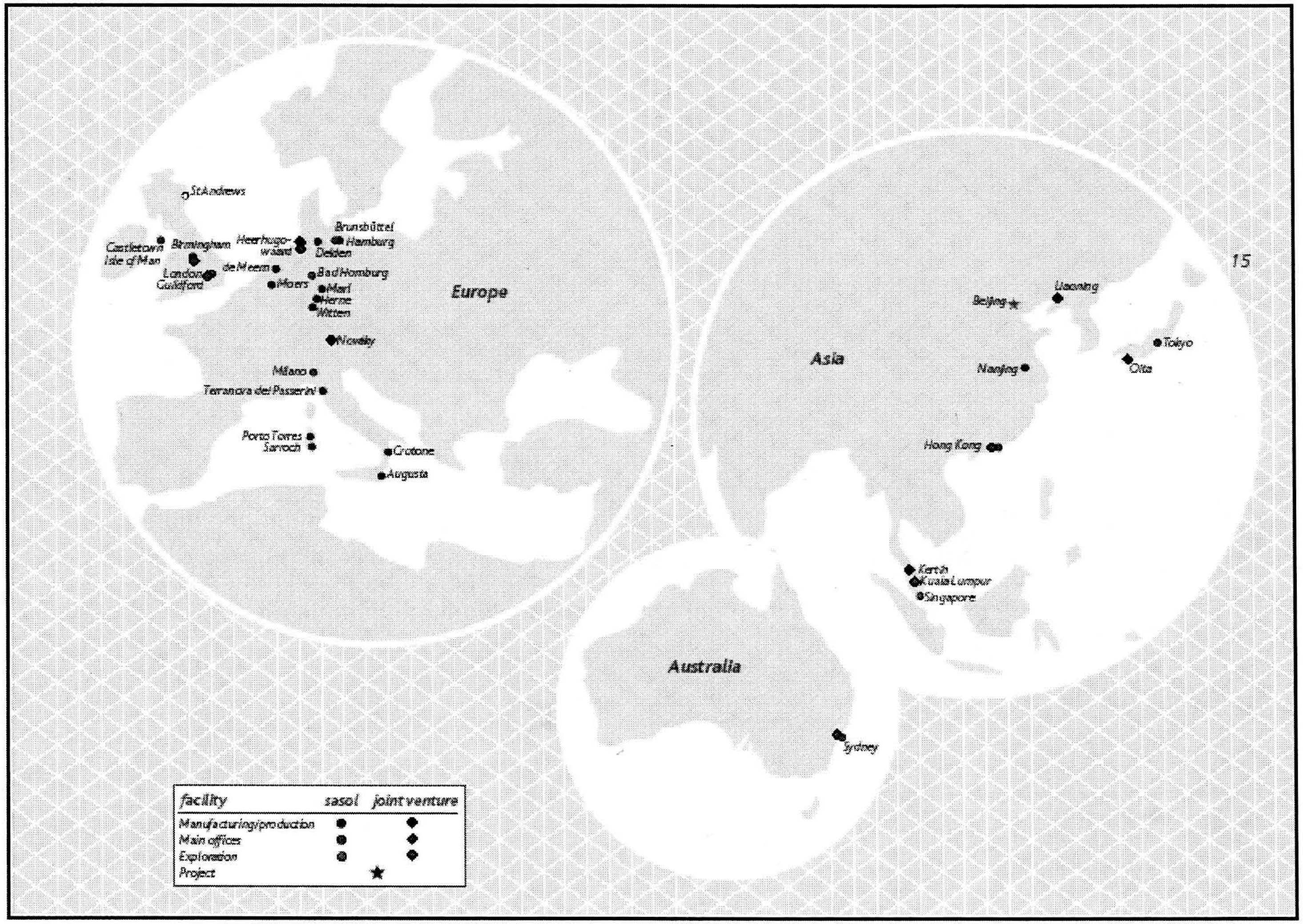

Figure 11: Sasol's global footprint (2)

4.4.2 An example – Sasolwax supply chain

One example of the many supply chains that exist within the Sasol company will now be discussed. The product Sasolwax[3] is produced by the business unit Sasol Wax (SA) (Pty) Ltd.[4] and used for a number of different applications:

- hot melt adhesives;
- printing inks, paints and varnishes;
- polishes;
- textiles;
- lubricants for the processing of plastics;
- electrical insulating; and
- paper conversion.

The high level supply chain for Sasolwax will be discussed (note that a number of variables have been ommited for the sake of simplicity).

Natural gas is extracted in Mozambique and transported to Sasol's chemical plant in Sasolburg by pipeline. Here it is used as feedstock (together with hydrogen and oxygen) in the presence of a catalyst to produce wax products through Sasol's chemical processes utilising Sasol's proprietary Fisher-Tropsh technology. The wax product (in solid form) is bagged, packaged, palletised and stored in a warehouse on site. It is then packed in containers and transported to the Durban port by rail, and loaded on a sea vessel to be exported to the three ports Hamburg, Hong Kong and Sydney. From these ports it is transported either to the global distribution centres or directly to customers. Road or rail transportation is used to deliver the wax product to final customers who use it for a number of different applications (*Figure 12*).

[3] Sasolwax is the trade name for the unique range of waxes produced by Sasol Wax's Fisher-Tropsch process.
[4] Sasol Wax (SA) (Pty) Ltd. is a subsidiary of Sasol Wax International AG.

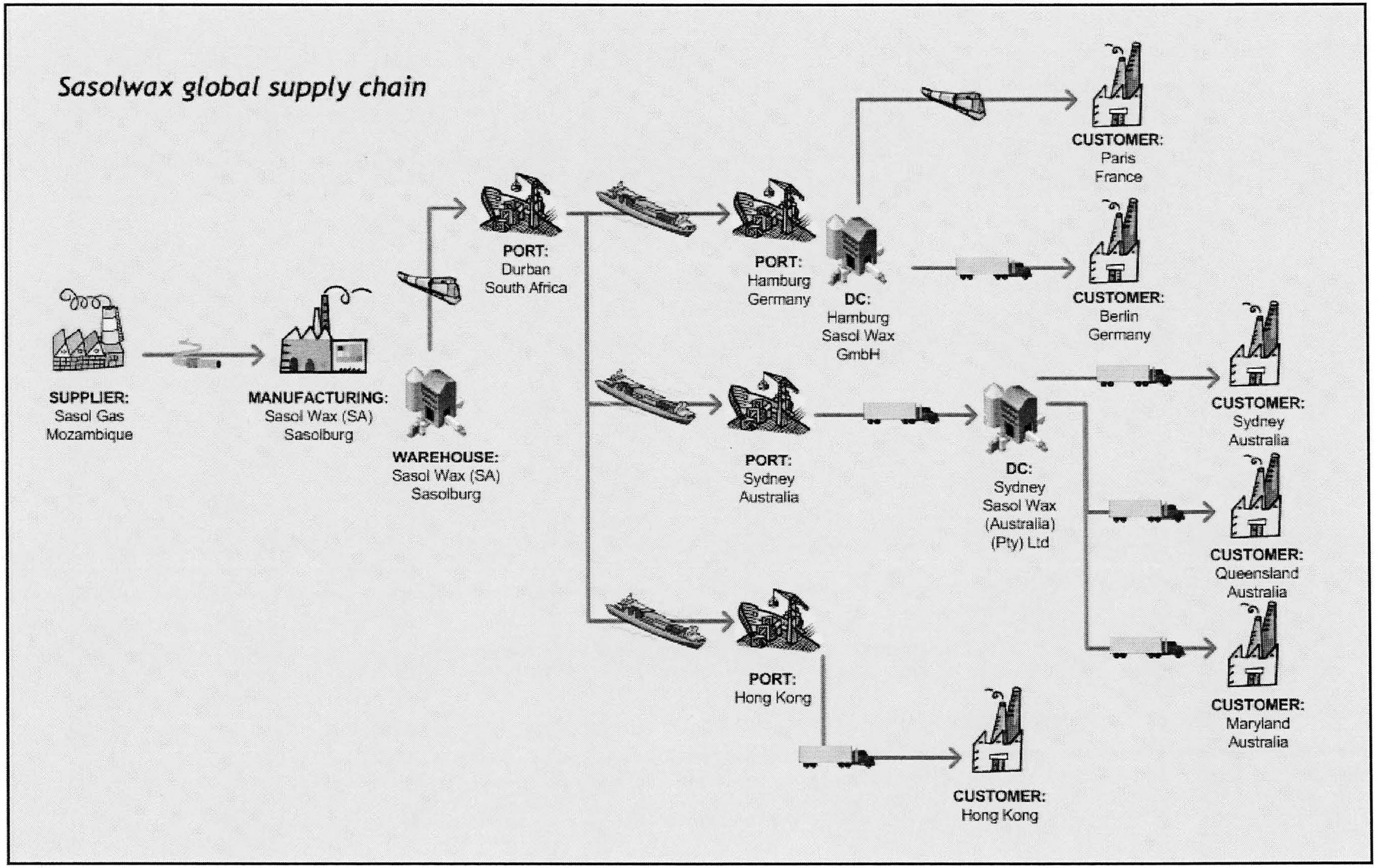

Figure 12: Sasol Wax supply chain

4.4.3 Sasol's supply chain taxonomy

The variety of products, geographical location of plants, warehouses and customers, different modes of transportation, *etc.* are some of the dimensions that make for highly complex supply channels. Louw (2004) classified the dimensions of the Sasol petro-chemical supply chains as follows:

1) **Chemical type clusters** (specific molecules that move along business unit value chains)
   - Nitrogenous (including ammonia, fertilizers, explosives, *etc.*)
   - Oxygenate (including ketones, ethanol, *etc.*)
   - Hydro carbons (including alpha olefins, solvents, polymers, *etc.*)

2) **Logistics value clusters** (product forms)
   - Liquid bulk (any product in liquid form, transported by road fuel tanker, bulk liquid sea freight)
   - Dry bulk (product in solid from, *e.g.* powder, flakes, granules)
   - Packaged goods (products packaged in bags, drums, containers, boxes)
   - Gasses (gaseous products, transported in specialised pressure vessels or pipelines)

3) **Supply chain components**
   - Facilities (plants, warehouses, tank storage, distribution centres, terminals, ports)
   - Transportation modes (road, rail, pipeline, ship)
   - Support services (surveying, clearing and forwarding)

This classification is used to understand Sasol's global supply chains across different business units and product ranges.

4.5 Supply chain management in Sasol

Sharman's (2002) statement that supply chain management is a difficult challenge for complex chemical companies, is also implicitly applicable to the Sasol environment where there exists a number of different business units (with different product ranges) with decentralised sourcing and logistics agendas. As a result of specialised business processes, supply chain fragmentation is common.

Business units differ in their maturity with regard to supply chain management. Some are leading the way with the implementation of Advanced Planning Systems (APS), while others lag behind without a defined supply chain strategy. It has become apparent that a huge obstacle for advancement in supply chain decision-making is the lack of accessible supply chain information of good quality. Most business units have transactional Enterprise Resource Planning (ERP) systems like SAP in place, but what is often lacking is a framework for transforming this data to intelligence that can be used for better supply chain decision-making.

Sasol has realised the need for a common supply chain strategy across the group, and there is currently a drive towards analysing and realising synergies and opportunities between fragmented supply chains. Supply Chain Optimisation (SCO) is a business unit in Sasol that focuses on optimising Sasol's global supply chains. It has a cross-functional and -organisational mandate, with the vision *"to have respected, world-class supply chains, creating significant value."* Focus areas include:

- supply chain network design and optimisation;
- logistics execution optimisation;
- supply chain business processes engineering;
- logistics economics and business case definition;
- supply chain strategy;
- analytical applications for advanced decision-making (*i.e.* modelling, simulation and optimisation); and
- joint contract negotiations with Sasol logistics service providers.

Sasol has taken up the challenge and the vision for world class supply chain management. This is a daunting task, encompassing many different issues, but this research will aim to contribute in some way to the realisation of this vision.

4.6 Concluding chapter 4

Chapter 4 introduced Sasol, the proudly South African petro-chemical company, currently attracting international interest in their alternative (proprietary) fuel production technologies. The company has various production facilities around the world, and with hundreds of products and customers around the world, they are faced with increasing pressure to leverage supply chain opportunities. Its fragmented nature, with various different business units with separate logistics agendas, result in the fact that different business units are currently in various stages of supply chain maturity. The general progression towards a supply chain view and increasing interest in the use of modelling and optimisation techniques provides a burning platform for the practical application of this research.

Chapter 5

Supply chain modelling and optimisation – enabling better decision-making

Supply chain planning was mentioned in chapter 2 as one of the categories within the supply chain management domain. In this chapter, the context of this research will be narrowed down by reviewing the concepts of supply chain modelling and optimisation, and how it supports integrated supply chain planning at different levels.

5.1 Integrated supply chain planning

The integrated nature of supply chain management necessitates and implies the concept of integrated supply chain planning. Where supply chain management is concerned with getting the right product at the right time at the right place, supply chain planning decisions are concerned with determining which is the right product, where is the right place and when is the right time (Stemmet, as quoted in Louw, 2004).

Fleischmann *et al.* (2000:57) states that supply chain planning supports decision-making by identifying alternatives of future activities and selecting some good ones or even the best one. Domschke & Scholl (as quoted in Fleischmann *et al.*, 2000:57) subdivided planning into the following phases:

- recognition and analysis of the decision problem;
- definition of objectives;
- forecasting of future developments;
- identification and evaluation of feasible activities (solutions); and
- selection of good solutions.

It is naïve to think that supply chain planning only involves looking at the alternatives, comparing them with respect to given criteria and selecting the best one (Fleischmann *et al.* 2000:58). This simplified approach encounters, in most cases, three major difficulties:

1) There are often several criteria which imply ***conflicting objectives*** and ambiguous preferences between alternatives. For example, customer services ought to be as high as possible, while – at the same time – inventories are to be minimised. In this case a compromise needs to be made between the conflicting objectives.

2) There is often a ***large number of alternatives*** when faced with a supply chain planning problem. As most combinatorial problems are hard to solve to optimality, heuristics are used to find near-optimal solutions in acceptable timeframes. Both optimising- and heuristic methods require advanced operations research skills[5].

3) All supply chain problems deal with ***uncertainty***. Planning anticipates future activities and is based on data about future developments. Nearly always, reality will deviate from the plan. The deviation has to be controlled and the plan has to be revised on a regular basis.

Thus advanced supply chain planning tools and methodologies are continually developed and refined to cater for integrated planning in the supply chain.

5.1.1 Supply chain planning domain

The supply chain planning and decision-making domain is not a simple one. Shapiro (2001:7) defines three dimensions of integrated supply chain planning:

- functional integration;
- spatial integration; and
- inter-temporal integration.

Functional integration relies on integrated planning between different functions in an organisation (including purchasing, manufacturing, transportation and warehousing activities). The second dimension refers to the ***spatial integration*** of these activities across geographically dispersed vendors, facilities and markets. ***Inter-temporal integration*** (also called hierarchical integration) refers to the planning of these activities over strategic-, tactical- and operational time horizons.

Fleischmann *et al.* (2000:58) categorised supply chain planning problems in the matrix illustrated in *Figure 13*. This illustration does not represent an exhaustive list of all supply

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[5] Optimisation and heuristic methods will be described in more detail in the subsequent paragraphs.

chain problems, but visualises the context of supply chain problems and how they fit together in terms of functional and hierarchical dimensions.

[**Source:** Fleischmann et al. (2000:58)]

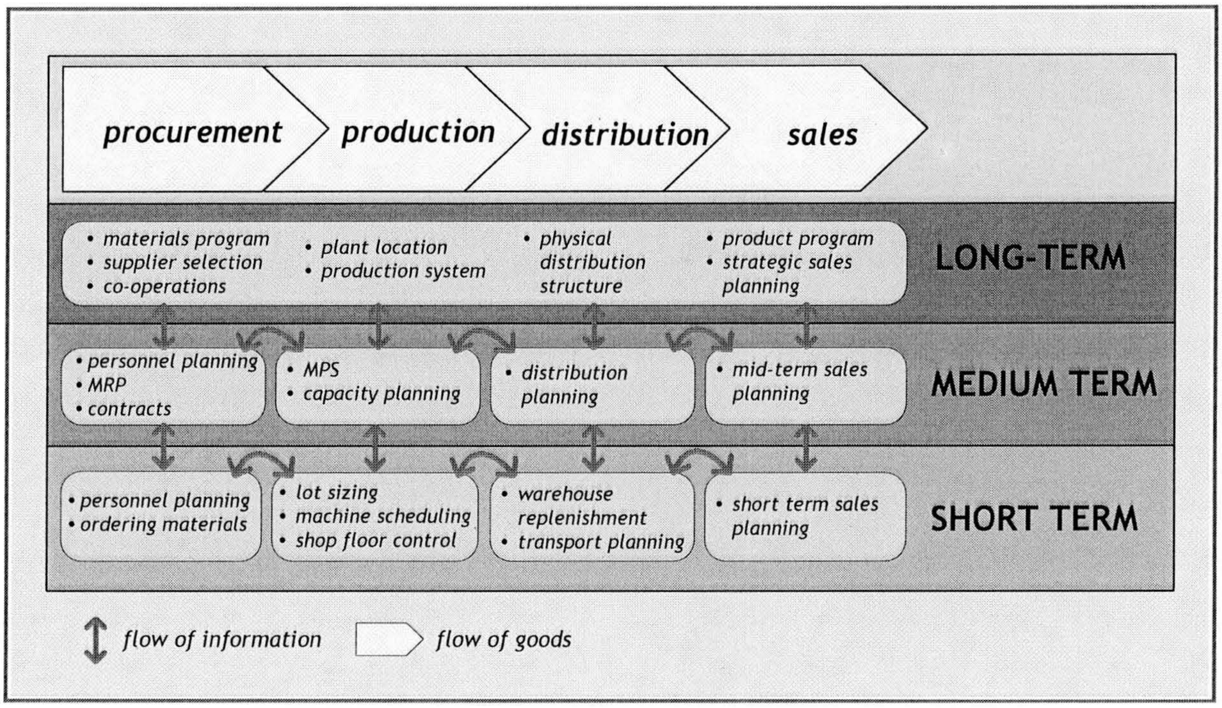

Figure 13: The supply chain planning matrix

The hierarchical dimension includes:

1) ***Long term planning*** (strategic decisions) creates the prerequisites for the development of an enterprise/supply chain in the future. It is typically concerned with the design and structure of a supply chain and have long term effects (1 to 5 years).

2) ***Medium term planning*** (tactical decisions) determines an outline of the regular operations within the long term planning context. These decisions provide rough cut product flow quantities, and resource requirements. The planning horizon ranges from 1 to 12 months.

3) ***Short term planning*** (operational decisions) encompass the lowest planning level and has to specify all activities as detailed instructions for immediate execution and control. Therefore, short-term planning models require the highest degree of detail and accuracy. The planning horizon is days or hours , and decisions are restricted by the directives on structure and quantitative scope from the upper levels.

Table 2 includes some supply chain planning examples within each domain.

Table 2: Hierarchical supply chain problem space

HIERARCHICAL LEVEL	TIME HORIZON	SUPPLY CHAIN DECISIONS
Strategic	years	Global configuration of a supply chain network
		Long-term manufacturing capacity management
		Where to locate new facilities (production, storage, logistics)
		Significant changes to existing facilities (expansion, closure)
		Sourcing decisions (which suppliers to use for each facility)
		Allocation decisions (which products to make at each production facility, which markets to serve from which warehouses)
Tactical	months	Monthly campaign planning at a manufacturing site
		Inventory holding policies at a network of warehouses
Operational	hours, days, weeks	Real-time supply chain management and control
		Daily production scheduling
		Daily transportation scheduling (e.g. vehicle routing)
		Human resources scheduling

5.1.2 Hierarchical planning systems

Hierarchical planning was first proposed by Hax & Meal (1975). They illustrated how to build hierarchically-coordinated, solvable models which provide effective decision-support for the different levels within a hierarchical organisation. The main idea of hierarchical planning is to decompose the total planning task into planning modules, *i.e.* partial plans, assigned to different decision-making levels (Stadtler, 2000b:25). The decreasing degree of detail is achieved by aggregating data and results when going up in the hierarchy.

Briefly, hierarchical planning is based on the following five elements (Stadtler, 2000b:25):

- decomposition and hierarchical structure;
- aggregation;
- hierarchical coordination;
- model building; and
- model solving.

The overall decision problem is ***decomposed*** into two or more decision levels (*Figure 14*). Decisions to be made are assigned to each level such that the top level includes the most important, long-term decisions. A separation into distinct decision levels is called ***hierarchical***, if for each level a single upper level can be identified which is allowed to set the frame within which decisions of the subordinate level have to take place. ***Aggregation*** serves to reduce problem complexity. It can also diminish uncertainty (*e.g.* of demand forecasts). Aggregation is possible in three areas: time, resources and products. ***Hierarchical coordination*** is achieved by directives and feedback. The upper decision level sets targets for subordinate decision units, which will then provide feedback regarding the fulfilment of those targets. These now allow for the upper level to revise plans, to better coordinate lower level decisions and to enable feasible plans at the lower level.

[**Source:** Adapted from Stadtler (2000b:26)]

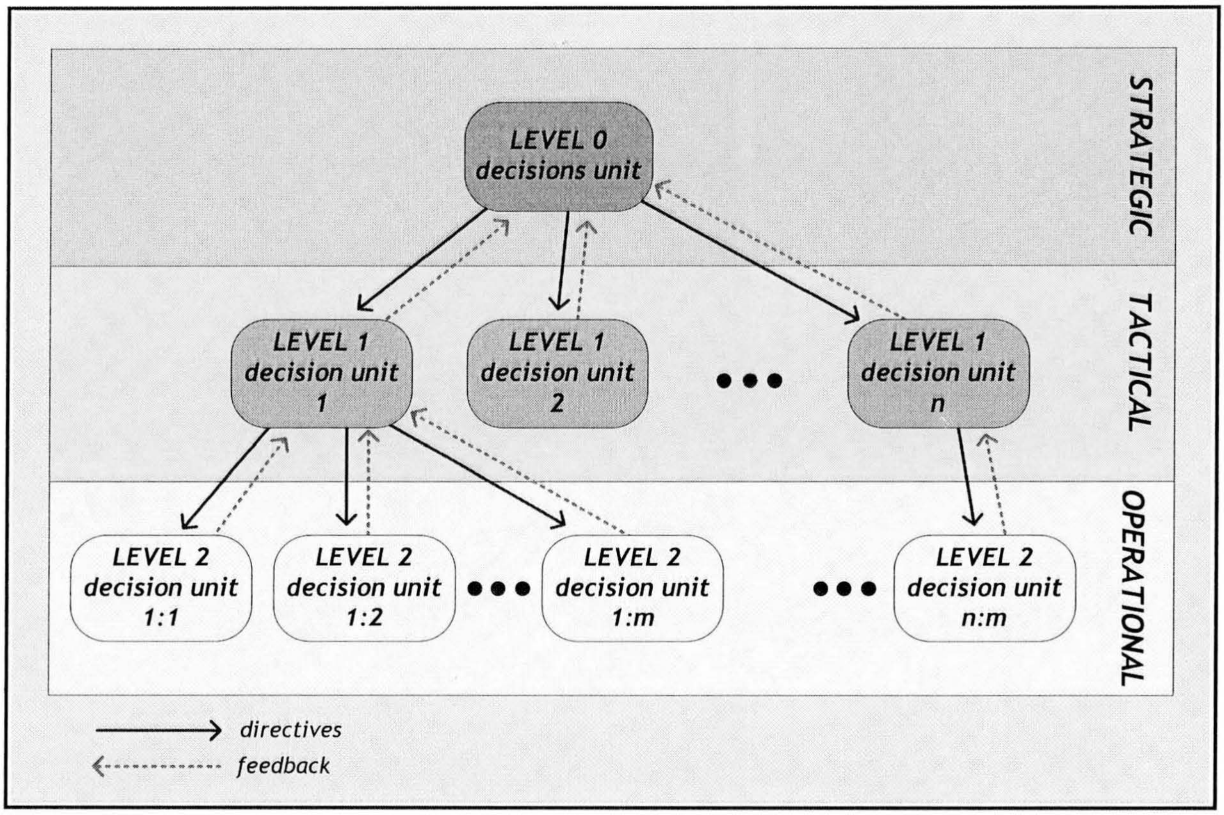

Figure 14: Basic structure of hierarchical planning

For each decision unit a ***model*** is generated which adequately represents the decision situation and which anticipates lower level reactions on possible directives. It links targets set by the upper level to detailed decisions to be made at the decision unit concerned.

Thereby the upper level plan will be disaggregated. Finally a suitable ***solution procedure*** has to be chosen for each model. These may consist of both optimum seeking algorithms as well as manual procedures for group decision-making.

Since hierarchical planning represents an appealing approach to conquer complex decision problems, while incorporating the experience of human decision-makers at different levels of an organisation, it is not surprising that today's advanced planning systems (APS) are constructed along the principles of hierarchical planning.

5.1.3 Advanced planning systems

One of the biggest challenges in facing the challenge of integrated supply chain management is the coordination of thousands of individual decisions that take place every minute in different parts of the chain. The dawn of ***advanced planning systems*** (APS) attempts to address this by offering advanced analytical ways of making decisions in a coordinated fashion (across the chain).

Meyr *et al.* (2000a:60) defines three main characteristics of APS:

1) ***Integral planning*** of the entire supply chain, at least from the suppliers up to the customers of a single enterprise, or even of a more comprehensive network of enterprises.

2) ***True optimisation*** by properly defining alternatives, objectives and constraints for the various planning problems and by using optimising planning methods, either exact ones or heuristics.

3) A ***hierarchical planning system*** which is the only framework permitting the combination of the two preceding properties. The hierarchical planning system makes it possible to split planning activities and allows for flexibility and use at different levels of decision-making.

Note that the traditional material resource planning (MRP) concept which is implemented in nearly all ERP systems does not have any of the above properties. It is restricted to the production and procurement area, does not optimise and in most cases does not consider an objective function, and it is a successive planning system.

APS have independently been launched by different software companies at different points in time. Nevertheless, a common structure underlying most of the APS can be identified. An APS typically consists of several software modules, each of them covering a certain range of planning tasks. *Figure 15* illustrates the planning tasks covered by respective software modules (refer back to *Figure 13* for comparison). The names that have been chosen in the figures try to characterise the underlying planning tasks, as the specific module names vary from APS vendor to APS vendor (Meyr *et. al*, 2000b:75). The leading APS software vendors (and their APS) include:

- i2 technologies – *i2 Six Supply Chain Management*™
- J.D. Edwards – *Active Supply Chain*
- SAP – *Advanced Planning & Optimisation (APO)*
- Logility – *Voyager Solutions*
- Aspentech – *Aspen SCM*™

[**Source:** Meyr *et. al* (2000b:75)]

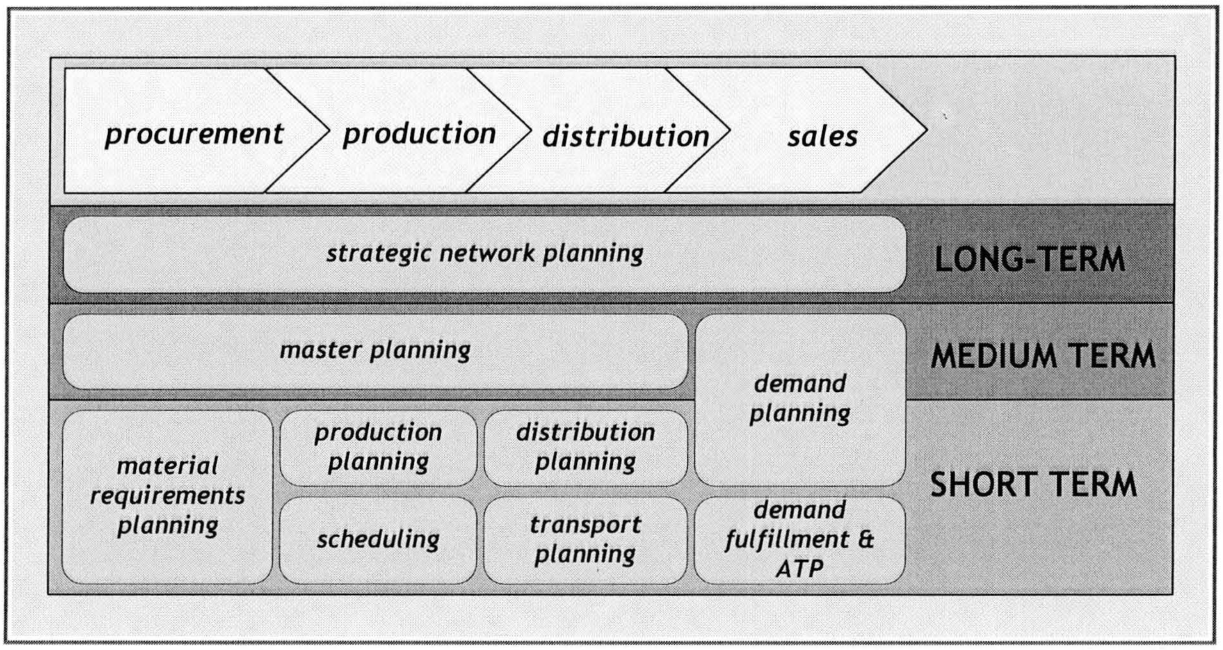

Figure 15: APS software modules

Planning tasks for different types of industries / supply chains can vary substantially. The nature of planning in the petro-chemical industry in particular does not always favour the traditional MRP-type approach to planning. For this reason, Aspen SCM™ has been developed to specifically deal with planning complexities associated with the continuous nature of the petro-chemical industry[6].

5.2 Strategic supply chain planning

The research in this study is specifically concerned with strategic supply chain management problems. The integrated (hierarchical) nature of the planning domain (*i.e.* strategic, tactical, operational) questions whether strategic planning can be studied in isolation from tactical and operational planning problems. It was however decided that due to the lack of the use of supply chain decision-support models for strategic problems in the petro-chemical industry, specific focus should be given to this type of supply chain problems. This will provide the strategic supply chain direction often lacking in organisations, and can be integrated in a hierarchical planning system as described above.

Virtually all organisations need to re-design their supply chains from time to time to respond to changing market conditions. The recent wave of mergers and acquisitions and the globalisation of the economy have increased the frequency and importance of this process (Goetschalckx, 2000:79). Thus, companies can no longer afford to look at strategic issues once in a blue moon, as the decisions made during strategic network planning have a major impact on the profitability and competitive position of the corporation.

Supply chain design ought to be thought of as a dynamic process of assembling chains of capabilities and not just collaborating organisations. This dynamic view is particularly important in a fast-evolving world where new products and emerging distribution channels necessitate a continuous review of supply chain design decisions (Akkermans *et. al*, 2003).

Typically, the planning horizon for strategic planning ranges from one to five years and the decisions involve the definition of customer and product zones, the definition of the stages in the manufacturing process, establishment or closure of manufacturing and distribution facilities and the installation of major manufacturing lines (Goetschalckx, 2000:79). The main objects in a strategic network design project are related to different countries, planning periods, products, customers, vendors and suppliers, manufacturing and distribution facilities, and transportation assets. Decisions are the status of a particular facility or

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[6] Aspen SCM™ will be discussed in more detail in paragraph 5.5.5.

relationship during a specific planning period, and the product flows and product storage in the supply chain during the planning period.

Corporations have also become interested not only in the economic efficiency of their supply chain for projected conditions, but also in the robustness and flexibility of their supply chain to adapt to changing and unanticipated conditions (Goetschalckx, 2000:80). To address these problems and assist managers in making intelligent strategic decisions about their supply chains, operations research academics and practitioners have developed modelling methodologies to describe and optimise the behaviour of supply chains. The next sections in this study will focus on modelling and optimisation techniques that can, and have been, used for strategic supply chain decision-making.

5.3 Models for strategic supply chain problems

The complexity of supply chains makes it impossible to deal with every single detail of reality during the planning process (Fleischmann *et al.*, 2000:57). Therefore, it is always necessary to abstract from reality and to use a simplified copy of reality, a so-called ***model***, as a basis for establishing a plan. The art of model-building is to represent reality as simple as possible but as detailed as necessary. The required detail will differ based on the decision-making level according to the hierarchical planning principle.

The use of modelling and optimisation methods is gaining popularity and application in the supply chain environment. These models can be classified as either ***descriptive*** or ***normative*** (Shapiro, 2001:10). Descriptive models are used to better understand the functional relationships within the company and between the company and the outside world. Examples include:

- ***forecasting models*** that predict some future state (be it demand, price or other factor) based on historical data;
- ***costing models*** that describe how direct and indirect costs vary as functions of cost drivers;
- ***resource utilisation models*** that describe how manufacturing activities consume resources;
- ***process models*** that establish a process view of all the activities related to a supply chain;

- ***simulation models*** that describe how all parts of the company's supply chain will operate over time as a function of parameters and policies; and
- ***graphical models*** are used to graphically represent a supply chain network to aid understanding and clear visualisation.

Normative models assist managers in making better decisions. It is concerned with the optimisation of a constrained objective, and is also referred to as optimisation models or mathematical programming models. Examples include:

- ***resource allocation models*** that determine how to best make use of scarce resources across the supply chain;
- ***transportation models*** that mimic the network structure of a supply chain to determine the optimal transportation schedule for distributing goods to multiple destinations;
- ***stochastic programming*** models that allow the decision maker to explicitly analyse uncertainties and risks in a problem; and
- ***financial models*** that are used to model the financial implications of capital investments.

Descriptive models are extremely useful in describing the functional relationships and complexities in the supply chain. It provides understanding that can assist managers in making decisions. However, only when descriptive models are used as input to normative models can its value be fully realised. This is because normative models make use of intelligent methods to provide the optimal (or near optimal) result for a given problem. It provides the decision-maker with the confidence to know that the solution does not rely on emotion, thumb-suck or hap-hazard methods, but on analytically sound methodologies.

5.4 Modelling and optimisation techniques

A discussion now follows on relevant modelling techniques/methodologies available for implementing some of the strategic models mentioned in the previous paragraph. Each paragraph will include:

- a description of the model type;
- a discussion on the technique(s) available for implementing this model; and
- examples of successful applications of this model from experience and literature.

5.4.1 *Supply chain network models*

5.4.1.1 Description - supply chain network modelling

Supply chain network modelling is used to determine the impact of business scenarios on a company's operations and costs. It involves the modelling of all the main supply chain network parameters and determines the optimal arrangement that will minimise cost while satisfying service requirements (Jimenez *et al.*, 1998:303). It has application on the three temporal levels, but is most widely used to provide answers to strategic supply chain problems.

Supply chain network decisions involve the definition of customer and product zones, the definition of the stages in the manufacturing process, the establishment or closure of manufacturing and distribution facilities and the installation of major manufacturing lines (Goetschalckx, 2000:79). These decisions have an impact on manufacturing and distribution capacity and allocation of these capacities to product and customer zones.

Shah (2005) claims that network modelling is essentially about trade-offs between different parameters. Some of the potential trade-offs in supply chain network modelling problems include:

- differences in regional production costs;
- distribution costs of raw materials, intermediates and final products;
- differences in regional taxation and duty structures; and
- exchange rate variations.

A good network model, evaluating these trade-offs (and more), should provide the decision-maker with the optimal network configuration, and can result in significant savings.

5.4.1.2 Technique - mathematical programming

Mathematical programming relies on the use of linear programming (LP) or some variant thereof (*e.g.* non-linear programming, mixed integer programming), to build normative models. It determines the best possible solution for an objective (*e.g.* revenue maximisation) that is subject to various resource constraints (*e.g.* limited production capacity). The benefit of using mathematical programming is that it provides an ***optimal solution*** to a problem where it is not possible to manually evaluate the millions of possible solutions that can exist.

A drawback of mathematical programming is that is requires advanced operations research skills, and that it becomes computationally expensive when considering large-scale problems. A further limitation is its assumption of deterministic behaviour, ignoring the variability and uncertainty that can exist in a supply chain (*e.g.* material prices, demand variability, production capacity variability, delivery time variability). It also assumes cost linearity, which might not be the true representation of reality. To overcome these problems, researchers have developed alternative strategies to more effectively deal with large-scale industrial problems. These methods will be discussed in the subsequent paragraph.

Mathematical models have been successfully applied in strategic supply chain dilemmas, and is perhaps the most widely used and researched method for supply chain improvement. Apart from network models, mathematical programming is also used to build (*inter alia*) resource allocation-, transportation-, and financial models.

5.4.1.3 Technique - meta-heuristics

An alternative to the use of mathematical programming is the use of meta-heuristics. According to the Glover & Kochenberger (2003), *"meta-heuristics, in their original definition, are solution methods that orchestrate an interaction between local improvement procedures and higher level strategies to create a process capable of escaping local optima and performing a robust search of the solution space"*. Where mathematical programming provides the best of the best solution, meta-heuristics (or rule-based decision-making) provides a reasonably good answer in much less time. Especially in the case of complex operational problems (like the daily scheduling of a chemical plant), solving a linear programming model may require too much solving time, in which case solution quality can be partly sacrificed for speed and flexibility provided by meta-heuristic techniques. All of the APS used today make use of meta-heuristics on operational planning and scheduling level. The intent of this study is not to elaborate on the different meta-heuristic techniques, as they are not particularly relevant to the strategic problems evaluated in this research, but it is worth mentioning some of the advanced meta-heuristics applied in industry. These include Genetic Algorithms (GA), Simulated Annealing (SA) and Tabu Search (TS), which have been successfully applied to (*inter alia*) production scheduling and vehicle routing problems.

The interested reader is referred to the following references for more information on the use of meta-heuristics in the supply chain environment:

- Jayaraman & Ross (2003) designed a simulated annealing approach for distribution network design and management.
- Klein (2000:345) discusses the use of genetic algorithms in supply chain planning.
- Abdinnour-Helm (1999) combined tabu search and genetic algorithms in designing supply chain networks.

5.4.1.4 Applications of supply chain network models

Here follows a list of examples from literature and experience, where network modelling (through mathematical programming) has been successfully applied to strategic supply chain related problems in the petro-chemical industry.

1) ***Sasol Fertilizers supply chain configuration:*** A linear programming (LP) model was developed for Sasol Fertilizers (a division of Sasol Nitro) to optimise the fertilizers supply chain configuration. It was successfully used to evaluate a number of different locations for a new plant. Its objective was to maximise revenue, with the main constraint being the cost of transportation to serve the different markets.

2) ***Global logistics configuration:*** Goetschalckx *et al.* (2002) designed a mathematical model that determines an optimal global logistics configuration, taking into account the effect of transfer prices and international taxes. They optimise the material flow between countries, and establish the optimal transfer pricing strategy.

3) ***Sasol Wax supply chain configuration:*** A transportation LP model was developed to determine the optimal utilisation of manufacturing plants for Sasol Wax. With sites in both South Africa and Germany and markets worldwide, the objective was to determine which products should be manufactured on which site and distributed to which markets, in order to minimise supply chain costs.

4) ***Sasol Synfuels International supply chain configuration:*** A network model aided Sasol Synfuels International (SSI) in determining the optimal supply configuration of catalyst supply to various globally distributed gas-to-liquids (GTL) plants. The model was integrated with easy-to-use input and output interfaces to enable management to make regular use of the model as market and cost conditions change.

5.4.2 *Multi-objective models*

5.4.2.1 Description - multi-objective modelling

The supply chain decision-maker is often faced with conflicting objectives and ambiguous preferences between alternatives. For example, customer services ought to be as high as possible, while - at the same time - inventories are to be minimised. In this case a compromise needs to be made between the conflicting objectives. Multi-objective decision-making seeks an optimal compromise between several conflicting objectives, or the achievement of satisfying levels in these objectives.

5.4.2.2 Technique - goal programming

Goal programming (GP) is a variant of mathematical programming, and is used when more than one goal or objective is considered. For example, it might be necessary to make a trade-off between minimising cost, maximising resource utilisation and minimising the amount of hazardous waste created in a chemical process. These goals are conflicting in nature, and carry different weights according to their relative importance. The aim of the goal programming model is to minimise the overall deviation from specific quantified goals (desired values) set by the decision maker for each of the objectives. The interested reader is referred to Winston (1994), chapter 14, for more information on goal programming.

5.4.2.3 Technique - analytical hierarchy process

The ***analytical hierarchy process*** (AHP) approach is used to evaluate priorities of goals and weights of deviation variables corresponding to various goals. It employs pair-wise comparison to determine the weights or priorities of a variety of factors, attributes, elements and alternatives (Saaty, as quoted in Zhou *et al.*, 2000). AHP involves the following steps (Huan *et al.*, 2004):

1) ***problem decomposition and hierarchy construction*** - establish the objective, criteria and sub-criteria groupings;
2) ***determine alternatives*** - define the alternatives to be evaluated;
3) ***pair-wise comparison*** - determine the relative importance of the different criteria;
4) ***weight calculation*** - mathematical normalisation methods are used to calculate the priority weights for each criterion;
5) ***consistency check*** - make sure that the decision-maker is consistent in his/her comparison of criteria;

6) ***hierarchical synthesis*** – score the alternatives for each of the criteria and compute the overall priority weights for each of the alternatives;
7) ***determine priority for all alternatives*** – the alternative with the highest priority weight is chosen as the best solution.

AHP offers several advantages (Suresh & Kapathi, as quoted in Zhou *et al.*, 2000):

- the ability to structure a complex problem analytically;
- consistency with management policies and preferences;
- incorporation of intangible, qualitative criteria into the decision-making process; and
- simplicity of application.

The interested reader is referred to Winston (1994), chapter 14, for more information on AHP.

5.4.2.4 Applications of multi-objective models

Here follows a list of examples from literature and experience, where multi-objective modelling has been successfully applied to strategic supply chain related problems in the petro-chemical industry.

1) ***AHP & GP for sustainable supply chains:*** Zhou *et. al* (2000) applied GP and AHP to the optimisation of a process industry supply chain where sustainability objectives were considered. Their problem included the following sustainability considerations (*i.e.* different goals):
   - ***economic sustainability*** – maximising economic benefit;
   - ***social sustainability*** – ensuring that products meet population needs;
   - ***resource sustainability*** – minimising raw material consumption, minimising energy consumption, and utilising facilities to maximum possible extent; and
   - ***environmental sustainability*** – minimising the amount of hazardous waste created.

   They successfully applied their integrated GP/AHP approach to the discrete time scheduling of a petro-chemical complex, consisting of a refinery plant, ammonia plant and polypropylene plant.

2) ***Site location with AHP:*** Schary & Skjott-Larsen (2001:391) presented an AHP approach that relates to choosing a site location. In this case, a choice has to be made for locating a

site in one of four candidate countries, based on quantitative and qualitative (intangible) criteria. AHP was therefore an obvious method for solving the problem. The seven major decision criteria in this problem were:

- the political climate;
- macro-economic factors;
- the accessibility to the market;
- the efficiency of public administration;
- operations and infrastructure;
- human resources; and
- natural resources.

Below this level were 33 items at secondary level that were selected to capture the full set of factors in the site location decision. After assigning a relative weight to each of the decision criteria, a comparison was made to determine the site that would best cater for all of these criteria combined.

3) ***AHP & SCOR for supply chain performance evaluation:*** An interesting application of AHP is found in Huan *et al.* (2004). They apply AHP in establishing an overall, quantifiable supply chain performance measure by which different supply chains can be compared. They make use of the 12 level 1 performance measures of SCOR (*Table 3*). These measures are modelled in an AHP structure, and the decision-maker makes use of the pair-wise comparison of performance measures in order to determine the relative weight of each of these measures. Supply chain alternatives can then be compared based on their performance at each of these weighted measures.

Table 3: SCOR level 1 performance metrics

DELIVERY RELIABILTIY	
1	Delivery performance
2	Fill rate
3	Order fulfillment lead time
4	Perfect order fulfillment
FLEXIBILITY & REPONSIVENESS	
5	Supply chain responsiveness
6	Production flexibility
COST	
7	Total logistics management cost
8	Value-added employee productivity
9	Warranty costs
ASSETS	
10	Cash-to-cash cycle time
11	Inventory days of supply
12	Asset turns

5.4.3 *Simulation models*

5.4.3.1 Description - simulation modelling

Simulation is a descriptive modelling approach and is defined as *"the process of designing a computer model of a real system and conducting experiments with this model to understand its behaviour or to evaluate strategies to its operations"* (Pedgen *et al.*, 1990). By definition, simulation has the following three characteristics (Kleijnen, 2003):

- it is a quantitative, mathematical, computer model;
- it is a dynamic model, *i.e.* it has at least one equation with at least one variable that refers to at least two different points in time; and
- the model is not solved by mathematical analysis; instead the time paths of the dependent variables (outputs) are computed – given the initial state of the simulated system, and given the values of the input variables.

Simulation has long been useful in understanding and improving complex systems and processes. The approach is particularly favourable for the complex and dynamic nature of the supply chain. It supports the stochastic nature of real-life processes, and allows for the evaluation of system dynamics based on variable process behaviour. This means that the model repetitively and randomly samples its values from distributions of uncertain parameters to build up distributions of performance measures (Shah, 2005). Simulation further caters for the evaluation of events' time dependency on the behaviour of the system, as it runs through a defined simulation timeframe.

For the purpose of this research, distinction is made between three types of simulation for supply chain management:

- Monte Carlo simulation;
- discrete-event dynamic system (DEDS) simulation; and
- agent-based simulation.

5.4.3.2 Technique – Monte Carlo simulation

Monte Carlo simulation refers to the implementation and application of computer programmes that mimic the behaviour of supply chain and other business systems in response to random variations in key parameters affecting them (Shapiro, 2001:463). It originated in the Monte Carlo casino, where French mathematicians developed many of the early results of probability theory while trying to beat the gambling odds. Monte Carlo simulation provides insights into the operational performance of supply chain systems that are complementary to those provided by optimisation models. It is a quick and simple method and usually implemented with the use of spreadsheet software, where random parameter values are repeatedly sampled from probability distributions. Monte Carlo simulation is most widely applied to operational supply chain problems, but can also be applied to include variability in a strategic simulation of a supply chain. The interested reader is referred to Winston (1994), chapter 23 for more information on Monte Carlo simulation.

5.4.3.3 Technique - discrete-event dynamic system simulation

Similar to, but more advanced than Monte Carlo simulation, is discrete-event dynamic system (DEDS) simulation. This type of simulation is based on specialised computer packages that allow for building models of complex real-life processes, and aids insight into the dynamics of environments where randomness and variability are a concern (which is always present in the supply chain).

DEDS simulation is a powerful tool for analysing policies on a tactical and operational process level, but has also been applied to evaluate strategic network design. Terzi & Cavalieri (2003) conducted a survey of simulation in the supply chain context. They claim that the main benefit of supply chain simulation is its ability to provide what-if analysis and to evaluate quantitatively the benefits and issues derived from operating in a co-operative environment. This implies the testing of different decision-making alternatives upon foreseeable scenarios, in order to ascertain in advance the level of optimality and robustness of a given strategy. It is important to note that simulation in itself will not provide an optimal solution, but can be used to test the robustness of solutions from normative models or intuitive strategies.

Vieira (2004) states the following objectives that are usually related to the use of supply chain simulation models:

- inventory reduction – setting appropriate levels according to production planning;
- performance improvement;
- making sure that new processes are tested and approved before their actual implementation;

- reaching the optimal use of resources (machines, production lines, equipment, personnel, *etc.*);
- obtaining better logistics results in the supply chain;
- use of the model to foresee future behaviour, that is, the effects of changes in the system or new operations methods; and
- study of capacity usage, inventory levels, control logic, integration, sequencing / scheduling, bottlenecks, search for better layouts.

Groenewald (2001) listed the following benefits that can be expected from the use of simulation in the supply chain context:

- the effect of time-dependent activities on a static model can be investigated;
- uncertainties in the supply chain network can be investigated by using probability distributions in the model;
- functional requirements can be specified by using a dynamic simulation model. The model, for example, could be used to calculate the size of storage tank facilities and the utilisation of critical resources;
- bottlenecks can be identified in the channel, and then, possible solutions for these bottlenecks could be tested for feasibility in the model;
- alternatives can be evaluated against each other. Calculated decisions could be made, based on the statistical outputs of the model.

The performance of the simulation model is interpreted with the use of statistical methods. The output data from a simulation always exhibit randomness, since random variables are input to the simulation model. Most simulation software vendors include functionality to analyse output with statistical methods.

Researchers have also been developing strategies to integrate the use of simulation and optimisation (mathematical programming). This marriage between normative and descriptive modelling can be used effectively to include stochastic behaviour in optimising a problem with mathematical programming. A mathematical model is used to optimise a problem by testing the feasibility of parameters with a simulation model. Some simulation software vendors have recently introduced optimisation functionality within their products, an example being Arena™, available from Rockwell Software Inc.

5.4.3.3 Agent-based simulation

Many different developments have been going on under the slogan of ***agent-based*** (AB) modelling in very different disciplines like artificial intelligence, complexity science, game theory, *etc.* (Borshchev & Filippov, 2004). It essentially differs from DEDS simulation in that agent-based models are essentially ***decentralized***. There is no place in an AB model where the global system behaviour (dynamics) would be defined. Instead, the modeller defines behaviour at individual level, and the global behaviour emerges as a result of many (tens, hundreds, thousands, millions) individuals, each following its own behaviour rules, living together in the same environment and interacting with each other and with the environment.

Figure 16 shows an agent-based model of country population dynamics from Borshchev & Filippov (2004). In this model the agent behaviour is defined with a state-chart; and housing, jobs, transport infrastructure, *etc.* are represented in an environment model. Individual objects with local behaviour rules drive the model, and interact with each other and the environment.

[**Source:** Borshchev & Filippov (2004)]

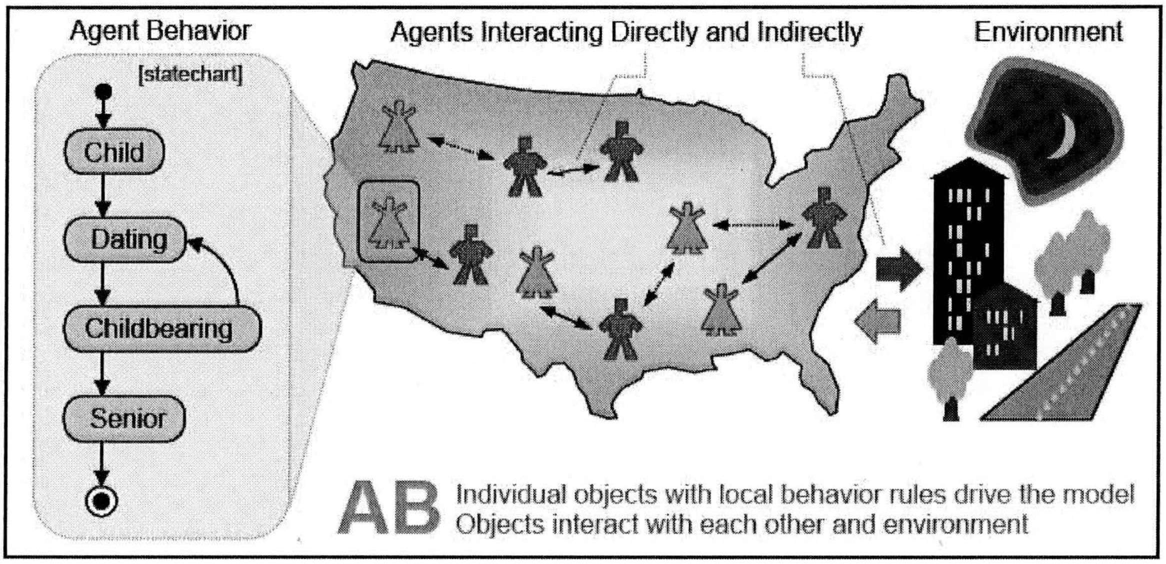

Figure 16: Agent-based model generic architecture. Behaviour in AnyLogic™

The agent-based approach is more general and powerful because it enables the capturing of more complex structures and dynamics (Borshchev & Filippov, 2004). The other important advantage is that it provides for construction of models in the absence of knowledge about the global interdependencies: one may know nothing or very little about how things affect each other at the aggregate level, or what is the global sequence of operations, *etc.*, but if one has some perception of how the individual participants of the process behave, one can construct the AB model and then obtain the global behaviour.

Borshchev & Filippov (2004) compares DEDS and AB modelling. In DEDS models, individual entities are modelled as passive objects and the rules that drive the system are concentrated in the flowchart blocks. The AB methodology allows explicit modelling of local behavioural rules. They argue that AB modelling is not a replacement of DEDS models, but that it can enhance the understanding of the problem if the problem favours its use.

Van der Zee & Van der Vorst (2005) discussed the limitations of current approaches (that is DEDS models) when it comes to supply chain simulation. They argue that most models strongly focus on physical transactions, leaving key decision variables implicit for some or all of the parties involved. They propose the use of agent-based modelling to explicitly address the modelling of control structure (that is, the managers or systems responsible for control).

5.4.3.4 Applications of simulation models

1) ***Supply chain simulation models*** – according to Terzi & Cavalieri's (2003) survey, the following supply chain problems have been addressed by using DEDS simulation techniques:
    - ***supply chain network design*** – strategic analysis of network design alternatives;
    - ***demand and sales planning*** – simulation of processes dealing with stochastic demand generation and forecasting planning definition;
    - ***supply chain planning*** – simulation of processes supporting production planning and distribution resource allocation;
    - ***inventory planning*** – simulation of processes supporting multi-inventory planning and inventory-holding policies;
    - ***distribution and transportation planning*** – simulation of distribution centres, site location and transport planning, in terms of resources, times and costs; and
    - ***production planning and scheduling*** – simulation of processes relating to production management.

2) ***Continuous process simulation*** – The research in this study focuses specifically on the petro-chemical industry, with the obvious need to simulate continuous production processes. A very practical application hereof is the development in Sasol of a simulation methodology for simulating chemical production processes. Stochastic parameters are used within a number of objects like splitter units, distillation units and reactor units. A benefit of modelling chemical production processes is in understanding the behaviour of a chemical process with stochastic parameters. This is particularly useful in sizing tanks to make provision for this production variability. The combination of continuous production processes and discrete logistics processes can easily be addressed in a simulation model.

3) ***Strategic inventory requirements*** – DEDS simulation is used on a regular basis within Sasol when designing new supply chains. It is effective in including variable parameters that might influence the size of storage infrastructure.

4) ***Multi-agent supply chain simulation modelling framework*** – Swaminathan *et al.* (1998) developed a multi-agent supply chain simulation modelling framework to enable rapid model development and a re-usable component library. Their approach utilises software components that represents types of supply chain agents (*e.g.* retailers, manufacturers, transporters), their control elements (*e.g.* inventory policies), and their interaction protocols (*e.g.* message types). Their framework was successfully applied in IBM supply chains to enable effective inventory management.

5) ***Agent-based supply chain models*** – Van der Zee & Van der Vorst (2005) proposed a supply chain modelling framework, utilising agent-based concepts. They applied their approach to a chilled salad supply chain. Wartha *et al.* (2002) developed an agent-based decision support tool for the supply chain (called DST-SC). It is an extension of the simulation software package AnyLogic™ by XJ Technologies[7]. Features include: the flexible ability to model complex supply chains; re-usability of model components; inter-operatability with third party software (*e.g.* GIS, databases); platform independence; and the potential for concurrent use by geographically distributed users.

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[7] The AnyLogic™ software will be discussed in more detail in subsequent paragraphs.

5.4.4 Geographical models

5.4.4.1 Description - geographical modelling

More often than not, supply chain strategists are not skilled in the advanced modelling and optimisation approaches discussed in this chapter so far. They need to visualise the impact of different strategies and for this reason it is extremely valuable to be able to graphically model supply chains. It helps managers to better understand their supply chain configurations as the dictum *"a picture speaks louder than a thousand words"* is particularly applicable in this context.

5.4.4.2 Technique - geographic information systems

Geographic information systems (GIS) is a very effective way of graphically modelling the spatial nature of supply chains. Although only a descriptive model by itself, its value lies in the effective visualisation of complex global supply networks. GIS has been the result of the development of geographic technology, from maps that simply tell us *"where is what?"* to systems that help us decide *"so what?"* A definition of GIS by Star & Estes, as quoted by Groenewald (2001):

> *"An information system that is designed to work with data referenced by spatial or geographic co-ordinates. In other words, a GIS is both a database system with specific capabilities for spatially-referenced data, as well as a set of operations for working [analysis] with the data."*

GIS can be regarded as the high-tech equivalent of the map. It combines the efficiency of a computerised mapping system with the power of a relational database. One can look at it as an intelligent map. One can query the map in much the same way as one can query a database. An individual map contains a lot of information, which is used in different ways by different individuals and organisations. It represents the means of locating oneself in relation to the world around one.

Using geography as the common denominator, GIS ties data from many different sources into a single base map, it incorporates changes as they are entered, and analyses information to solve specific problems. The real power of GIS lies in analysis - linking layers of data and determining the impact of each layer upon another. GIS can be used to try out an idea first on the computer to test it and see the potential results long before the idea becomes a costly reality. The power of GIS is in quantitative and qualitative analysis. It can be used to solve hypotheses and plan changes, and is particularly effective in the design and analysis of global supply chains.

5.4.4.3 Applications of GIS

The following is a list of examples from experience in the Sasol environment, where GIS modelling has been successfully applied to strategic supply chain related problems:

1) ***Site location for Sasol Fertilizers:*** GIS was used in establishing the location of a new site for the Sasol Fertilizers business. By combining various layers of data such as local roads, rivers and environmentally sensitive areas, a holistic approach could be taken to selecting the best site.

2) ***Sasol supply chain mapping:*** GIS is used extensively in the geographical mapping of specific supply chains in Sasol during supply chain design.

3) ***Sasol's gas pipeline:*** GIS was used extensively in the design and construction of a natural gas pipeline between Mozambique and South Africa.

4) ***Sasol's South African logistics corridors:*** GIS has been used in the analysis of the South African logistics corridors for Sasol products. This resulted in business intelligence about the movement of product within South Africa.

5.4.5 Schematic models

Another important way of graphically modelling a supply chain is to create a schematic model of the supply chain configuration. In a supply chain schematic model, the various components of the supply chain network is modelled with specific corresponding pictures to ease differentiation between the elements. Text and other information are displayed together with the graphics as required by the decision-maker. It is also possible to super-impose the schematic model on a geographical orientation to show the spatial nature of the different elements. Although supply chain schematic models are not scientifically or analytically based, it is a very practical implementation of a descriptive supply chain model. Refer to *Figure 12* on page 31 for an example of a supply chain schematic model.

5.4.6 *Supply chain cost models*

5.4.6.1 Description - cost modelling

Supply chain managers are interested in the cost of a specific supply chain in order to determine the profitability of serving a customer (and assigning an appropriate service level to that customer). This requires 1) understanding of all the supply chain activities related to that customer, and 2) understanding the cost associated with these activities.

In addition, cost data is a fundamental ingredient in the building of most supply chain models. ***Management accounting*** offers the necessary mechanisms for providing cost information to enhance supply chain decision-making. Management accounting is defined as "*the process of identifying, measuring, reporting and analysing information about the economic events of organisations*" (Atkinson *et al.*, 1997), and encompasses a number of techniques, *e.g.* activity-based costing (ABC), balanced scorecard (BSC), value chain analysis (VCA), and total cost of ownership (TCO). The research in this study will focus on ABC as the preferred method for treating supply chain cost modelling, as it logically allocates costs to activities, which can then be meaningfully allocated to supply chain cost objects.

5.4.6.2 Technique - activity-based costing

Customer service, the outcome of the logistics function, involves "*getting the right product to the right customer at the right place, in the right condition and at the right time, at the lowest total cost possible*" (Lambert *et al.*, 1998). To know the lowest total cost at a given level of customer service, a keen understanding of the logistics activities and underlying costs of those activities is paramount (Lin *et al.*, 2001). ***Activity-based costing*** (ABC) is the method by which critical cost data can be gathered for analysis and utilisation either in a single firm or among the firms of the supply chain. ABC is defined as a process of "*...calculating the costs of individual activities and assigning those costs to cost objects such as products and services on the basis of the activities undertaken to produce each product or service*" (Lin *et al.*, 2001).

As part of strategically examining the service level to different customer segmentations, understanding the total profitability of a customer is crucial. ABC helps reveal the true cost of doing business with a particular customer, supplier, or distributor by comparing the revenues earned to the cost incurred on each particular party. Traditional cost accounting systems have become extremely inadequate since they continue to allocate escalating overhead (indirect) costs on a volume-driven basis such as labour hours or machine hours which no longer depict the true consumption of resources in modern manufacturing and design (Lin *et al.*, 2001). Some proponents of ABC contend that overhead costs should not be allocated at all, but become directly traceable, variable costs of the individual product or process (Harrison & Sullivan, 1995).

ABC recognises the causal relationship between cost drivers and activities (Shapiro, 2001:247). The following are involved:

- ***activities*** – describe work performed in the organisation that consume resources and cause cost to be incurred;
- ***resources*** – the economic objects that are consumed in the performance of activities. The term resource is used in a general sense to connote physical, human, financial, information technology, marketing, organisational, and legal resources to be allocated to activities at the facility, while incurring indirect costs;
- ***cost drivers*** – the factors affecting the cost of an activity and the resources they consume; and
- ***cost objects*** – the output of activities that correspond to products, customers and services.

The ABC modelling process is described by Lin *et al.*, (2001), as illustrated *Figure 17*. It involves the following:

- analysing supply chain functions;
- breaking processes down into activities;
- identifying the resources consumed in performing the activities;
- determining the costs of the activities associated with cost drivers;
- tracing the costs to the cost objects; and
- analysing the final cost information from a total cost perspective.

ABC is a descriptive modelling methodology that could prove very valuable to companies where the communication and management of transactional, financial data has been streamlined through the implementation of ERP systems (Shapiro, 2001:249). In addition, ABC has the potential to assist multiple firms in a virtual supply chain to understand their individual and collective supply chain costs. Combined with analysis by optimisation models, these firms could identify opportunities for shifting activities among partners to achieve cost savings and eliminate redundancy (Shapiro, 2001:249).

[**Source:** Lin *et al.*, 2001]

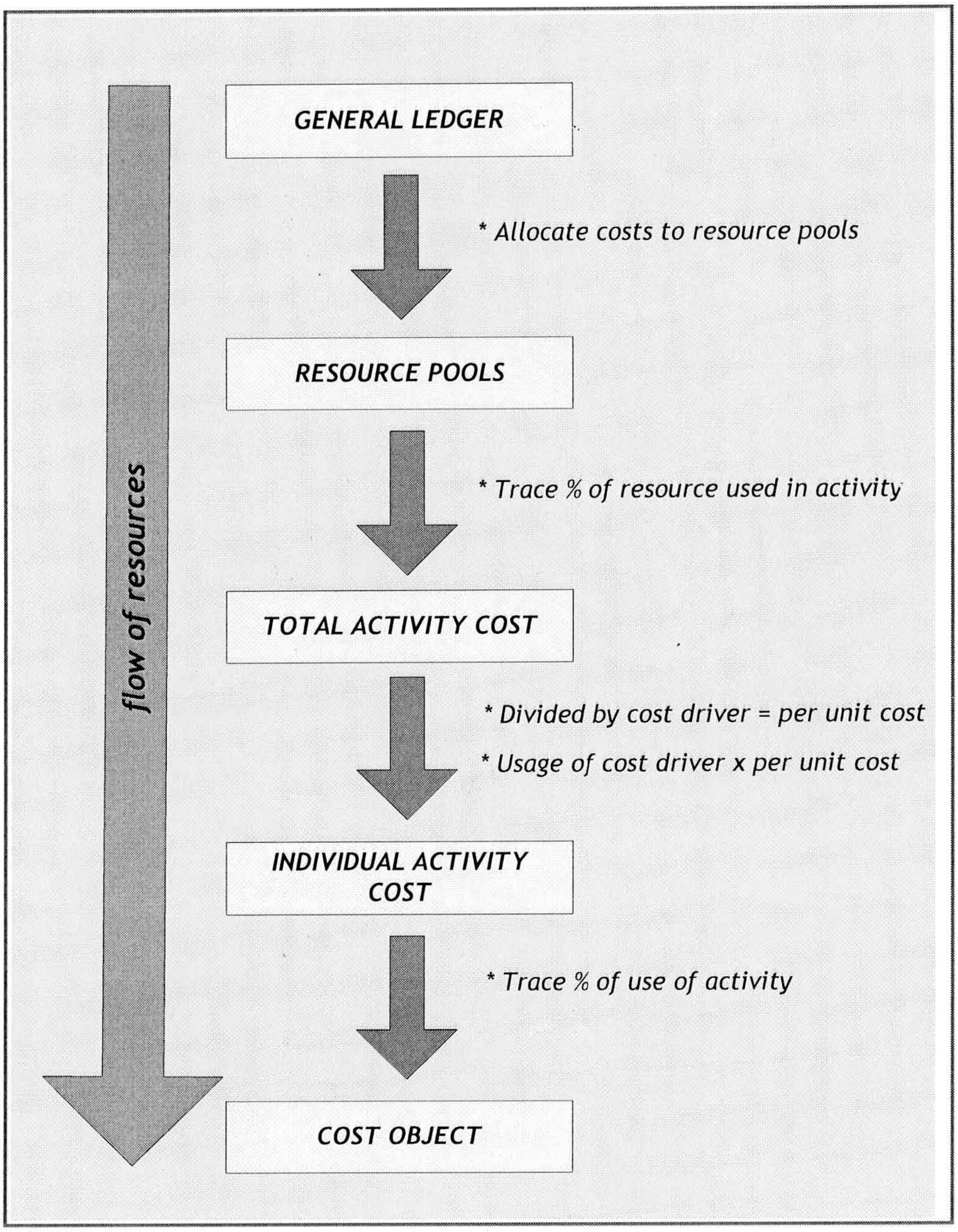

Figure 17: Flow of resources within ABC

5.4.7 Supply chain process models

5.4.7.1 Description - process modelling

Since the supply chain is all about establishing a ***process view*** of an organisation (*vs.* a functional view), it is only expected to want to model supply chain processes, and how they involve different functional areas within and between supply chain organisations. Supply chain processes and activities exist at various levels of detail and decomposition, as with the supply chain planning hierarchies (*i.e.* strategic, tactical and operational).

5.4.7.2 Technique - SCOR

Supply Chain Operations Reference (SCOR) models integrate the well-known concepts of business process re-engineering, benchmarking, and process measurement into a cross-functional framework (Huan *et al.*, 2004). It was developed by the Supply Chain Council, a group established in 1996 by 70 companies that envisioned a standarised methodology of describing supply chain processes. The aim is to enable companies to compare and learn from companies within and outside their own field. Unlike optimisation models, no mathematical formal description of a supply chain and no optimal or heuristic methods for solving a problem are given (Meyr *et al.*, 2000a:37). Instead, standarised terminology for processes is specified, enabling a general description of supply chains to be formulated. This enables different supply chain configurations to be compared based on a common language. The SCOR framework entails:

- standard descriptions of management processes;
- a framework of relationships among the standard processes;
- standard metrics to measure process performance;
- management practices that produce best in class performance; and
- standard alignment of software features and functionality.

The 5 distinct supply chain management process types in the SCOR taxonomy are illustrated in *Figure 18*.

SCOR Process	Definitions
Plan	Processes that balance aggregate demand and supply to develop a course of action which best meets sourcing, production and delivery requirements
Source	Processes that procure goods and services to meet planned or actual demand
Make	Processes that transform product to a finished state to meet planned or actual demand
Deliver	Processes that provide finished goods and services to meet planned or actual demand, typically including order management, transportation management, and distribution management
Return	Processes associated with returning or receiving returned products for any reason. These processes extend into post-delivery customer support

Figure 18: SCOR supply chain management process types

These process types are used to describe the overall holistic supply chain picture (called a Level 1 model in SCOR terminology). These processes are defined in increasing levels of detail: Level 2 is the configuration level and deals with process categories. Level 3 is the process element level and the lowest decomposition in the scope of the SCOR model. Further decomposition is possible, but falls outside the scope of the SCOR model, as it is usually organisation-specific. *Figure 19* illustrates the different levels of detail in the SCOR modelling framework.

[**Source:** Supply Chain Council (2005)]

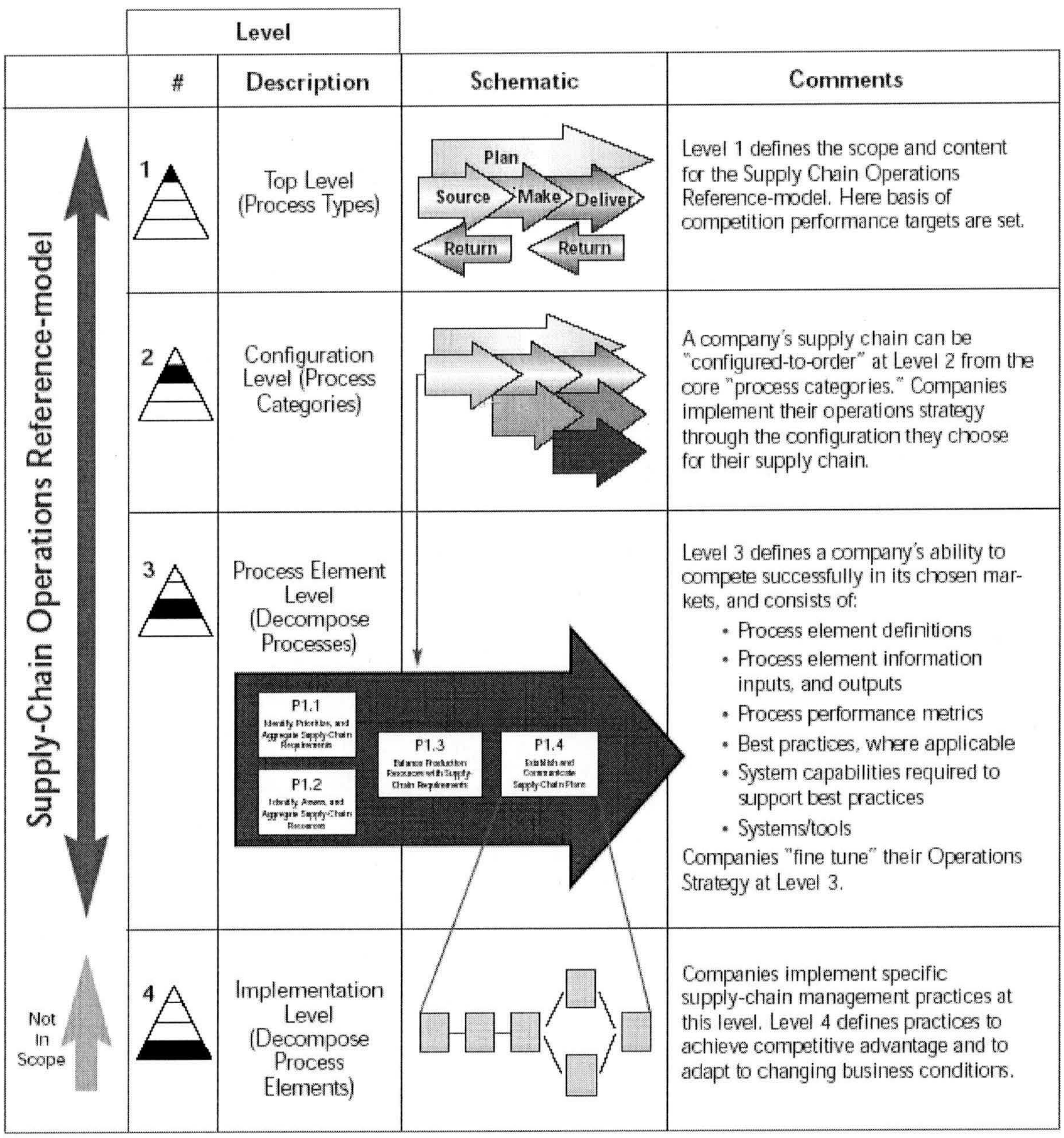

Figure 19: SCOR modelling levels of process detail

Apart from mapping processes with SCOR modelling constructs, it is usually accompanied by a geographical mapping of the physical flow of products between different nodes in a supply chain. It provides insight by mapping the processes that take place at each of the supply chain locations, as illustrated in *Figure 20*.

[**Source:** Supply Chain Council (2005)]

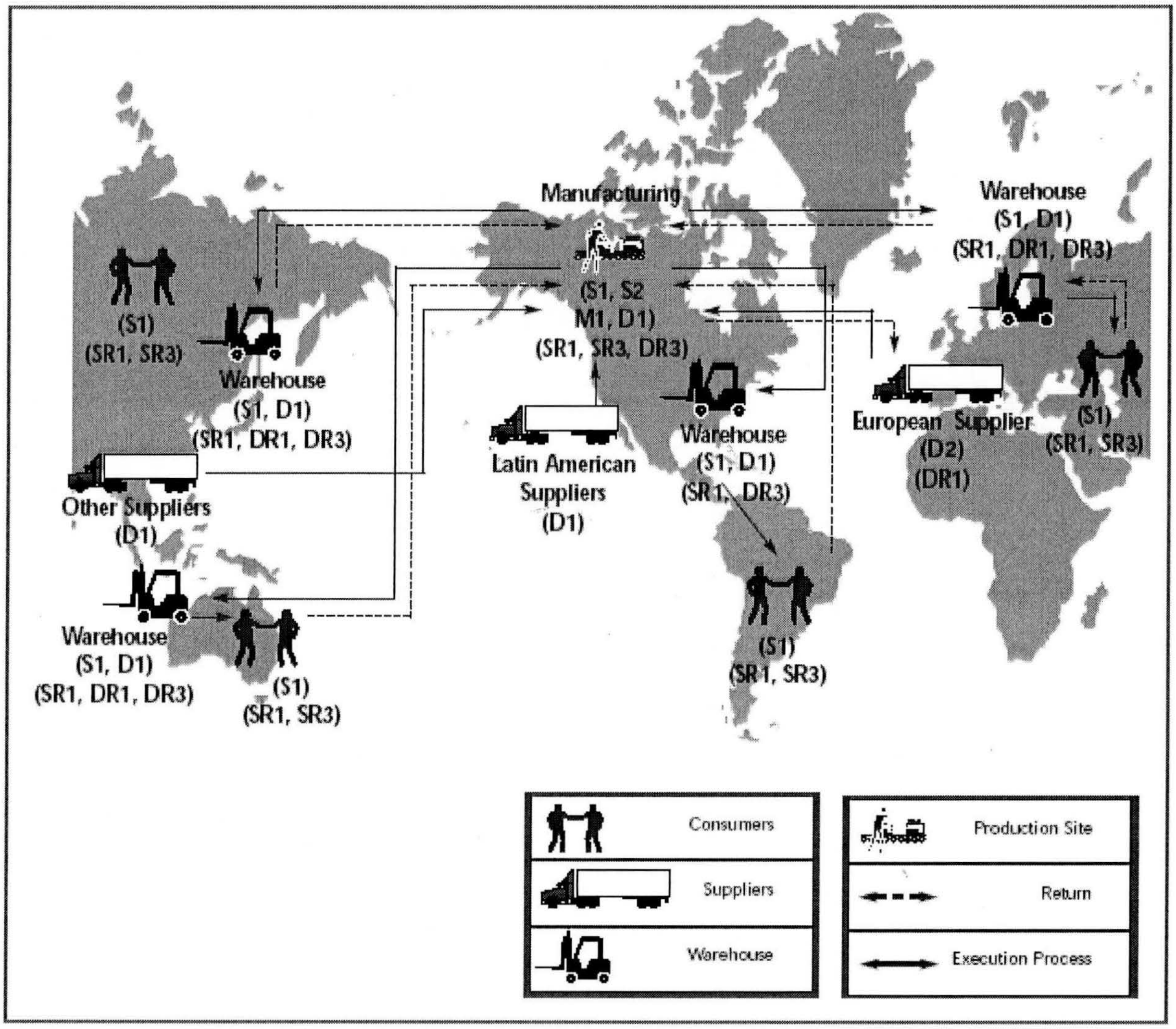

Figure 20: Geographical mapping of SCOR processes

The benefits of creating a SCOR model for a supply chain are that it:

- creates a common understanding among the participants in the supply chain;
- articulates the responsibilities and interactions of different participants in the supply chain;
- establishes a process view of the supply chain, crossing functional boundaries;

- provides benchmarks and performance metrics for the supply chain; and
- identifies process improvement opportunities.

The interested reader is referred to Supply Chain Council (2005) for detail on SCOR 7.0.

5.4.7.3 Applications of process models

Here follows a list of examples from literature and experience, where process modelling (through the SCOR framework) has been successfully applied to strategic supply chain related problems in the petro-chemical industry.

1) ***SCOR in industry:*** SCOR is fast becoming the industry standard when it comes to supply chain process modelling. Companies that are using SCOR include: HP, Caltex, Richman Chemical, Boeing, *etc.* These and other case studies are available at *www.supply-chain.org*.

2) ***SCOR in Sasol:*** Sasol is currently implementing SCOR as the standard methodology for modelling supply chain processes, as is evident by the formation of a supply chain process modelling (SCOR) centre of excellence. One example of using SCOR modelling constructs was to model the total supply chain for Safol 23, a product of Sasol Solvents & Olifens and Surfactants. The modelling exercise included all the supply chain participants, from the procurement department to logistics experts and global planning coordinators. This multi-functional task team successfully mapped supply chain processes across the organisational boundaries, which is significant due to the fragmented nature of the Sasol structure where different business units are responsible for different processes of the supply chain.

3) ***SCOR and simulation:*** Since SCOR and simulation (discussed in paragraph 5.4.3) are both involved with the modelling of processes, one expects some kind of synergy between these approaches. Röder & Tibken (2006) developed a simulation-based decision-support system using modular modelling concepts from the SCOR framework for intra- and inter-company supply chains. Their approach makes use of the SCOR process buildings blocks to configure a supply chain, and then simulate that process chain to evaluate the best configuration alternative.

5.4.8 Marketing models

5.4.8.1 Description - marketing modelling and demand planning

The integration of supply chain and demand management decisions should be a prime concern of any firm concerned with maximising profit. Yet, marketing managers and supply chain managers are often chasing conflicting goals. Shapiro (2001:325) states that the first step in using data and models to reconcile conflicts is to agree about quantitative methods for constructing descriptive models that forecast or otherwise project future demand for finished products, ideally as functions of marketing and sales decisions. Descriptive models of supply chain and marketing and sales costs are also needed (with the help of ABC), along with other descriptive data such as manufacturing capacities, transformation activities, *etc.* Once this has been accomplished, the descriptive models should be imbedded in optimisation models that analyse how to link supply chain decisions with marketing and sales decisions.

Wagner (2000:97) defines demand planning as comprising of three tasks: 1) forecasting, 2) what-if analysis, and 3) safety stock calculation (*Figure 21*).

[**Source:** Wagner (2000:98)]

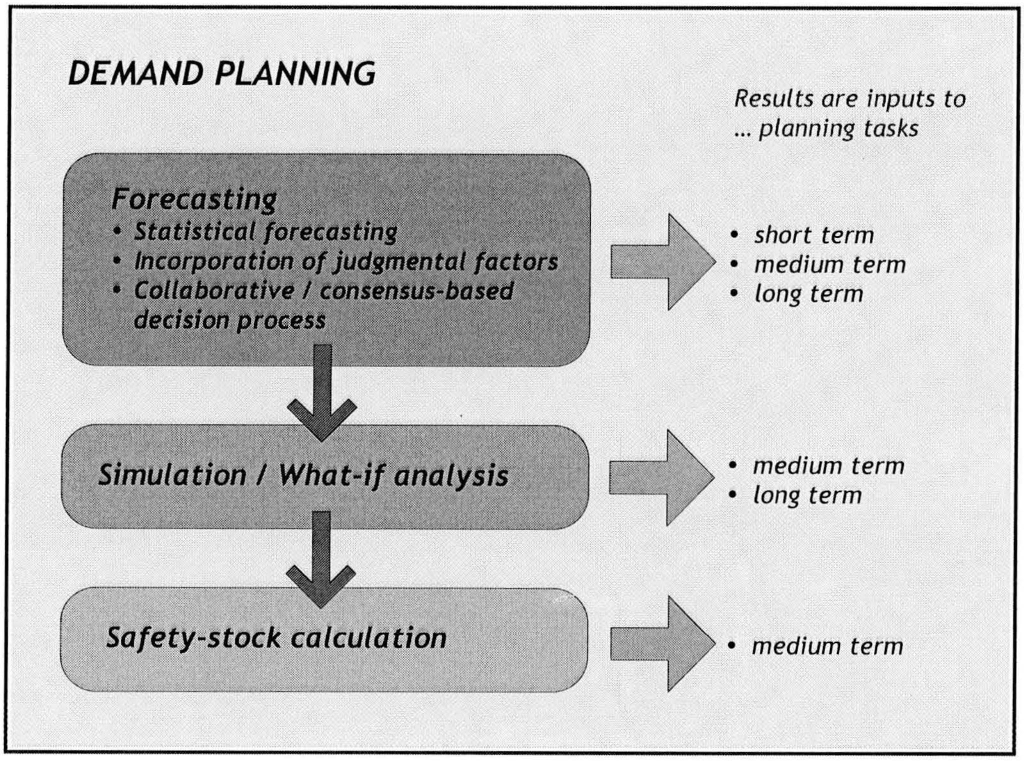

Figure 21: Demand planning tasks

The results from these tasks are used in other supply chain decisions on the three hierarchical dimensions as indicated in *Figure 21*. ***Statistical forecasting*** uses sophisticated methods for creating forecasts over a certain time horizon. ***Simulation/what-if analysis*** enables the planner to view the consequences of different scenarios (due to new product introduction, promotions, *etc.*). As demand planning is concerned with the prediction of demand in future, it contains uncertainty. For this reason ***safety stocks*** are kept to guarantee the necessary service level.

5.4.8.2 Technique - forecasting

Statistical forecasting incorporates information on the history of a product/item in the forecasting process for future figures. There exist two different approaches to forecasting, namely time-series analysis and causal models (Wagner, 2000:101). ***Time-series analysis*** assumes that demand follows a specific pattern. Therefore, the task of forecasting method is to estimate the pattern from the history of observations. The most common demand patterns include 1) level demand, 2) trended demand, and 3) seasonal demand. Techniques for this approach include the following:

- simple moving average;
- exponential smoothing;
- regression analysis; and
- ARIMA/Box-Jenkins method;

The second approach to statistical forecasting is ***causal models***. They assume that the demand process is determined by some known factors. For example, the sales of ice cream might depend on the weather or temperature. If enough observations of sales and temperature are available, then the underlying model can be estimated. The interested reader is referred to Wagner (2000) and Winston (1994), chapter 24, for more information on forecasting methods.

5.4.8.3 Technique - stochastic programming and decision trees

Since demand uncertainty is probably the leading cause of uncertainty in supply chain planning, a systematic process of evaluating multiple possible scenarios is needed. Stochastic programming differs from its deterministic counterpart in that it allows for evaluating the ***expected outcome*** of a number of different possible options. The expected outcome is a result of a deterministic outcome and a probability of occurrence. For example, if one has a 1/100 000 (0.001%) chance of winning the lotto of R1m, the expected outcome is only R10 (R1m multiplied by 0.001%). From a methodological viewpoint, stochastic programming models combine ***decision trees*** describing an uncertain future with mathematical programming models describing resource acquisition and allocation decisions (Shapiro, 2001:364). It allows for supply chain plans to be hedged against risks. Decision trees combine ***states*** and ***chance nodes***, in describing possible future scenarios. Alternative strategies can be evaluated by determining which is the best expected outcome of the branches of the decision tree. The interested reader is referred to Shapiro (2001: 364) and Winston (1994), chapter 13, for more information on stochastic programming and decision trees in the supply chain environment.

5.4.9 Financial models

5.4.9.1 Description - financial modelling

Physical supply chains are paralleled in all firms by financial supply chains involving decisions about capital investments, borrowing, dividends, and other factors under the control of the firms' financial managers (Shapiro 2001:391). The two chains are inextricably linked, especially on the strategic level of planning. On the one hand, the purpose of integrated supply chain management is to improve the firm's financial performance, and on the other hand, strategic supply chain planning involves capital investments in new plants, technologies and products, implying that financial factors such as the cost of capital and borrowing constraints should be considered in the planning process (Shapiro, 2001: 391).

The objectives of driving the optimisation of financial performance may include:

- maximisation of the discounted sum of after-tax profits;
- maximisation of equity at the end of a finite planning horizon; or
- maximisation on any one or more of a number of financial performance measures.

Financial policy constraints imposed by banks and management may include:

- debt-to-equity constraints;
- debt service constraints; and
- minimum working capital constraints.

Coordination of the physical and financial supply chains is especially complex for a multi-national corporation that has partially or wholly owned foreign subsidiaries. For a multi-national corporation, the financial supply chain will be complicated by legal structures, the business arrangement between the parent and foreign subsidiaries, tax laws in countries where the company makes or sells its products, the requirements of trade agreements on local content, and many other factors (Shapiro, 2001:391). The location of facilities and their operations can have a large impact on flows in the supply chain and therefore on how the multi-national firm wishes to optimise its financial performance.

5.4.9.2 Techniques

Financial models are usually implemented with the use of ***mathematical programming*** (as discussed in paragraph 5.4.1.2). The most benefit is obtained when integrating the financial model objectives and constraints with supply chain network models (paragraph 5.4.1).

Since financial models are often concerned with a number of financial performance measures, it tends towards the use of ***multi-objective decision models*** (as discussed in paragraph 5.4.2).

Financial uncertainty, such as currency exchange rates, interest rates, and economic conditions, can be included in the analysis with the use of ***stochastic programming*** and decision tree (discussed in chapter 5.4.8.3).

5.4.9.3 Applications of financial models

Shapiro (2001:406) provides a detailed discussion of the practical implementation of a mathematical programming model that integrates strategic financial and supply chain issues for a multi-national pharmaceutical firm. The financial flow model (FFM) developed in this application considers the product-, financial- and tax information for each legal entity in each country of operation. The objective of the model was to maximise the net present value of earnings in each period of the planning horizon in all entities. Some of the constraints included:

- demand constraints;
- manufacturing sourcing constraints;
- income equations;
- changes in working capital;
- interest rates constraints;
- debt/equity constraints;
- minimum dividend requirements;

- minimum earnings constraints;
- tax credit equations; and
- various others.

The model successfully balanced financial and supply chain decisions to ensure the optimal financial performance (and shareholder value) and supply chain configuration.

5.4.10 Inventory models

5.4.10.1 Description - inventory modelling

A company holds inventory (be it raw materials, parts, work in progress, or finished product) for a number of reasons. Shapiro (2001: 477) mentions a few:

- to create buffers against uncertainties of supply and demand;
- to take advantage of lower purchasing and transportation costs associated with high volumes;
- long and infrequent shipments to export clients;
- to take advantage of economies of scale associated with manufacturing products in batches;
- to build up reserves for seasonal demands or promotional sales;
- to accommodate products flowing from one location to another; and
- to exploit speculative opportunities for buying and selling commodities and other products.

Recently, attention has focused on creating business processes that reduce or eliminate inventories, mainly by reducing or eliminating uncertainties that make them necessary (Shapiro, 2001:478). These measures include:

- improving the accuracy of forecasts by developing better forecasting models and by promoting better communication between supply chain managers and marketing and sales personnel;
- sharing supply chain information with vendors, third-party transportation providers and other suppliers;
- consolidating the number of locations where products are held and reducing product variety; and
- postponing product customisation to downstream stages of the supply chain.

Despite these efforts however, significant uncertainty may remain between stages of a supply chain, implying that inventories will still be needed to ensure effective operations. Inventory management problems are characterised by holding costs, shortage costs, replenishment delays, and probabilistic demand distributions for products. Models for optimising inventory policies use methods from statistics and applied probability theory.

The continuous nature of the petro-chemical environment necessitates inventory. It is a make-to-stock environment, where demand pull and supply push need to be balanced. Shah (2005) suggests that process industry supply chain benchmarks do not measure up well in comparison with other sectors (*i.e.* discrete manufacturing). Examples include:

- stock levels in the whole chain can amount to a large percentage of annual demand;
- there are usually 4-24 weeks' of finished goods supply;

Petro-chemical supply chains are characterised by different demand patterns. For example, the seasonal demand of the fertilizer business is much different from the level demand of the propylene business. A multi-national firm is also much affected by global economic and political indicators, resulting in spot-buying from customers and sudden increases or decreases in demand.

This implies that the petro-chemical industry can greatly benefit from using modelling and optimising techniques in reducing the cost of working capital and inventory.

5.4.10.2 Techniques

Although most inventory policy decisions are made on the tactical and operational time-frames, it still has strategic significance. For strategic supply chain problems, the role of inventory decisions is to approximate inventory deployment plans and their implied costs across the supply chain (Shapiro, 2001:487). Before continuing with the discussion on techniques for implementing inventory decisions on a strategic level, it is necessary to mention a few techniques that are typically employed in inventory management. These include:

- deterministic models;
- probabilistic models; and
- ABC classification.

The simplest and most common deterministic model is the ***economic order quantity*** (EOQ) model. It determines the most economical order quantity given a deterministic yearly demand, a fixed ordering/setup cost, zero lead time, zero shortages, and a cost per unit year of holding inventory.

To overcome the limitations of the assumption that all parameters are deterministic, probabilistic models allow for hedging risk against demand uncertainty. Techniques include the following models to determine safety stock levels:

- ***(r,q)*** model – when inventory falls to the re-order point ***r***, order the replenishment quantity ***q***;
- ***(s,S)*** model – when inventory falls below **s** place an order to bring it up to ***S***;
- ***(R,S)*** model – every ***R*** periods of time, check the inventory level...if it is below ***S***, place an order to bring it up to *S*.

Another technique, ***ABC[8] classification***, recognises that a small percentage of SKU's account for the majority of sales. It is divided into classes A, B, and C according to the percentage of sales it accounts for. Different inventory management methods and models are then applied for each of the three categories.

Back to strategic planning, the key inventory planning phenomena to be captured in a strategic optimisation model are as follows (Shapiro, 2001:486):

- pipeline inventories;
- safety stock inventories; and
- replenishment inventories.

For a product flowing along a transportation arc, ***pipeline inventory unit cost*** is added to the transportation unit cost. This cost is determined by multiplying the value of average unit of product times the average number of days in transit on the arc, times the daily cost of capital.

There exist numerous methods for calculating safety stock and replenishment levels. It remains difficult however to include such approximations in a model. Shapiro (2001:491) suggests that ***safety stock- and replenishment inventory cost*** can be approximated as a function of the holding cost and demand variability of a given product. This simplified approach has the benefit of incorporating simple cost functions in a supply chain optimisation model, and accuracy is sacrificed for practicality.

[8] Note that ABC in this context has nothing to do with activity-based costing, which has the same acronym.

5.5 Supply chain modelling and optimisation software tools

The implementation of these modelling and optimisation techniques relies heavily on the evolution of information technology. Recent advances in the processing power of computers, have paved the way for solving large-scale industrial supply chain problems in acceptable timeframes. A great number of software tools have been developed to address different supply chain problems, each supporting different methods and models. Some of these tools will be briefly described, concentrating on those used for strategic supply chain models in Sasol's petro-chemical supply chains.

5.5.1 ARENA™

Arena™ , developed by Rockwell Software Inc., is a powerful generic simulation tool that is widely used for stochastic simulation in various fields. Arena™ software enables one to bring the power of modelling and simulation to business process analysis. It is designed for analysing the impact of changes involving significant and complex redesigns associated with supply chain, manufacturing, processes, logistics, distribution and warehousing, and service systems. Arena™ software provides the maximum flexibility and breadth of application coverage to model any desired level of detail and complexity. Rockwell Software offers a full suite of products to provide enterprise-wide simulation, templates for various vertical markets, and an optimisation template. It includes functionalities for input data analysis and output analysis with statistical methods, as well as a built-in optimisation function[9].

5.5.2 ArcGIS

ArcGIS, a product of ESRI, is used for geographical mapping, visualisation and analysis. ArcGIS is an integrated collection of GIS software products for building a complete geographic information system. The fundamental architecture of ArcGIS enables users to deploy GIS functionality and business logic wherever it is needed on desktops, on servers, over the Web, or in the field. *Desktop GIS* consist of ArcReader, ArcView, ArcEditor, ArcInfo, and ArcGIS extensions, and is a scalable suite of products for authoring, sharing, managing, and publishing geographic information[10].

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[9] For more information on the Arena™ software visit *www.arenasimulation.com*.
[10] For more information on ArcGIS software visit *www.esri.com/arcgis*.

5.5.4 GAMS

The General Algebraic Modelling System (GAMS) is a high-level modelling system for mathematical programming problems. It consists of a language compiler and a suite of integrated high-performance solvers. GAMS is tailored for complex, large-scale modelling applications, and allows one to build large maintainable models that can be adapted quickly to new situations. GAMS syntax is very quick to learn as it is similar to algebraic mathematical notation. It is flexible in the sense that the formulation can be changed quickly, solvers are easily swapped, and changing from a linear to non-linear model is possible with little trouble. GAMS allows for the formulation of model in many different problem classes, including linear programming (LP), mixed integer programming (MIP), nonlinear (NLP), mixed integer non-linear (MINLP), and others. GAMS has been successfully used in both industry and academia since 1987 and has a user base of over 10 000 in 100 countries[11].

5.5.5 Aspen SCM™

Aspen Supply Chain Management (Aspen SCM™), formerly Aspen MIMI™, powers the full range of planning and scheduling applications from strategic planning to detail plant scheduling and process optimisation. It is an advanced planning system (APS), specifically tailored to the needs of the process industry. Aspen SCM™ components include:

- ***data manager*** – providing both relational and hierarchical data features used in models;
- ***graphical user interface*** (GUI) – for graphical data visualisation and visual representations of manufacturing and distribution models;
- ***expert system*** – to include the unique business-specific "rules of thumb" in the models;
- ***linear programming*** capabilities – for solving models to optimality;
- ***scheduling algorithms*** – up to 20 scheduling algorithms and heuristics to provide feasible solutions quickly; and
- ***planning board*** – an interactive Gantt chart used in scheduling applications acting as primary interface with the scheduler.

[11] For more information on GAMS software visit *www.gams.com*.

Aspen SCM™ provides a fully integrated (hierarchical) approach to supply chain problems[12].

5.5.6 Expert Choice®

Expert Choice® is designed for those who are making group decisions (*i.e.* where multiple parties needs to take part in the decision-making process). It is based on the analytical hierarchy process (AHP) and provides for a structured decision-making approach where alternatives are evaluated based on qualitative and quantitative criteria. Expert Choice® is particularly effective as it accepts judgement from multiple stakeholders using wireless keypads for same time, same place or remote decision-making. It has been used in companies such as America Online, Ford Motor Company, IBM and the United States Army[13].

5.5.7 OptiMatix

OptiMatix is a South African developed product that is concerned with improving supply chain decision-making. The software enables the creation of supply chain models (using LP, MIP, statistics and heuristics) - customised to each business environment. They provide an integrated planning solution, involving strategic planning, production scheduling, demand planning and supply planning[14].

5.5.8 e-SCOR

Gensym Corporation capitalised on the natural fit between SCOR and process simulation, by developing a software program called e-SCOR. Based on the Supply Chain Council's SCOR standard, e-SCOR drives strategic decisions by evaluating and comparing alternative supply chain designs and management strategies. e-SCOR allows one to simulate various configurations to test the robustness of a supply chain. e-SCOR models a supply chain based on the SCOR processes (plan, source, make, deliver, return) to compute numerous SCOR metrics based on the supply chain model, such as inventory levels, standard asset calculations, order fulfillment response times and operating costs. This can assist in running

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[12] For more information on Aspen SCM™ visit *www.aspentech.com*.
[13] For more information on Expert Choice® software visit *www.expertchoice.com*.
[14] For more information on OptiMatix software visit *www.optimatix.co.za*.

various what-if scenarios to enhance the understanding of the sensitivity of the supply chain solution[15].

5.5.9 AnyLogic™

AnyLogic™ from XJ Technologies is an innovative simulation tool built on the latest advances in modelling science and information technology. It supports virtually all existing approaches to discrete and continuous modelling, such as process flow diagrams, system dynamics, agent-based modelling, state charts, equation systems, *etc.* (*Figure* 22). These approaches can be combined in the same model to more accurately describe the problem.

[**Source:** Borshchev & Filippov (2004)]

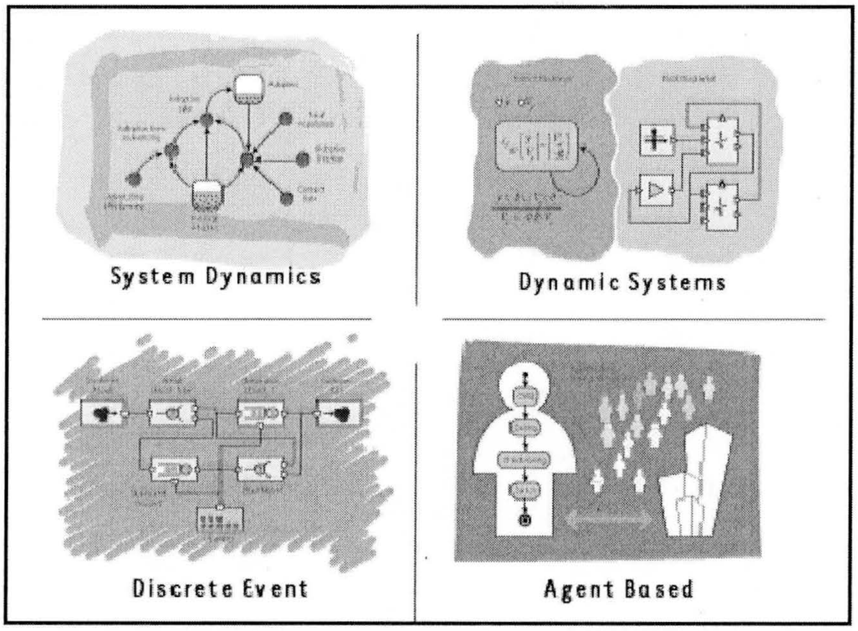

Figure 22: Tools for simulation modelling

The AnyLogic™ features *inter alia*:

- open architecture that allows for inter-operatability with any office or corporate software;
- analysis of model output data;
- an integrated optimizer (OptQuest™) that uses heuristics, neural networks, and mathematical optimisation methods;

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[15] For more information on e-SCOR software visit *www.gensym.com*.

- interactive 2D and 3D animation; and
- portable web-enablement of models for remote clients to run fully functional models directly in their web browsers.

Current users of AnyLogic™ include Accenture, Boeing, Eskom, Hewlett-Packard, General Electric, IBM, General Motors, Sony Corporation, Johnston & Johnston, *etc.*[16]

5.6 Advantages of the use of models for strategic supply chain decision-making

As in many industries, the use of scientific analytical methods for making decisions is increasing in the petro-chemical industry. It is supported by development of new tools that are designed to incorporate continuous industry specific issues. A number of advantages that can be obtained by making use of models to assist in the decision-making process are:

- emotion and politics are taken out of decision-making;
- managers can make decisions with confidence as it is based on scientifically sound methods;
- the supply chain is complex, it is not possible to consider all possible solutions manually;
- a better understanding of the intricacies and complexities of the business is obtained;
- many companies have realised huge financial savings after implementing model-based decision-making;
- increased business intelligence and visibility of information;
- evaluating alternatives before making costly investment decisions; and
- establishing optimal supply chain configurations.

This non-exhaustive list of benefits attempts to contextualise the potential of using advanced computer tools in the quest for a better supply chain.

5.7 Data...the common denominator for modelling success

Any analyst who has ever developed a model of whatever nature will testify that the biggest challenge is the collection of data. This is the result of the lack of good quality data...readily

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[16] For more information on AnyLogic™ software visit <u>*www.xjtek.com*</u>.

available on the right level of abstraction. Data is a common issue in many companies today. Despite the vast amount of data that has become available though the implementation of enterprise resource planning (ERP) systems, the problem remains that these systems have been designed to manage ***transactional*** data. The ***analytical*** data needed for modelling supply chain problems is of a quite different nature. The next chapter will focus on the analytical data needs for supply chain modelling, and what is needed to bridge the present gap.

5.8 Concluding chapter 5

Chapter 5 started with a discussion of the integrated supply chain planning domain. Strategic supply chain problems, being the focus of this research, were highlighted, followed by a discussion of the modelling and optimisation techniques that are available for decision support in this domain. There are countless software tools on the market today supporting these techniques…a few that are of particular interest were highlighted. The chapter concluded with the benefits that can be expected from the use of modelling and optimisation techniques to assist supply chain strategists in making better decisions.

Chapter 6

Supply chain information management

The lack of information visibility and accessibility has been identified as one of the main factors limiting integrated supply chain decision-making in Sasol. In this chapter we focus on the need for analytical data as input to modelling, and what is needed to achieve this.

6.1 Advancements in information systems

Information Systems (IS) have dramatically transformed the way enterprises use their supply chain operations to achieve competitive differentiation. In the context of this research, IS is referred to as the ***arrangement*** of people, data, processes, interfaces, network(s) and technology, that ***interact*** to support and improve day-to-day operations in the business, and support the problem-solving and decision-making needs of management (Whitten *et al.* (2001:8). Successful firms have used IS to support their business strategies, and in doing so they have generated tactical efficiencies, created operational excellence and enhanced decision-making capabilities across their supply chains (Nickles *et al.*, 1998:494). This has been the result of the vast advances in information systems in the past decade. Today there exist more powerful database management systems, more effective communication means (like electronic data interchange (EDI) via the internet) and solution methods and tools that can solve large quantitative models (*e.g.* mathematical programming solution algorithms). This opened up new perspectives for planning and controlling flows in the supply chain (Stadtler, 2000a:2).

Two areas that have been influenced by advancements in IS that are of particular interest to this research will be discussed: 1) enterprise-wide IS solutions, and 2) modelling/ optimisation systems.

6.1.1 Enterprise-wide information systems

Early corporate leaders in IS recognised the bottom-line savings that could be achieved by automating the more clerical and labour-intensive aspects of their business. They developed

IS solutions to deal with this, resulting in many customised and unique solutions for dealing with the different automation aspects. These unique IS solutions helped divisional and functional leaders to capture and automate the flow of information in their division. But, it was soon realised that different systems working independently from each other, with separated data sources and databases, were producing less than optimal results.

Today, enterprise-wide solutions link processes across functions and provide for enterprise-wide flow of information. These enterprise resource planning systems (or ERP as it is commonly known) aim to ensure information integrity and availability across divisional boundaries by using one common data platform for various organisational tasks. The supply chain management process is a significant beneficiary of this new shared information platform, and this information accessibility has served to promote interest among supply chain managers in fact-based decision-making.

But, the reality of ERP systems today is twofold. Firstly, the implementation of an ERP system is no longer a competitive advantage, but simply a condition for continued survival in the marketplace. Secondly, the implementation of an ERP system will not automatically lead to improved supply chain decision-making.

Akkermans *et al.* (2003) investigated the impact of ERP systems on supply chain management by using a Delphi study research methodology[17]. Their panel of experts saw only a modest role for ERP in improving future supply chain effectiveness and a clear risk of ERP actually limiting progress in supply chain management. ERP was seen as only offering a positive contribution to 4 of the top 12 future supply chain issues, as identified by the experts. These include:

- more customisation of products and services;
- more standarised processes and information;
- the need for worldwide IT systems; and
- greater transparency of the marketplace.

They identified the following limitations of current ERP systems in providing effective supply chain management support:

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[17] The Delphi study is a method for structuring a group communication process so that the process is effective in allowing individuals to deal with complex problems.

- its insufficient extended enterprise functionality in crossing organisational boundaries;
- its inflexibility to ever-changing supply chain needs;
- its lack of functionality beyond managing transactions; and
- its closed and non-modular system architecture.

ERP systems were never designed just to support supply chain management, and certainly not across multiple enterprises (Akkermans *et. al*, 2003). ERP systems were developed to automate transactional processes within an organisation, resulting in the generation of transactional data. Methods need to be implemented to transform these data to analytical knowledge that can be used to aid decision-making. The current trend towards integrating APS with ERP systems is a step towards providing for better supply chain planning and decision-making.

6.1.2 Modelling & optimisation systems

Vast improvement in the processing power of computers has opened a great number of opportunities for using modelling and optimisation techniques to assist in day-to-day decision-making. A decade ago, it would take days to solve a monthly production planning model. Today, it can take a matter of minutes. This has made the use of modelling and optimisation much more accessible and attractive. It allows the modeller to develop a modelling solution much quicker, and makes it possible to experiment with different scenarios and options. Advances in software solutions have opened the door to modelling for analysts without advanced programming capacity. The current interest in APS is advancing the use of modelling and optimisation on a day-to-day level.

6.2 Transactional versus analytical data

The difference between transactional and analytical data is the key to understanding the intent of this research.

Shapiro (2001:36) describes in detail the multiple differences that exist between transactional and analytical data. He claims that *"to effectively apply IT in managing the supply chain, a company must distinguish between the form and function of* ***transactional*** *IT and* ***analytical*** *IT."*

Transactional IT is concerned with acquiring, processing and communicating raw data about the company's supply chain, and also with the compilation and dissemination of reports summarising these data. It occurs on a day-to-day basis. There are multiple internal and external sources for transactional data, the major one today being the company's ERP system. External sources include data accessed by electronic data interchange (EDI) and the internet.

The role of ***analytical IT*** is to help managers fathom the complexity of supply chain planning problems using descriptive and normative models. It consists of data that have been processed using data aggregation methods and descriptive models, to be used as input to models that assist in decision-making. Analytical IT is synonymous with the term ***decision support system*** (DSS). By constructing and deploying optimisation models (from analytical data), the decision-maker is provided with rigorous solution methods to support them in making decisions. The application of analytical IT differs depending on the specific supply chain problem at hand, and is applied across the three hierarchical domains.

Shapiro (2001:37) discusses 5 aspects where transactional and analytical IT differ fundamentally (*Table 4*).

Table 4: Transactional vs. analytical IT

ASPECT	*TRANSACTIONAL IT*	*ANALYTICAL IT*
Time frame	Past and present	Future
Purpose	Communications	Forecasting and decision-making
Business Scope	Myopic	Hierarchical
Nature of databases	Raw and lightly transformed objective data	Moderately and heavily transformed data that is both objective and judgemental
Response time for queries	Real-time	Real-time and batch processing

Each aspect in *Table 4* is discussed below:

1) ***Time frame*** – transactional IT is concerned with acquiring current supply chain data and reporting on past performance. Analytical IT extrapolates data into the future and analyses it to make effective decisions for the future of the supply chain.

2) ***Purpose*** – transactional IT focuses on communicating data across the functional boundaries of a company, whereas analytical IT seeks to forecast scenarios of the future and optimise decisions associated with these scenarios.

3) ***Business Scope*** – transactional data have a myopic nature, meaning that it is concerned only with current transactions and histories that are compiled based on them. Analytical IT addresses future decisions through a hierarchy of decision problems at all levels of planning – operational, tactical and strategic.

4) ***Nature of databases*** – the databases created by transactional IT are derived from raw data that are stored in formats that leave the data unchanged or "lightly transformed". By contrast, optimisation models employed by analytical IT require data inputs derived from raw data that may involve significant transformations. Analytical databases also contain judgemental data about the company's supply chain based on management intuition and subjective constraints.

5) ***Response time for queries*** – advances in computing speeds have reached a point where users expect instantaneous responses from data queries, especially in the case of transactional IT that retrieves raw data from corporate databases. For analytical IT, the response time differs based on the complexity of the supply chain problem. Some large-scale problems might take several minutes (or even hours) to solve based on the computational complexity of the underlying mathematical model.

6.3 The information value chain

The transformation of transactional data into analytical data (information) and knowledge is illustrated by the information value chain of Koutsoukis *et al.* (2000) (*Figure 23*). Transactional data are collected and processed on a day-to-day basis by enterprise information systems (*e.g.* ERP). By applying analysis and aggregation techniques to this data, it is transformed to meaningful information. But this is not the end; knowledge is created once this information is applied to descriptive and normative models to gain insight into the problem at hand. ***Intelligence*** can also be added as the final result of the value chain. Only once data, information and knowledge are applied in driving behaviour and decisions, has the full value of information been achieved, in the form of intelligence.

[**Source:** Koutsoukis *et al.* (2000)]

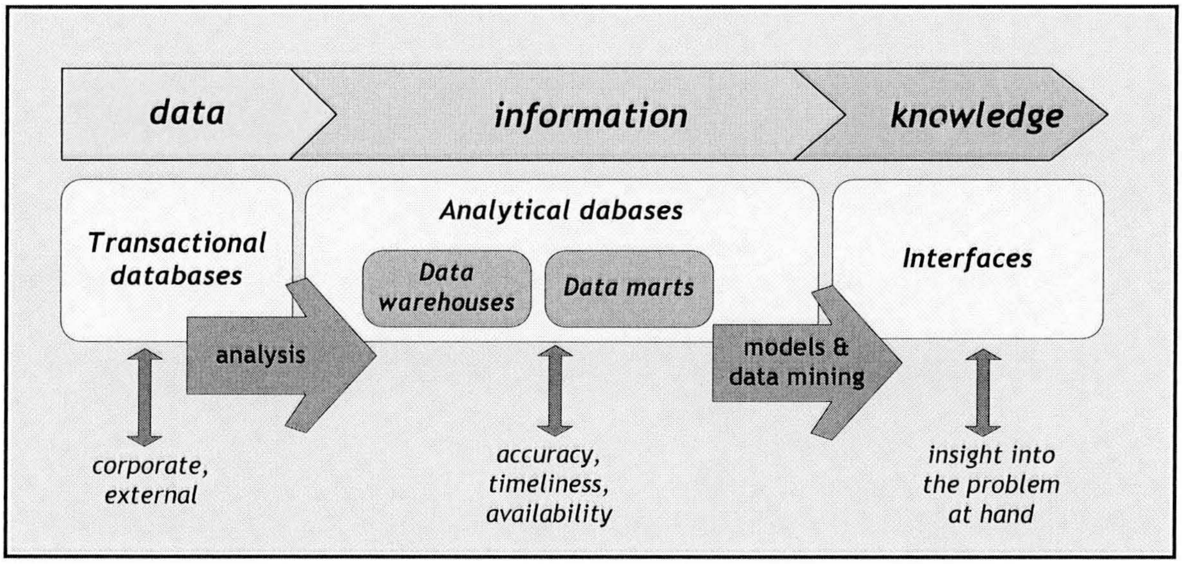

Figure 23: The information value chain

It is clear that information systems and decision modelling are closely intertwined in the information value chain. The increased popularity of data-driven, model-based reasoning and decision-making thus also implies the importance of data-modelling. This integration is crucial to ensure that the appropriate transactional data and information is available to populate the models used by decision makers with analytical data.

Kousoukis *et al.* (2000) describes the decision process as follows:

1) The first step is the structured extraction and categorisation of recorded facts (internal and external to the organisation), also referred to as ***data modelling***. Data modelling provides the modeller with information about the decision problem at hand. Data modelling involves defining relationships between data items leading to a relational data model, or identifying categories of data items that lead to a multidimensional data model.

2) Next, a normative or descriptive model is developed to be used by a rational decision maker. This is called ***decision modelling***. Decision models include all of the models we discussed before, including simulation, mathematical programming, forecasting, GIS and AHP.

3) Lastly, the decision model is populated with information. This information is in the form of analytical data, transformed according to the supply chain problem at hand.

The results of the decision model is analysed and investigated, often relying on the knowledge of the decision-maker to evaluate alternate scenarios.

This research has particular interest in the information value chain, *i.e.* the progression from transactional to analytical data, because it is analytical data that drives strategic decision-making models.

6.4 Supply chain information systems

6.4.1 Background

Effective supply chain management is not possible without information systems designed to provide readily accessible and accurate information to all supply chain participants (Balsmeier & Voisin, 1996). Since information systems form the backbone of most corporate supply chains (Cooke, 1999), managing the flow of information in the supply chain has become as important as managing the flow of products (Factor, 1998). It is especially critical that supply chain partners have access to information on activities they do not control. Ellram & Cooper (1990) states that mutual sharing of information among the members of a supply chain is required especially for planning and monitoring processes. The Global Logistics Research Team at Michigan State University (1995) defines information sharing as the *"willingness to make strategic and tactical data available to other members of the supply chain"*. It also proposes that the open sharing of information such as inventory levels, forecasts, sales promotion strategies, and marketing strategies reduces the uncertainty between supply partners and results in enhanced performance. A new, complex, and more committed form of collaboration, *"collaborative business communities"*, requires companies to share proprietary information with firms among the supply chain (Taylor & Terhune, 2000).

6.4.2 Supply chain decision database

Although there are many different information systems and applications for supply chain management, the interest in this study lies in a database containing analytical data that can be used for strategic and tactical supply chain planning. Shapiro (2001:225) proposes a new concept to interface between transactional data systems and supply chain modelling systems. His ***supply chain decision database*** (SCDD) attempts to bridge the gap between ERP systems and hierarchical supply chain planning and decision-making as illustrated in *Figure 24*.

[**Source:** Shapiro (2001: 317)]

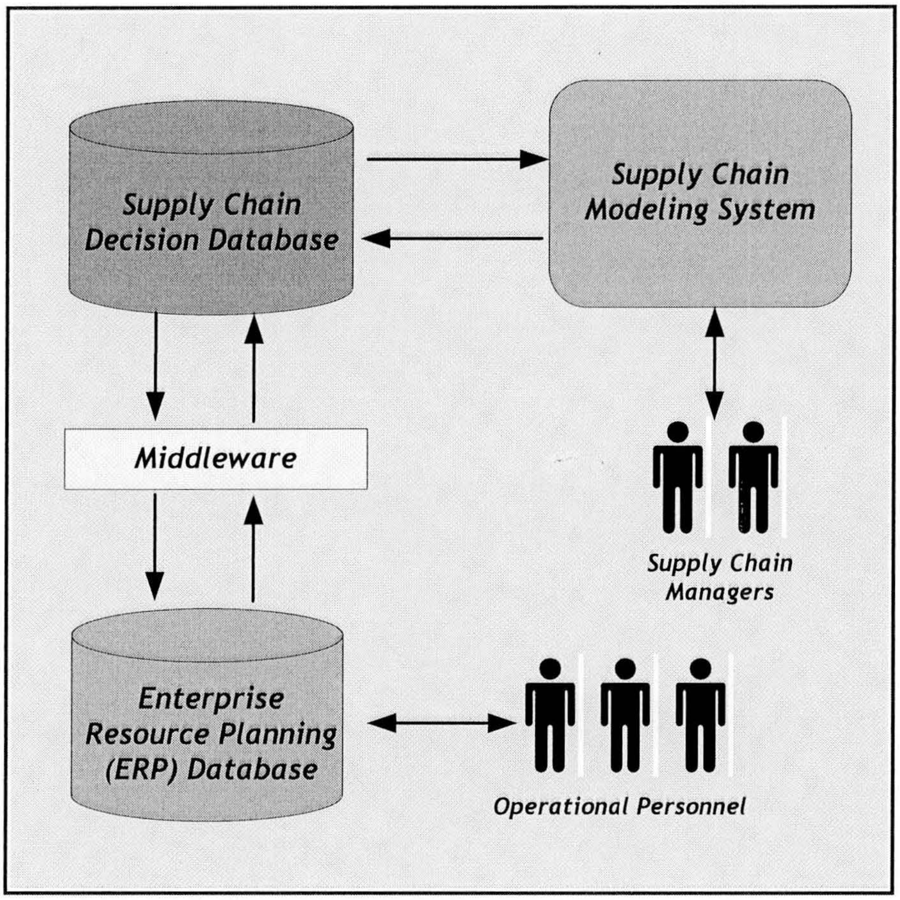

Figure 24: Interaction between ERP and supply chain modelling

The ***ERP system***, as described before, facilitates the flow of transactional data in a company relating to manufacturing, logistics, finance, sales and human resources. Operational personnel interface with ERP systems on a daily basis in different functional areas of the organisation.

Middleware is needed to bridge the gap between ERP and SCDD, by aggregating and translating transactional data to analytical data.

The ***supply chain decision database*** (SCDD) facilitates the storage of analytical data to be used in supply chain planning activities.

The ***supply chain modelling system*** involves the use of models for decision-making on the hierarchical supply chain planning levels, and interfaces with supply chain managers to assist them in making informed decisions about their supply chains.

Different from many companies that treat strategic and tactical planning studies as isolated activities for analyzing specific issues of current importance, Shapiro's framework aims to keep the SCDD updated with the most current information from the ERP systems. This will facilitate the frequent analysis of strategic supply chain plans centred about what-if scenario runs made by optimisation models created from timely and accurate data. This approach is in line with the intent of this research, and has a significant influence on the thinking around the framework.

6.4.3 Supply chain decision database data structure

For the purpose of understanding the content of a SCDD, we include some of the data elements in Shapiro's SCDD. Note that this does not represent an elaborate discussion, but is merely an illustration of the kind of data that should be included in such a repository.

6.4.3.1 Facility data

Facility data describes the firm's ***facilities*** as supply chain nodes. A facility can be a manufacturing plant, distribution centre, liquid bulk storage tank, warehouse, *etc.* Each of these facilities will undergo certain transformation ***activities*** which consume ***resources***, incur ***costs***, and are subject to ***capacity constraints***. Facilities may also include logistics nodes that belong to logistics service providers as part of the supply chain.

6.4.3.2 Transportation network data

The next element in the SCDD is network ***links*** that connect an origin node to a destination node. These links are directed and describes how products can flow in the network. ***Transportation cost*** is incurred when products flow on a link and is described as a function of the ***volume*** of product on that link. Implicit in the relationship is a ***maximum transport capacity***, which can be the result of contractual commitments, company policy or other reasons.

6.4.3.3 Supplier data

Suppliers include ***vendors*** and other sources of raw materials, feed streams, parts, components or finished products. Products are supplied at a ***procurement cost*** in specific ***volumes***, with ***capacity constraints*** on the volume that can be supplied.

6.4.3.4 Customer data

Customers include either intermediate or final customers, and consume the final products of the firm. Customers have a specified ***demand*** for the firm's products, and are what ultimately drives the whole supply chain, as the firm would want to meet all customer demand. Customers will typically be ***segmented*** based on strategic importance and service level.

6.5 Data aggregation & transformation

Management is starting to realise that easy access to transactional data from the ERP system does not automatically lead to effective supply chain management. In most instances, 80% of data in a transactional database are irrelevant to supply chain decision-making. Data aggregations and other transformations are needed to transform the remaining 20% into useful information in the supply chain decision database (Shapiro, 2001:225).

The mapping of SKU's into product families, customers into markets, and suppliers into supplier groups is an important first step in conceptualising and implementing a supply chain model for strategic planning. Such aggregations are necessary and desirable for management to achieve a global view of the company's supply chain, by restricting the number of elements in the supply chain to a manageable level.

Referring back to the information value chain (*Figure 23*), data aggregation and structuring are addressed as the first step in the information value chain – ***data modelling***. Data modelling involves defining relationships between data items leading to a relational data model, or identifying categories of data items that lead to a multidimensional data model. It is believed that the success of a SCDD is rooted in the clear definition of a data model / structure in the ERP system. This data structure must be architected with a view of the end in mind, which is the specific analytical data needs of the supply chain modelling systems. Effective mechanisms should then be implemented to ensure the integrity of these data structures.

6.6 Data modelling & master data management

Regardless of which business processes or enterprise applications are studied, master data is always an issue (Swanton & Samaraweera, 2005). Their research shows that all major opportunities for system benefits hinge on a global view of customers, suppliers, and materials. This necessitates highly accurate and consistent transactional data. They claim that over 80% of support calls for supply chain planning is traced to master data problems. In a global supply chain, where interfaces to data are distributed over many different individuals, departments, and geographies, the need for a properly defined data management strategy is crucial. The data aggregations and transformations needed for strategic supply chain decision-making rely heavily on the accuracy and consistency of the transactional system from which it comes. An example to illustrate: there is no purpose in aggregating customer data from transactional sources, when transactional data for customers are captured by different functions in different formats and by different names. This gives analysts headaches when trying to make sense of transactional data, and usually requires an extensive data cleanup exercise.

Swanton & Samaraweera (2005) suggest a solution to the problem of transactional data integrity with the concept of ***master data management*** (MDM). They define master data management as *"a system of business processes and technology components that ensures information about business objects, such as materials, products, employees, customers, suppliers, and assets, is current, consistent, and accurate wherever they are used inside or exchanged outside the enterprise."*

Traditional enterprise applications treat master data, such as material masters, as static information, loaded once in a single form and used forever. The reality is more like the following:

- the data may not be transactional, but it does change frequently due to changing markets or continuous improvement projects;
- different enterprise applications may need the same data elements; and
- dozens of departments and individuals are responsible for the different elements in a single object.

Figure 25 illustrates the master data management framework of Swanton & Samaraweera (2005). It consists of a 1) master data architecture (data modelling), and 2) MDM components and services.

[**Source:** Swanton & Samaraweera (2005)]

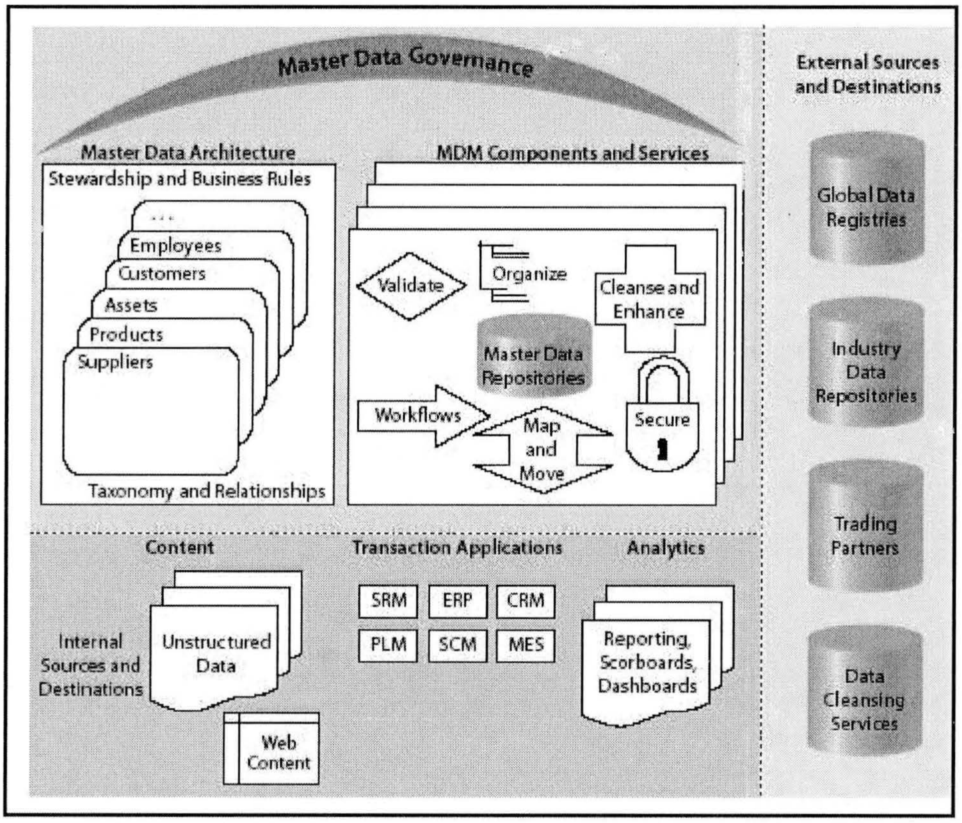

Figure 25: Master Data Management Framework

The ***master data architecture*** is an explicit plan for master data that does the following:

- identifies the objects and data elements to be managed;
- specifies the policies and business rules for how master data is created and maintained;
- describes any hierarchies, taxonomies, or other relationships important to organizing or classifying objects; and
- explicitly assigns data stewardship responsibility to individuals and organizations.

Stewardship is a key word. Organizations cannot "own" the data; they have to maintain it for the benefit of the whole company and its partners.

A ***master data management system*** for any object requires the following components and services:

- ***master data repositories*** – a trusted master for items, which contains a subset of attributes used by multiple systems;

- *workflows* – enforce stewardship policies and speed changes even in a highly distributed company, while maintaining an audit trail of changes;
- *security* – control access, prevent unauthorized change, and enforce privacy regulations;
- *cleansing and enhancement* – standardise attributes and enhance with data from other systems or external services to complete the record;
- *organizing* – classify items in a taxonomy or hierarchy for analysis and to assign stewardship responsibility;
- *validation* – ensure that all attributes (and attributes stored in target systems) are complete, consistent, and valid and measure the quality of the data;
- *mapping and moving* – use Enterprise Application Integration (EAI) and Extraction, Transformation, and Loading (ETL) tools to interface to source and target systems.

The use of accurate effective data aggregation and transformation - made possible by clear data modelling and master data management - is critical to the effectiveness and success of the frequent use of strategic supply chain decision-making models.

6.7 Concluding chapter 6

Recent advances in enterprise-wide information systems and computer technologies have brought the vision of integrated supply chain decision-making a step closer. This chapter introduced the information concepts needed to help understand the data needs for strategic supply chain models. Differentiating between transactional and analytical data is an important first step in the definition of a supply chain decision database. Extensive data aggregation and transformation is needed to convert transactional data from ERP systems into usable analytical data for supply chain models. The chapter is concluded with a discussion of the approach needed to make sure that transactional data is of the necessary quality with the help of master data management. The next chapter will elaborate on the specific data requirements for each of the strategic supply chain planning models as discussed in chapter 5.

Chapter 7

Data requirements for strategic supply chain planning models

This research is particularly interested in strategic supply chain planning problems, and in this chapter the detailed analytical data requirements for each of the chosen decision-making modelling techniques will be discussed. This will include mathematical programming of network models, AHP for site selection and performance evaluation, discrete event simulation models of supply chain strategies, GIS to implement geographical models, schematic models, process models in SCOR, financial models, and forecasting models for demand planning. For each of the techniques, three areas are discussed: 1) the strategic supply chain problem description, 2) the data fundamentals of the particular tool, and 3) the specific data requirements for implementing the supply chain model concerned.

7.1 Mathematical programming requirements

Mathematical programming, as discussed in paragraph 5.4.1.2, is a true optimisation technique that provides an ***optimal solution*** to a problem where it is not possible to manually evaluate the millions of possible solutions that can exist. It is particularly effective in finding the optimal network configuration for a supply chain.

7.1.1 Network modelling problem description

Network modelling involves the modelling of all the main supply chain network parameters and determines the optimal arrangement that will minimise cost while satisfying service requirements (Jimenez *et al.*, 1998:303). It is a form of normative modelling which aims to optimise the structure of the global supply chain.

In this supply chain problem the objective is to maximise total yearly profit, constrained by resource capacities and other constraints. The mathematical formulation is in the form of a ***capacitated multi-period, multi-echelon, multi-commodity network flow problem***. There exist numerous network model formulations in literature (see Goetschalckx, 2000:85).

Goetschalckx's (2000:83) formulation (in words) for a global supply chain network model is preferred[18]:

Maximise:

sum of the global after-tax discounted yearly profits in the reference currency of the corporation

Subject to the following constraints:

- expressions for the nett income before taxes of the activities of the corporation;
- expressions for the after tax profit in each country;
- supplier's capacity;
- production capacity at manufacturing plants and distribution centres;
- transportation capacity of the transportation channels and modes;
- customer demand constraints;
- bill-of-materials and flow balance constraints at the facilities, for manufacturing lines and in the transportation channels;
- minimum profit for subsidiaries on a country basis;
- linkage constraints between manufacturing lines and facilities and between material flows and facilities and transportation channels;
- bounds on transfer prices; and
- general bounds on decision variables.

The nett income before taxes consists of the difference between the sales price to either the final customer or a downstream subsidiary minus the total cost which includes operating and acquisition costs. The total cost on a country and planning period basis is defined as:

Total Cost =

supply cost +
fixed manufacturing cost +
variable manufacturing cost +
fixed facility operating cost +
variable facility operating cost +

[18] Note that for the purpose of this discussion the number of products in the network model is limited to only 1, and the number of planning periods to only 1.

warehousing cost +
cycle inventory cost at the facilities +
pipeline inventory cost +
inventory carry-over cost between periods +
transportation cost

Note that the formulation discussed makes provision for certain costing-, inventory- and financial model data, as discussed in paragraphs 5.4.6, 5.4.10 and 5.4.9 respectively.

Figure 26 illustrates an example of the node-arc network that would be optimised for this type of problem. Each node represents a supply chain structural element, *e.g.* suppliers, plants, customers. An arc connects two nodes, and defines the links on which product flow is possible. The volume that flows on each arc for the planning period is a variable (denoted in *Figure 26* by V_{xy}), and the model determines the optimal configuration of product flows for the given objective and constraints.

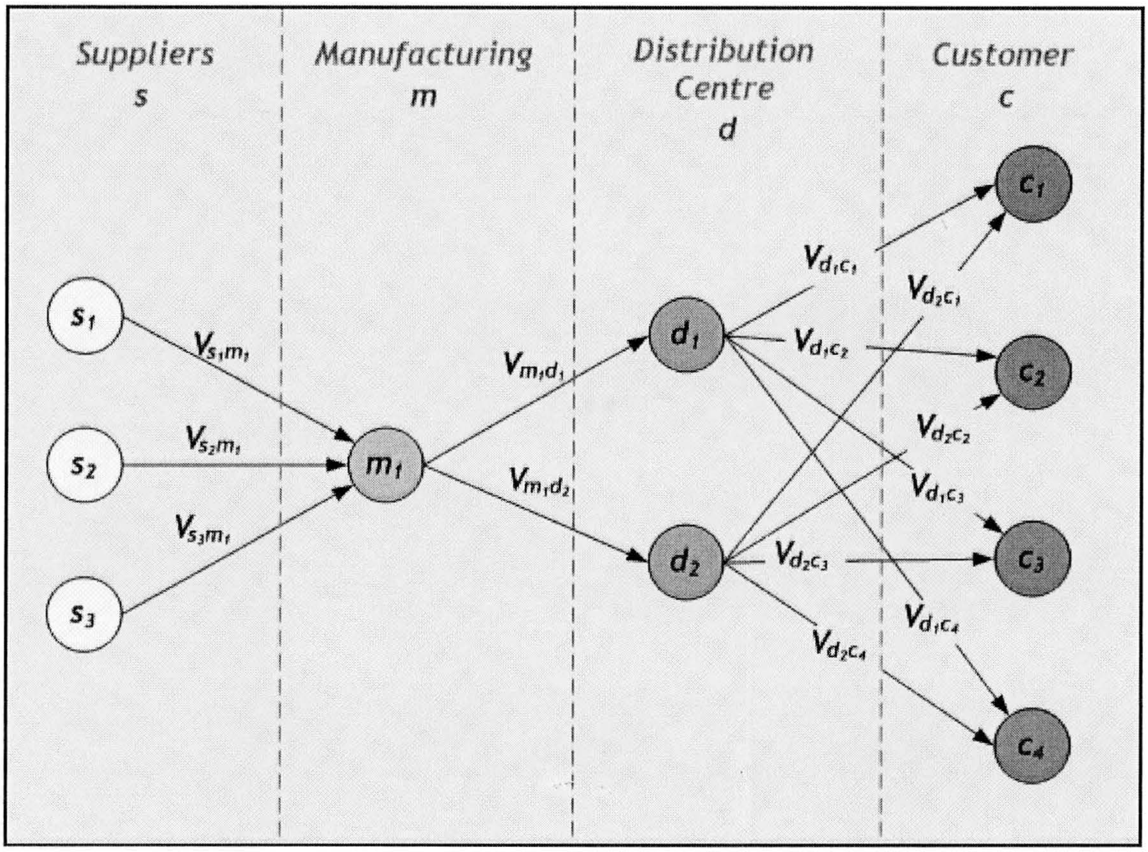

Figure 26: A node-arc presentation of the network modelling problem

In a network modelling problem, all structural possibilities need to be explored, including potential new sites, customers and suppliers. This can be included in the mathematical model, by specifying binary variables. This restricts the mathematical model to only choose a certain number of nodes, and results in a mixed integer programming (MIP) problem.

7.1.2 Mathematical modelling data fundamentals

A mathematical model is made up of the following elements:

- *indices* (or sets) – which define the set of possible nodes and arcs and products;
- *variables* – which are altered by the model until the optimal solution is found;
- *parameters* – which are all the input data that is specified in the model equations; and
- *equations* – including the objective function and constraints (expressing variables and parameters in mathematical equations).

These elements are programmed in mathematical programming software with specific mathematical notation and syntax. The general way of structuring the data is generic, although the exact format will be software dependant. In most cases, inputs can be imported from a spreadsheet format with the use of a programming language like Visual Basic.

7.1.3 Network modelling data requirements

As mentioned before, the network modelling problem is based on nodes and arcs, and aims to optimise the product flow on arcs between nodes. Because the need is naturally to want to explore new possibilities of a supply chain configuration, existing as well as potential new nodes and arcs are included in a model. On each node the following data are needed:

- capacity constraints;
- material balance (defines output volume as a function of input volume); and
- cost incurred at this node.

And at each arc we want to know the

- transport cost;
- transport capacity constraints; and
- inventory cost.

The input data requirements for a network modelling problem are defined in *Table 5* (sets), *Table 6* (variables) and *Table 7* (parameters). Note that the interest lies in the data that will be needed for building a successful model and therefore the equations are left out.

Table 5: Network modelling data requirements - SETS

Group	Element	Description	Symbol
Nodes	Suppliers	The set of supplier nodes in the supply chain, with a unique name for each supplier.	*s*
	Manufacturing Facilities	The set of manufacturing facility nodes in the supply chain, with a unique name for each manufacturing facility.	*m*
	Distribution Facilities	The set of warehouses and distribution centres in the supply chain, with a unique name for each facility.	*d*
	Customers	The set of customer nodes in the supply chain, with a unique name for each customer.	*c*
Products	Raw Materials	The set of raw materials in the supply chain with a unique name for each raw material.	*rm*
	Intermediate Product	The set of intermediate products in the supply chain with a unique name for each intermediate product. Intermediate products are any product (even in final form) that is transported between manufacturing facilities or from a manufacturing facility to a distribution facility.	*ip*
	Final Product	The set of final products in the supply chain with a unique name for each final product. A product is only classified as final product when it flows between a distribution facility and a customer.	*fp*
Node subset	Suppliers per Raw Material	Subset of suppliers per raw material *rm*.	*s(rm)*
	Production Facilities per Intermediate Product	Subset of manufacturing facilities per intermediate product *ip*.	*m(ip)*
	Distribution Facilities per Final Product	Subset of distribution facilities per final product *fp*.	*d(fp)*
	Customers per final product	Subset of customers per final product *fp*.	*c(fp)*
Arcs	Supplier Arcs	The set of arcs where flow is possible between supplier *s* and manufacturing facility *m* for product *rm*.	*SA(s,m,rm)*
	Facility Arcs 1	The set of arcs where flow is possible between manufacturing facility *m* and distribution facility *d* for product *ip*.	*FA1(m,d,ip)*
	Facility Arcs 2	The set of arcs where flow is possible between manufacturing facility *m* and manufacturing facility *m* for product *ip*.	*FA2(m,m,ip)*
	Customer Arcs	The set of arcs where flow is possible between distribution facility *d* and customer *c* for product *fp*.	*CA(d,c,fp)*

Table 6: Network modelling data requirements – VARIABLES

Group	Element	Description	Symbol
Flow Volume	Volume	The volume of product on a supply chain arc (from any node *x* to any node *y*). Determined by the model.	*V(x,y)*

Table 7: Network modelling data requirements - PARAMETERS

Group	Element	Description	Symbol
Supplier Nodes	Supplier Capacity	Supply capacity of any supplier node *s* for raw material *rm*.	*SCap(s,rm)*
	Supply Cost	Supply cost of raw material *rm* by supplier *s*.	*SCost(s,rm)*
Manufacturing Nodes	Facility capacity	Manufacturing capacity at manufacturing facility *m* for intermediate product *ip*.	*FCap(m,ip)*
	Material balance	Manufacturing yield percentage per product. Expressed as output volume for product *y* as a % of input volume for product *x*.	*ManYield(y,x)*
	Fixed manufacturing cost	Fixed manufacturing cost to operate a manufacturing facility *m*.	*FManCost(m)*
	Variable manufacturing cost	Variable manufacturing cost to produce intermediate product *ip* at manufacturing facility *m*.	*VManCost(m,ip)*
	Raw material storage cost	Cost to store raw materials *rm* at manufacturing site *m*.	*RMStCost(m,rm)*
	Final product storage cost	Cost to store intermediate product *ip* at manufacturing site *m*.	*FPStCost(m,ip)*
Distribution Nodes	Storage Capacity	Storage capacity for final product *fp* at distribution centre *d*.	*StCap(d,fp)*
	Material balance	Storage yield percentage per product (in case of product losses at DC). Expressed as output volume for product *y* as a % of input volume for product *x*.	*StYield(y,x)*
	Fixed facility operating cost	Fixed facility cost to operate a distribution facility *d*.	*FDistCost(d)*
	Variable facility operating cost	Variable facility operating cost to handle final product *fp* at distribution facility *d*.	*VDistCost(d,fp)*
Customer Nodes	Customer Demand	Demand of each customer node *c* for product *fp*.	*Demand(c,fp)*
Arcs	Transport Capacity	Capacity of any supply chain arc (from any node *x* to any node *y*).	*TCap(x,y)*
	Transport Cost	Cost of transporting one unit on a supply chain arc (from any node *x* to any node *y*).	*TCost(x,y)*
Financial	Tax rate	The tax rate in the country where the manufacturing facility *m* or distribution facility *d* is located.	*Tax(m)* *Tax(d)*
	Minimum Profits	Minimum lower bound for profit per manufacturing facility *m* or distribution facility *d*.	*MinProf(m)* *MinProf(d)*
	Duties	Duties payable when moving product *ip* or *fp* between node *x* and node *y* in the supply chain.	*Duty(ip,x,y)* *Duty(fp,x,y)*
Inventory	Pipeline Cost	Pipeline cost per unit of product *ip* or *fp* that flows between node *x* and *y*.	*PipeC(ip,x,y)* *PipeC(fp,x,y)*
	Cycle Cost	Cycle cost of holding inventory of product *ip* at manufacturing facility *m*.	*CycleC(ip,m)*
	Satety stock Cost	Cost of holding safety stock of product *fp* at a distribution facility *d*.	*SafetyC(fp,d)*

7.2 AHP requirements

The analytical hierarchy process (AHP) can be effectively used for strategic supply chain problems where there exist multiple objectives, both quantitative and qualitative. It evaluates priorities of goals and weights of deviation variables corresponding to various objectives, and analytically determines the best of a number of alternatives.

7.2.1 AHP problem description

AHP can be applied to any problem where the decision-maker has to choose between a number of alternatives, based on weighted criteria. It is often used in conjunction with other models (*e.g.* network modelling or simulation models), where the outputs of these models become one of the criteria for the AHP model.

For the purpose of this research, 2 applications of AHP in strategic supply chain planning will be considered: 1) site location, and 2) overall supply chain performance evaluation (with the help of SCOR metrics).

7.2.1.1 Site location

The site location problem favours the use of AHP, in that many quantitative and qualitative criteria can be included in the decision-making process. The specific strategic supply chain problem of determining the location of a new production facility (either local or international) is examined here. There is no limit on the number of criteria to consider, but one will typically consider criteria like political & economic indicators, resource availability, logistics infrastructure and supply chain configuration. Each of these will have sub-criteria that provides for measurable quantitative or qualitative criteria.

7.2.1.2 Supply chain performance evaluation

In the second strategic supply chain problem, AHP is used to determine a global performance score for a specific supply chain. This enables the analyst to evaluate and compare the performance of different supply chains. This approach is based on the 12 high-level performance metrics as defined in the SCOR model. These performance metrics cover the four important measures for supply chain performance:

- delivery reliability;
- flexibility & responsiveness;
- cost; and
- assets.

7.2.2 AHP data fundamentals

An AHP model is relatively simple, as it basically involves a few matrices and mathematical computations. Firstly, all criteria are compared with a ***pair-wise comparison matrix***, to find the relative weight of each criterion (*Table 8*). "Importance" of the criteria relative to other criteria is measured on an integer-valued 1 to 9 scale, with the number having the interpretation shown in *Table 9*.

Table 8: Pair-wise comparison matrix of criteria

	Criterion 1	Criterion 2	Criterion 3	Criterion 4	Criterion 5	Weight
Criterion 1	1	1/3	1	2	1/5	0.11
Criterion 2	3	1	1/2	3	1/7	0.15
Criterion 3	1	2	1	1	1	0.19
Criterion 4	1/2	1/3	1	1	1/9	0.08
Criterion 5	5	7	1	9	1	0.46

Table 9: Interpretation of entries in pair-wise comparison matrix

"Importance" value of entry a_{ij}	Interpretation
1	Criteria *i* and *j* are of equal importance
3	Criterion *i* is weakly more important than criterion *j*
5	Experience and judgement indicate that criterion *i* is strongly more important than criterion *j*
7	Criterion *i* is very strongly or demonstrably more important than criterion *j*
9	Criterion *i* is absolutely more important than criterion *j*
2, 4, 6, 8	Intermediate values

From *Table 8* an example to illustrate: **Criterion 2** is weakly ***more*** important than **Criterion 1**. The inverse also counts, that is **Criterion 1** is weakly ***less*** important than **Criterion 2**. The pair-wise comparison process for this example (which also includes a process of normalisation) results in the relative weights indicated in the last column of *Table 8*.

Secondly, all alternatives are compared based on these criteria with a similar pair-wise comparison matrix (for each of the criteria). The outcome is a "performance score" for the alternatives based on the various criteria. Finally, the alternative scores and criteria weights are combined in a mathematical computation to find one overall score for each of the alternatives. A decision can then be made on the best alternative that balances all of the criteria in a global optimum solution.

7.2.3 AHP data requirements

7.2.3.1 Site location data requirements

The data required for the plant location problem include the following main criteria:

- political climate;
- economic conditions;
- business environment;
- workforce;
- raw materials;
- suppliers;
- utilities;
- logistics infrastructure;
- markets; and
- supply chain configuration.

Under these criteria, a number of quantitative and qualitative sub-criteria are defined. *Table 10* includes the data requirements for site selection with the use of AHP. The column *"Criterion Type"* gives an indication of whether this criterion is quantitative of qualitative, and the column *"Data type"* expresses the kind of data related to general, marketing, cost, or structure.

Table 10: Site location data requirements for AHP

Criterion	Sub-criteria	Description	Criterion Type	Data type
POLITICAL CLIMATE	General political climate	What is general political climate in the prospective country of location?	Qualitative	General
	State of democracy	How advanced is the democracy (if any) in this country?	Qualitative	General
	Level of government corruption	How corrupt is the government in this country?	Qualitative	General
ECONOMIC CONDITIONS	General economic conditions	What are the general economic conditions in the prospective country of location?	Qualitative	General
	Growth rate	The economic growth rate of the past 3 years.	Quantitative	General
	Technological advancement	How technological advanced is this country?	Qualitative	General
	Gross Domestic Product (GDP)	The GDP of the past 3 years.	Quantitative	General
BUSINESS ENVIRONMENT	Tax incentives	Tax incentives by government for this industry.	Quantitative	General
	Tax rate	The current and projected tax rate for companies.	Quantitative	General
	Free market	Maturity of free market conditions.	Qualitative	General
	Competition	Level of competition in this industry.	Qualitative	General
	Regulatory conditions	Is the regulatory environment conducive to this industry?	Qualitative	General
WORKFORCE	Labour cost	Cost of blue collar and professional labour in this country.	Quantitative	Cost
	Favourability of labour law	How restrictive are labour laws in this country?	Qualitative	General
	Availability of labour	Are the necessary labour skills available in this country?	Qualitative	General
RAW MATERIALS	Cost	Cost of sourcing raw materials in this country.	Quantitative	Cost
	Availability	Availability of raw materials in this country.	Qualitative	General
SUPPLIERS	Cost	Cost competitiveness of suppliers.	Quantitative	Cost
	Accessibility	Accessibility to suppliers in this location.	Quantitative	Structure
UTILITIES	Cost	Cost competitiveness of utilities.	Quantitative	Cost
	Availability	Availability of utilities at this location.	Quantitative	General
LOGISTICS INFRA-STRUCTURE	Proximity to ports	How close is this location to marine transportation?	Quantitative	Structure
	Rail infrastructure	Level of rail infrastructure and accesibility from this location.	Quantitative	Structure
	Road infrastructure	Level of road infrastructure and accesibility from this location.	Quantitative	Structure
	Service providers	Number of logistics service providers in this location.	Quantitative	General
	Competitiveness	Cost competitiveness of logistics service providers.	Quantitative	Cost
MARKETS	Accesibility	Accessibility to markets.	Quantitative	Structure
	Distribution cost	Distribution cost to markets.	Quantitative	Cost
	Growth potential	Potential for growth in market.	Qualitative	Marketing
	Local opportunities	Local opportunities for product.	Qualitative	Marketing
SC CONFIGU-RATION	Strategic fit	Strategic fit of this location in the company supply chains.	Qualitative	General
	Optimality of configuration	Optimality of supply chain configuration.	Quantitative	Structure

7.2.3.2 Supply chain performance evaluation data requirements

The performance of supply chains can be compared by constructing a global performance score based on the 12 level 1 SCOR metrics. *Table 11* includes the data requirements for the 12 level 1 SCOR metrics. It includes a formal description of how each of the metrics is calculated, stating the implicit data requirements for defining each of the criteria.

Table 11: Supply chain performance evaluation data requirements

Criterion	Sub-criteria	Description	Unit
DELIVERY RELIABILITY	Delivery performance	The percentage of orders that are fulfilled on or before the original scheduled or committed date.	%
	Fill rate	The percentage of ship-from-stock orders shipped within 24 hours of order receipt.	%
	Order fulfillment lead time	The average actual lead times consistently achieved, from Customer Signature/ Authorization to Order Receipt, Order Receipt to Order Entry Complete, Order Entry Complete to Start-Build, Start Build to Order Ready for Shipment, Order Ready for Shipment to Customer Receipt of Order, and Customer Receipt of Order to Installation Complete.	hrs
	Perfect order fulfillment	A "perfect order" is defined as an order that meets all of the following standards: Delivered complete; all items on order are delivered in the quantities requested Delivered on time to customer's request date, using your customer's definition of on-time delivery Documentation supporting the order including packing slips, bills of lading, invoices, etc., is complete and accurate. Perfect condition: Faultlessly installed (as applicable), correct configuration, customer-ready, no damage.	%
RESPONSIVENESS & FLEXIBILITY	Supply chain responsiveness	The time between the initial creation of the regenerated forecast and its reflection in the Master Production Schedule of the end-product production facilities.	hrs
	Production flexibility	The percentage order reduction sustainable at 30 days prior to delivery with no inventory or cost penalties.	%
COST	Total supply chain management cost	Costs associated with the supply chain including execution, administration, and planning.	R
	Value-added employee productivity	Value added per employee is calculated as total product revenue less total material purchases ÷ total employment (in full-time equivalents).	R
	Warranty costs	Warranty costs include materials, labour and problem diagnosis for product defects.	R
ASSETS	Cash-to-cash cycle time	Equals inventory days of supply + days sales outstanding – average payment period for materials (time it takes for a dollar to flow back into a company after its been spent for raw materials).	hrs
	Inventory days of supply	Equals total gross value of inventory at standard cost before reserves for excess and obsolescence. Only includes inventory on company books, future liabilities should not be included. Five point annual average of the sum of all gross inventories (raw materials & WIP, plant FG, field FG, field samples, other) ÷ (Cost of goods sold ÷ 365).	hrs
	Asset turns	Total gross product revenues ÷ Total net assets.	#

7.3 Discrete event simulation requirements

This research will specifically focus on discrete event dynamic system (DEDS) simulation as an effective simulation technique for understanding and improving the dynamic nature of supply chain processes. It includes stochastic parameters, which allow for the evaluation of system dynamics based on variable process behaviour.

7.3.1 Discrete event simulation problem description

Although supply chain simulation is mostly used for analysing policies on a tactical and operational process level, it can also be successfully applied to evaluate the feasibility of a strategic supply chain network design. While a mathematical model will determine the optimal network configuration, simulation modelling is powerful in that it is able to test the robustness of the network, and the impacts of dynamics and eventualities on the design.

The proposed problem will include a global supply chain network, with suppliers, production facilities, storage facilities, inter-modal nodes, and customers. At each of these nodes there are a number of activities/processes that takes place, each with specific process times:

- manufacturing processes (according to process recipes, batch manufacturing runs, *etc.*);
- logistics activities (*e.g.* storage, packaging, loading, *etc.*); and
- administration processes.

Other supply chain elements in a simulation model include:

- arrival and departure rates at each of the nodes;
- product movements in specific parcel sizes in accordance to order quantities;
- transportation lead times between the supply chain nodes;
- minimum and maximum storage levels;
- information exchange, *i.e.* order triggers.

7.3.2 Discrete event simulation data fundamentals

A discrete event simulation model is built using building blocks that are linked sequentially to model the process flow of entities through sequential activities. Each of these building blocks has specific properties that determine what happens to an entity when it enters that block. The entity is usually delayed for a time to undergo a specific activity before moving on to the next block (process). *Figure 27* illustrates some of the blocks that are available in the ARENA (version 9) software.

Entities are created at discrete time events according to some arrival time probability distribution. It then moves through a number of process steps, before being disposed. Statistics are easily captured (*e.g.* time intervals, queue lengths and times, resource usage, *etc.*). Input data are captured in a table-like format, and can easily be imported from a text or spreadsheet source with the use of Visual Basic.

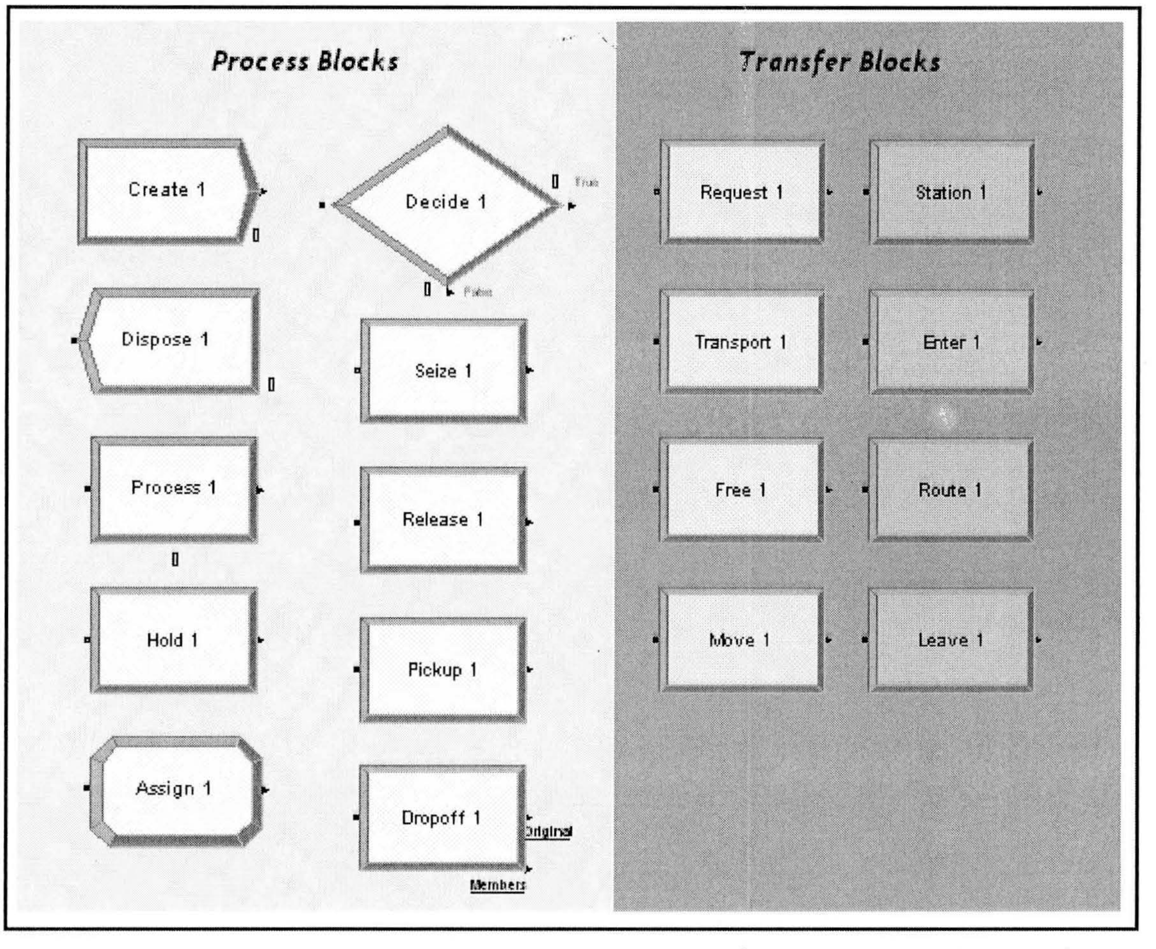

Figure 27: Simulation model building blocks

7.3.3 Discrete event simulation data requirements

What makes a simulation model of the petro-chemical industry supply chain interesting is that it combines both continuous and discrete elements. Production processes are of a continuous nature, while the transportation of chemical products usually occurs in discrete format (with the exception of pipeline).

The network structure is modelled similarly to the other modelling approaches discussed before. The difference is that in the case of simulation the interest extends to additional information about processes including a time dimension. Supply chain nodes (*e.g.* suppliers, plants, customers) are modelled as stations. An entity arrives at a station and then undergoes a number of processes before being routed to a next station. Arrival at a station can be according to business rules set in a probability distribution or as the result of the routing from a previous station. Supply chain arcs are modelled as a transportation movement between two stations, with the associated lead time. Other parameters like parcel sizes and minimum/maximum tank levels should also be specified, as well as all business rules with regards to product movement along the supply chain.

For a supply chain model as described in the problem description, the following data would be required (*Table 12*).

Table 12: Simulation data requirements

Element	Attribute	Description	Example
STATIONS	*A station is used for each supply chain node, i.e. supplier node, storage facility, production facility, mode switch node, customer node*		
	Station Name	Unique, descriptive name of a station.	Sasolburg Plant
	Station Type	The station type will determine which activities/processes take place when an entity enters the station. Types include suppliers, storage, production facility, mode switch, customers.	Production facility
ARCS	*The transportation of product from one station to another*		
	Origin Station	Defines the origin station from where product is moved.	Sasolburg Plant
	Destination Station	Defines the destination station to where product is moved.	Durban Storage
	Lead time	The time it takes for the product to be transported on the arc. Expressed as a probability distribution.	TRIA(10,12,14) hours
	Transporter resource	Which transporter resource is used to move the products. Implies a specific mode of transport.	Road Transporter
	Parcel Format	Format of the parcel, *i.e.* liquid bulk, dry bulk, package goods, *etc.*	Liquid Bulk
	Transport Unit	Unit of transport (*e.g.* road tanker, container, palletised drums, *etc.*)	Road Tanker
	Parcel Size	Size of one Transport Unit	33 tons
LOGISTICS ACTIVITIES	*Logistics processes that take place at a station*		
	Activity	Unique, descriptive name of an activity	Road loading
	Process time	The time for this activity (expressed as a probability distribution)	TRIA(1,2,3) hours
	Special Rules	Specific business rules regarding this activity	Only loaded after documentation approved

Simulation data requirements (...continued)

Element	Attribute	Description	Example
TRIGGERS	*Defines the triggers for events to happen*		
	Arrivals	The arrival times of entities (expressed as probability distribution).	2 Road tankers arrive every day of the week
	Departures	The departure times of entities (expressed as probability distribution).	A ship departs once every 30 days
ENTITIES	*Defines the different entities that flow through the model. Separate entities created for different materials*		
	Product	Unique, descriptive name of a product.	Methanol
	Product Type	Type of product (*e.g.* Raw Material, Intermediate product, Final product).	Final Product
	Batch size	Size of batches in which this product is transported.	33 tons
PRODUCTION PROCESSES	*Defines the processes that take place at a production facility*		
	Material Balances	The process recipe / material balance for the production of a product.	1:2:3 (Methanol:Hydrogen:catalyst ratio)
	Process Rates	The rate at which products are manufactured.	10 tons per day
	Production schedule	Defines rules w.r.t. when products are made.	Batch runs, every 10th day
RESOURCES	*Defines the resources used to process entities. These can be shared among processes, and consist of a specified number of that resource*		
	People	Human Resources that perform the processes.	Loading Operator
	Equipment	Equipment used in performing processes.	Methanol Distillation Unit
	Equipment Reliability	Schedules for equipment availability (including breakdowns).	Shutdown once every 6 months for 2 days
	Shifts	Schedules for people availability.	9 am to 5 pm 5 days a week

7.4 GIS requirements

Geographic Information Systems (GIS) provide for a descriptive model of the geographic orientation of a supply chain. Since any supply chain is structurally dispersed over different geographical locations, it makes for effective modelling, and helps management to understand a visual, geographical mapping of their suppliers, customers, logistics corridors, *etc.*

7.4.1 Geographical modelling problem description

Although there are many different applications of GIS in the supply chain environment, the focus will be on the high level, strategic supply chain mapping of global supply chains. Petro-chemical companies typically want to visualise where all their products went during a specific historical period. This can help them with a number of strategic decision-making issues, *e.g.* to identify synergies on transportation corridors across multiple business units and products.

Figure 28 illustrates a GIS map for a petro-chemical company with different product supply chains. The aim of this application is to analyse the marine shipping corridors by volume, for different products, business units and customers.

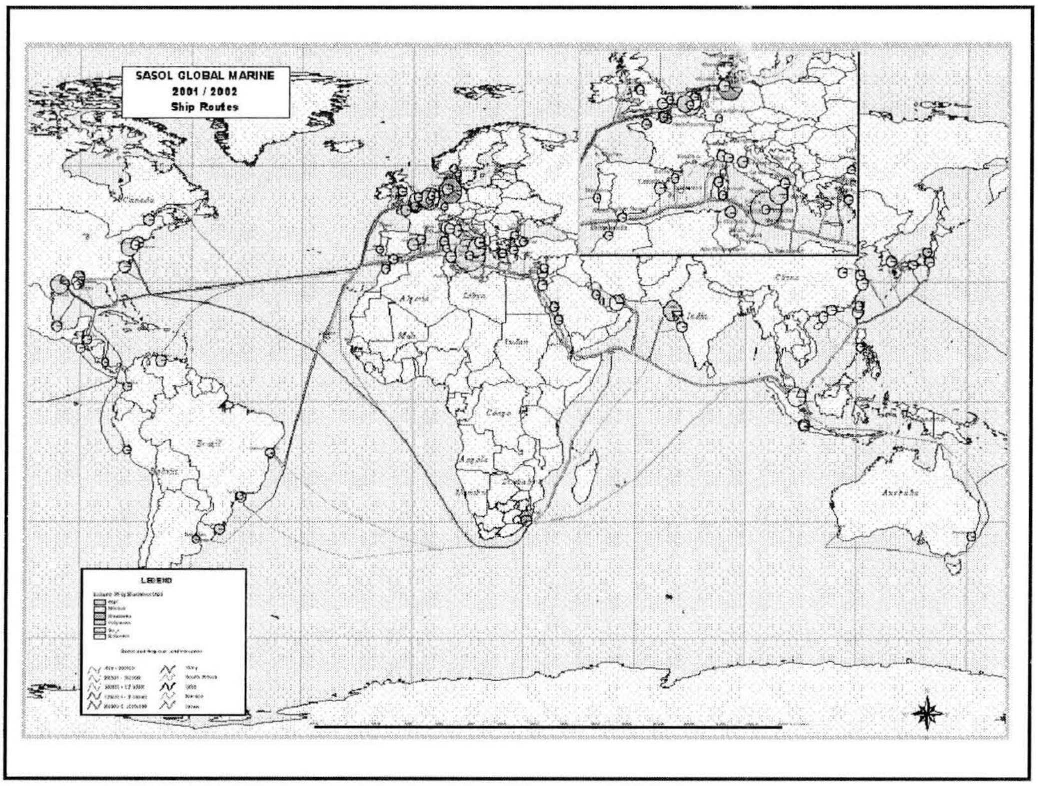

Figure 28: Example of a GIS model for global supply chains

What makes GIS so effective is that many different visualisations can be achieved from the same underlying data. Another map could for example be created to illustrate road or rail corridors for the same supply chains. GIS maps can be seen as a visual report (like that in a database report) that illustrate information from "database" queries, in whatever way the analyst needs it. *Figure 29* illustrates another example of a GIS mapping of road and rail transport corridors for South African distribution logistics of a petro-chemical company.

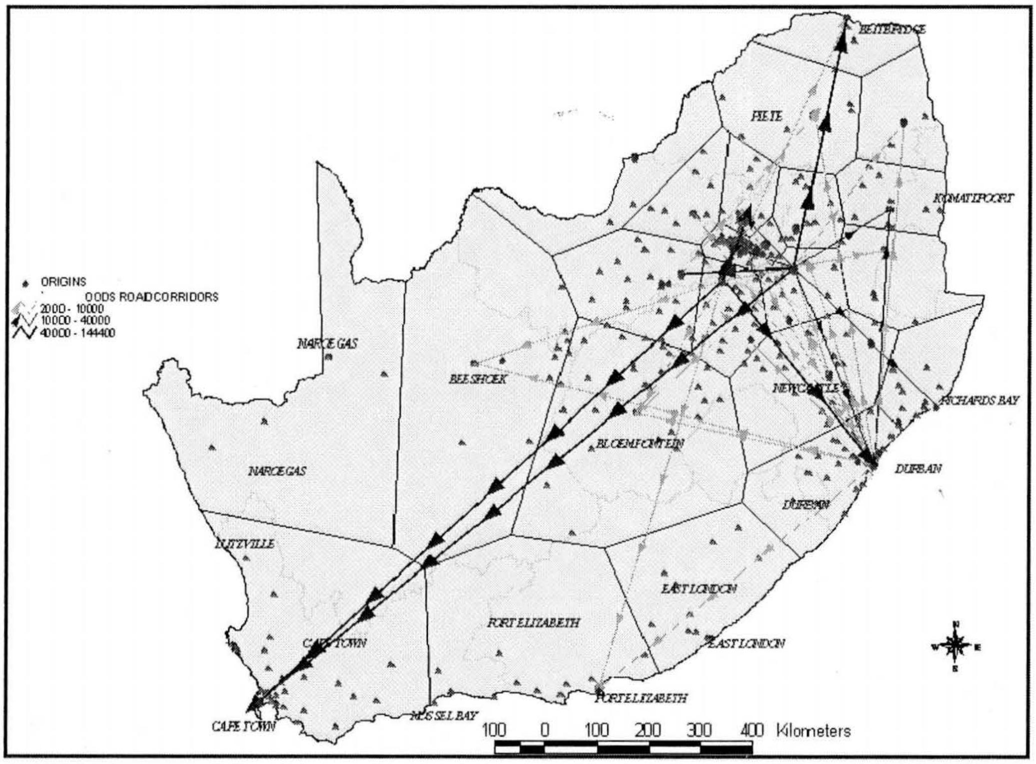

Figure 29: GIS model of road & rail transport corridors

7.4.2 GIS data fundamentals

A GIS model is based on 3 types of data:

- lines (*e.g.* a road link between two cities);
- points (*e.g.* the coordinates of a city); and
- polygons (*e.g.* the shape of a country).

Any data field can be added to a data entry (as attributes) to enhance the information available for analysis. For example, it is easy to add a city name, city population, city average temperature, *etc.* to the city data point. Attributes form the basis for modelling different views of the same information, depending on the requirement of the decision-maker.

The GIS data is combined in different layers (*e.g.* a layer for all countries or a layer for all rivers) that can be displayed (put on and off) based on what the analyst wants to display on a GIS model (*Figure 30*). All of the information is stored in a geo-database – a relational database similar to an Access or SQL database – where tables are related to each other with defined relationships.

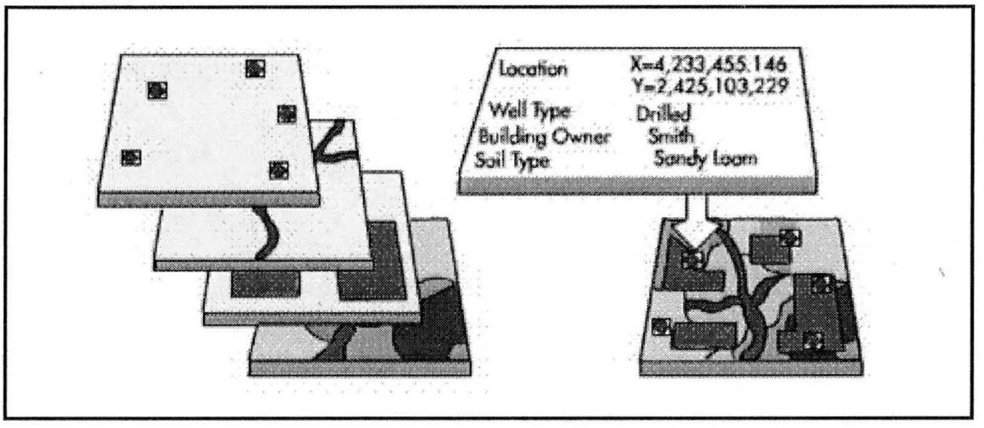

Figure 30: GIS data layers

An important requirement of GIS is that all data need to be spatially enabled. This requires the geo-coding of data into geographical coordinates (longtitudes and latitudes).

Data inputs can be made manually or automated via a translation tool in the software. Thus, if the structural data of a supply chain are already in a database, all that needs to be changed is to geo-code the locations of the various supply chain nodes and arcs.

GIS software further includes many tools for analysing, transforming and displaying spatially enabled information.

7.4.3 GIS data requirements

The main data elements for mapping a supply chain (on strategic level) with GIS include:

- supply chain ***structural elements*** (suppliers, production facilities, customers, *etc.*) – configured as points in the geo-database,
- ***network links*** (mode of transport, origin, destination, *etc.*) – configured as lines in the geo-database,
- ***volume*** data (volume shipped per network link, demand per customer, *etc.*) – configured as attributes of points and lines,
- ***geographical*** data (countries, places, railways, rivers, roads, *etc.*) – configured as lines, points and polygons.

Table 13 includes a non-exhaustive list of data elements that can be included in the GIS modelling of a supply chain on strategic level. This is based on the supply chain problem as described above. The first column *"Table"* refers to the data tables (like those in a database) to structure the data. The second column *"Field"* describes the attributes of each of the data elements in a table. Column 4 *"1 or many"* states whether there will be a single data entry or if there could be several data entries. The last column *"Related Table"* show the relationship to another table in the data structure.

This data is combined within geographical data layers, such as countries, water, continents, *etc.*, to spatially complete the picture.

Table 13: GIS data requirements

Table	Field	Description	1 or many	Related Table
SUPPLY CHAIN	*Contains data that describe the specific supply chain*			
	Supply Chain Name	Unique, descriptive name of a supply chain.	1	
	Business Unit	Name of company business unit who "owns" the supply chain.	1	BUSINESS UNIT
	Product Name	Final product - only one per supply chain.	1	PRODUCT
	Period	Period under analysis (*e.g.* 2005, January 2004, *etc.*).	1	
SUPPLIER NODE	*Contains data that describe a supplier node*			
	Supplier Name	Unique, descriptive name of a supplier.	1	
	Location	Longtitude, Latitude, City, Country, Region.	1	
	Product Name	Raw material X supplied by this supplier.	many	PRODUCT
	Supply Volume	Volume of raw material X supply for the period.	many	
	Supply Chain Name	Relates to a specific supply chain.	1	SUPPLY CHAIN
PRODUCTION FACILITY NODE	*Contains data that describes a production facility node*			
	Production Facility Name	Unique, descriptive name of a specific production facility.	1	
	Production Facility Type	Describe the type of production facility (*e.g.* blending, oxidation, *etc.*).	1	PRODUCTION FACILITY TYPE
	Location	Longtitude, Latitude, City, Country, Region.	1	
	Production Site	Relates to a high level production site which can be a combination of different production facilities.	1	
	Product Name	Intermediate or final product X produced at this facility.	many	PRODUCT
	Production Volume	Volume of product X produced for the period.	many	
	Supply Chain Name	Relates to a specific supply chain.	1	SUPPLY CHAIN

GIS data requirements (...continued)

Table	Field	Description	1 or many	Related Table
DISTRIBUTION FACILITY NODE	*Contains data that describe a distribution facility node. A distribution facility is any facility where final product is stored temporarily.*			
	Distribution Facility Name	Unique, descriptive name of a specific distribution facility.	1	
	Distribution Facility Type	Describe the type of distribution facility (*e.g.* tank, warehouse, *etc.*).	1	DISTRIBUTION FACILITY TYPE
	Location	Longtitude, Latitude, City, Country, Region.	1	
	Distribution Site	Relates to a high level storage site which can be a combination of different storage facilities.	1	DISTRIBUTION SITE
	Storage Capacity	Maximum volume stored at any given time in this storage site.	1	
	Product Name	Product X stored in this storage facility.	many	PRODUCT
	Throughput	Total volume of product X that passed through this storage site.	many	
	Service provider	Relates to name of service provider (*e.g.* Vopak, IVS).	1	SERVICE PROVIDER
	Supply Chain Name	Relates to a specific supply chain.	1	SUPPLY CHAIN
INTER-MODAL NODE	*Contains data that describe a node where a switch of transport mode takes place*			
	Inter-modal Name	Unique, descriptive name of a specific inter-modal node.	1	
	Inter-modal Type	Describes the type of inter-modal node (*e.g.* port, inter-model hub, *etc.*).	1	MODE SWITCH TYPE
	Location	Longtitude, Latitude, City, Country, Region.	1	
	Supply Chain Name	Relates to a specific supply chain.	1	SUPPLY CHAIN
CUSTOMER NODE	*Contains data that describe a customer node*			
	Customer Name	Unique, descriptive name of a specific customer.	1	
	Parent Company Name	Relates to a high level customer (parent company).	1	PARENT COMPANY
	Customer Type	Describe type of customer (*e.g.* intermediate, strategic, *etc.*).	1	CUSTOMER TYPE
	Location	Longtitude, Latitude, City, Country, Region.	1	
	Product Name	Product X delivered to this customer.	many	PRODUCT
	Order volume	Total volume of product delivered to this customer.	many	
	Supply Chain Name	Relates to a specific supply chain.	1	SUPPLY CHAIN
SUPPLIER ARC	*Contains data that describe an arc between supplier and production facility*			
	Product Name	Product X moved on this link.	many	PRODUCT
	Transported volume	Total volume moved on this arc per product X.	many	
	Service Provider	Relates to name of service provider (*e.g.* Tanker Services, KN).	1	SERVICE PROVIDER
	Distance	Distance of this link.	1	
	Supplier Name	Relates to node of origin.	1	SUPPLIER
	Production Facility Name	Relates to node of destination.	1	PRODUCTION FACILITY
	Transport Mode	Mode of transportation (*e.g.* road, rail, pipeline, barge, ship).	1	TRANSPORT MODE
	Transport Unit	Unit of transport (*e.g.* tanker, container, palletised drums, *etc.*).	1	TRANSPORT UNIT
	Parcel Format	Product format (*e.g.* dry bulk, packaged goods, gasses, *etc.*).	1	PARCEL FORMAT
	Method of Packaging	How is product packaged (*e.g.* palletised drums, bulk bags, *etc.*).	1	METHOD OF PACKAGING
	Supply Chain Name	Relates to a specific supply chain.	1	SUPPLY CHAIN

GIS data requirements (...continued)

Table	Field	Description	1 or many	Related Table
FACILITY ARC	*Contains data that describe an arc between production and/or distribution facilities*			
	Product Name	Product X moved on this link.	many	PRODUCT
	Transported volume	Total volume moved on this arc per product X.	many	
	Service Provider	Relates to name of service provider (*e.g.* Tanker Services, KN).	1	SERVICE PROVIDER
	Distance	Distance of this link.	1	
	Origin Facility Name	Relates to the production node of origin.	1	PRODUCTION FACILITY
	Destination Facility Name	Relates to the production node of destination.	1	PRODUCTION FACILITY
	Transport Mode	Mode of transportation (*e.g.* road, rail, pipeline, barge, ship).	1	TRANSPORT MODE
	Transport Unit	Unit of transport (*e.g.* tanker, container, palletised drums, *etc.*).	1	TRANSPORT UNIT
	Parcel Format	Product format (*e.g.* dry bulk, packaged goods, gasses, *etc.*).	1	PARCEL FORMAT
	Method of Packaging	How is product packaged (*e.g.* palletised drums, bulk bags, *etc.*).	1	METHOD OF PACKAGING
	Supply Chain Name	Relates to a specific supply chain.	1	SUPPLY CHAIN
CUSTOMER ARC	*Contains data that describe an arc between a production facility and a customer*			
	Product Name	Product X moved on this link.	many	PRODUCT
	Transported volume	Total volume moved on this arc per product X.	many	
	Service Provider	Relates to name of service provider (*e.g.* Tanker Services, KN).	1	SERVICE PROVIDER
	Distance	Distance of this link.	1	
	Production Facility Name	Relates to node of origin.	1	PRODUCTION FACILITY
	Customer Name	Relates to node of destination.	1	CUSTOMER
	Transport Mode	Mode of transportation (*e.g.* road, rail, pipeline, barge, ship).	1	TRANSPORT MODE
	Transport Unit	Unit of transport (*e.g.* tanker, container, palletised drums, *etc.*).	1	TRANSPORT UNIT
	Parcel Format	Product format (*e.g.* dry bulk, packaged goods, gasses, *etc.*).	1	PARCEL FORMAT
	Method of Packaging	How is product packaged (*e.g.* palletised drums, bulk bags, *etc.*).	1	METHOD OF PACKAGING
	Supply Chain Name	Relates to a specific supply chain.	1	SUPPLY CHAIN
PRODUCT	*Contains data that describe and classify products in the supply chain*			
	Product Name	Unique, descriptive name of a product.	1	
	Product Type	Type of product (*e.g.* Raw Material, Intermediate product, Final product).	1	PRODUCT TYPE
	Product Family	Product family (*e.g.* inorganic, hydrocarbon, oxygenate, *etc.*).	1	PRODUCT FAMILY
PRODUCT TYPE	*Contains data that describe different product types*			
	Product Type Name	Unique, descriptive name of a product type.	1	
PRODUCT FAMILY	*Contains data that describe different product families*			
	Product Family Name	Unique, descriptive name of a product family.	1	
PRODUCTION SITE	*Contains data that describe different production sites*			
	Production Site Name	Unique, descriptive name of a production site.	1	

GIS data requirements (...continued)

Table	Field	Description	1 or many	Related Table
PRODUCTION FACILITY TYPE	*Contains data that describe different production facility types*			
	Production Facility Type	Unique, descriptive name of a production facility type.	1	
SERVICE PROVIDER	*Contains data that describe different service providers*			
	Service Provider Name	Unique, descriptive name of a service provider.	1	
	Service Provider Type	Type of service provider (*e.g.* storage, road transport, rail transport, *etc.*).	1	SERVICE PROVIDER TYPE
	Service Provider Rank	Rank of service provider (*e.g.* 1 = preferred, 2 = average, 3 = poor, *etc.*).	1	
SERVICE PROVIDER TYPE	*Contains data that describe different service provider types*			
	Service Provider Type	Unique, descriptive name of a service provider type.		
TRANSPORT UNIT	*Contains data that describe different transport units*			
	Transport Unit	Unique, descriptive name of a transport unit..	1	
PARCEL FORMAT	*Contains data that describe different parcel formats*			
	Parcel Format	Unique, descriptive name of a parcel format.	1	
METHOD OF PACKAGING	*Contains data that describe different methods of packaging*			
	Method of Packaging	Unique, descriptive name of a method of packaging.	1	
TRANSPORT MODE	*Contains data that describe different transport modes*			
	Transport Mode	Unique, descriptive name of a transport mode.	1	
CUSTOMER TYPE	*Contains data that describe different customer types*			
	Customer Type	Unique, descriptive name of a customer type.	1	
PARENT COMPANY	*Contains data that describe different parent companies*			
	Parent Company Name	Unique, descriptive name of a parent company name.	1	
BUSINESS UNIT	*Contains data that describe different business units*			
	Business Unit Name	Unique, descriptive name of a business unit.	1	

The geo-database is structured as a relational database. Data entities (whether points, lines or polygons) are structured in different tables, with multiple fields to describe the attributes of the specific data point. These data entities are related to each other in the form of an entity relationship diagram (ERD)[19] which strictly defines the relationships of the data.

7.5 Supply chain schematic requirements

A supply chain schematic model provides a descriptive model of the supply chain configuration. Nodes and arcs are graphically illustrated to provide insight into the structure of a particular supply chain.

[19] The reader is referred to Whitten *et al.* (2001) for more on the entity relationship diagram.

7.5.1 Supply chain schematic modelling problem description

A supply chain schematic can be modelled for any supply chain configuration (both existing and new), and would include the following elements:

- supply chain nodes (*i.e.* suppliers, plants, customers);
- supply chain arcs (*i.e.* product flow between two supply chain nodes);
- mode of transport for a supply chain arc;
- product volume on a supply chain arc; and
- supply chain activities and processes.

Refer to *Figure 12* on page 31 for an illustration of a supply chain schematic.

7.5.2 Supply chain schematic modelling data fundamentals

Data used to build a supply chain schematic involves graphical, numerical and text data for each of the supply chain elements. A supply chain element used in the schematic will have a corresponding symbol/graphic associated with it, *e.g.* any supplier element in the model has a certain picture that is always used to identify suppliers, with the name of the specific supplier next to it. Supply chain activities at each of the nodes should also be included in the form of a symbol, *e.g.* at a storage facility there are packaging, weighing and documentation activities involved. A supply chain schematic can be implemented in an easy and flexible manner with graphical software utilities like Microsoft Visio.

7.5.3 Supply chain schematic data requirements

The text and numerical data required for creating a supply chain schematic is summarised in *Table 14*. *Figure 31* illustrates the pictures and symbols that would be associated with the supply chain elements.

Table 14: Supply chain schematic data requirements

Element	Attributes	Description
SUPPLIER	Supplier Name	Unique, descriptive name of a supplier.
	Location	Longtitude, Latitude, City, Country, Region.
	Supplier Capacity	Supply capacity per raw material.
	Supply chain Activities	Activities that take place at this node.
MANUFACTURING FACILITY	Manufacturing Facility Name	Unique, descriptive name of a specific production facility.
	Manufacturing Facility Type	Describe the type of production facility (*e.g.* blending, oxidation, *etc.*).
	Location	Longtitude, Latitude, City, Country, Region.
	Manufacturing Site	Relates to a high level production site which can be a combination of different production facilities.
	Manufacturing capacity	Manufacturing capacity per product.
	Supply chain Activites	Activities that take place at this node.
DISTRIUTION FACILITY	Distribution Facility Name	Unique, descriptive name of a specific distribution facility.
	Distribution Facility Type	Describe the type of distribution facility (*e.g.* tank, warehouse, *etc.*).
	Location	Longtitude, Latitude, City, Country, Region.
	Distribution Site	Relates to a high level storage site which can be a combination of different storage facilities.
	Storage Capacity	Maximum volume stored at any given time in this storage site per product.
	Service provider	Relates to name of service provider (*e.g.* Vopak, IVS).
	Supply chain Activities	Activities that take place at this node.
INTER-MODAL FACILITY	Mode Switch Name	Unique, descriptive name of a specific mode switch node.
	Mode Switch Type	Describe the type of mode switch node (*e.g.* port, inter-model hub, etc.).
	Location	Longtitude, Latitude, City, Country, Region.
	Supply chain Activities	Activities that take place at this node.
CUSTOMER	Customer Name	Unique, descriptive name of a specific customer.
	Parent Company Name	Relates to a high level customer (parent company).
	Customer Type	Describe type of customer (*e.g.* intermediate, strategic, *etc.*).
	Location	Longtitude, Latitude, City, Country, Region.
	Customer Demand	Demand of each customer for final product.
	Supply chain Activities	Activities that take place at this node.
SUPPLY CHAIN ARC	Product Name	Product name moved on this arc.
	Transported volume	Total volume moved on this arc.
	Service Provider	Relates to name of service provider (*e.g.* Tanker Services, KN).
	Distance	Distance of this link.
	Origin Facility Name	Relates to the node of origin.
	Destination Facility Name	Relates to the node of destination.
	Transport Mode	Mode of transportation (*e.g.* road, rail, pipeline, barge, ship).
	Parcel Format	Product format (*e.g.* dry bulk, packaged goods, gasses, *etc.*).

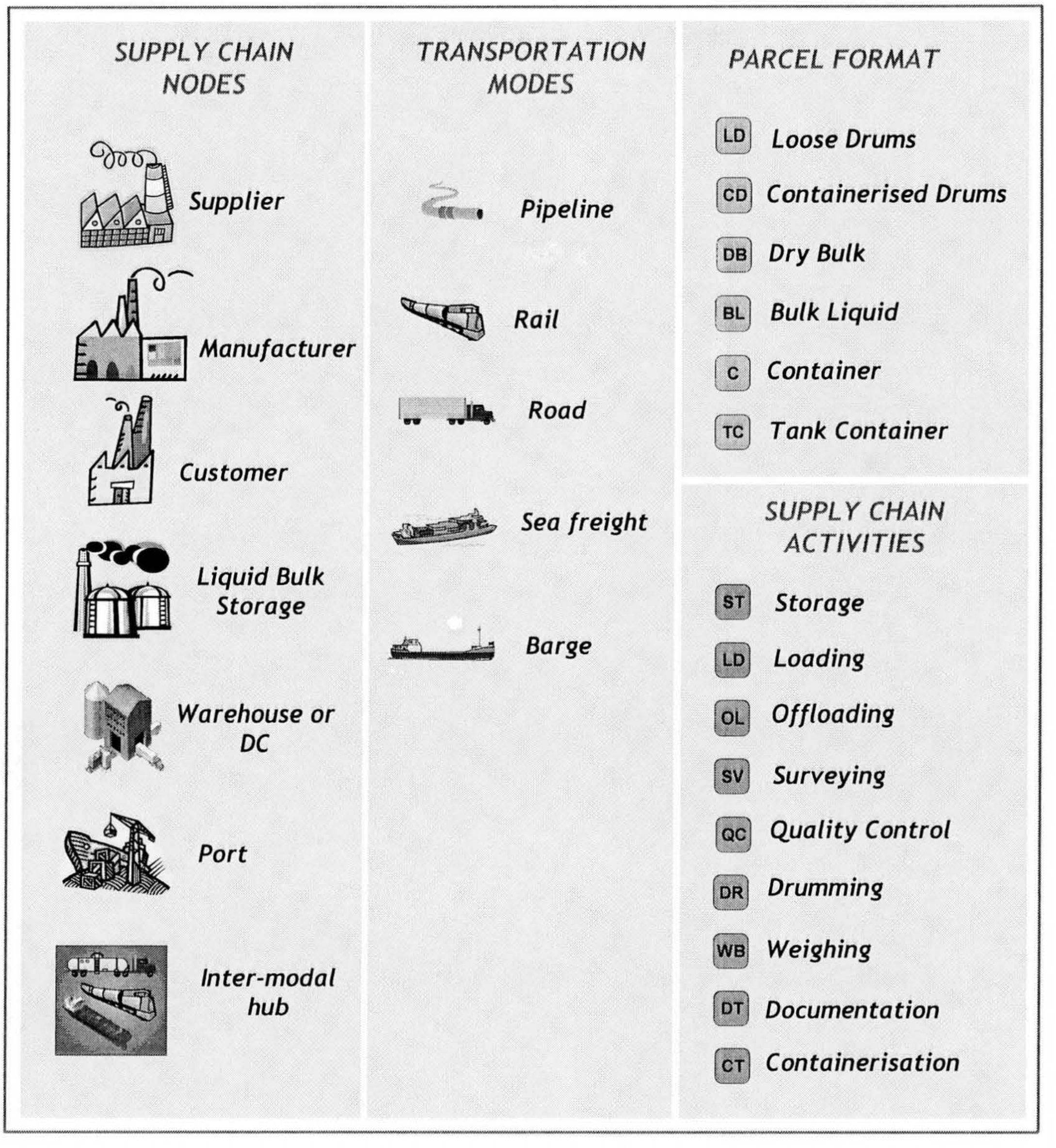

Figure 31: Supply chain schematic pictures and symbols

7.6 SCOR process modelling requirements

SCOR process modelling involves the mapping of the firm's supply chain processes and how they involve different functional areas within and between supply chain organisations. It encompasses an array of different functional processes, like planning, reverse logistics, sourcing, manufacturing and distribution. The SCOR framework provides for a process taxonomy that enables a shared supply chain language among different supply chains and businesses.

7.6.1 SCOR process modelling problem description

The key motivation for applying SCOR process modelling is to enable a shared understanding of supply chain business processes among partners of the supply chain. It provides for the clear definition of roles and responsibilities, communication structures, and assistance in identifying opportunities for integration and standardisation. It further helps to define KPIs for the different business processes while keeping the holistic objective of the entire supply chain in mind, and enable benchmarking with other supply chains.

7.6.2 SCOR process modelling data fundamentals

The SCOR framework allows for process modelling on different levels of decomposition. For the purpose of this research, the focus will be limited to SCOR Level 1 and Level 2 process elements. A Level 1 process model provides the holistic picture of the supply chain with the use of "process types" elements (see the 5 process types in *Figure 32*). Level 2 is the configuration level, where "process category" elements are used for modelling (see the 30 process categories in *Figure 33*).

Apart from mapping processes with SCOR modelling constructs, it is usually accompanied by a geographical mapping of the physical flow of products between different nodes in a supply chain. It provides insight by mapping the processes that take place at each of the supply chain locations, as illustrated in *Figure 21*.

[**Source:** Supply Chain Council (2005)]

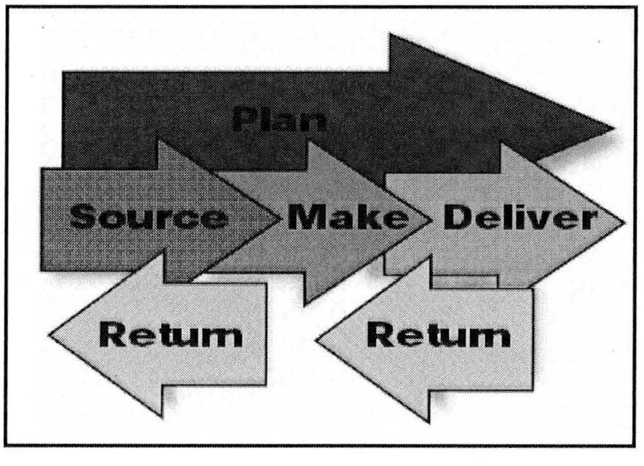

Figure 32: SCOR level 1 process types

[**Source:** Supply Chain Council (2005)]

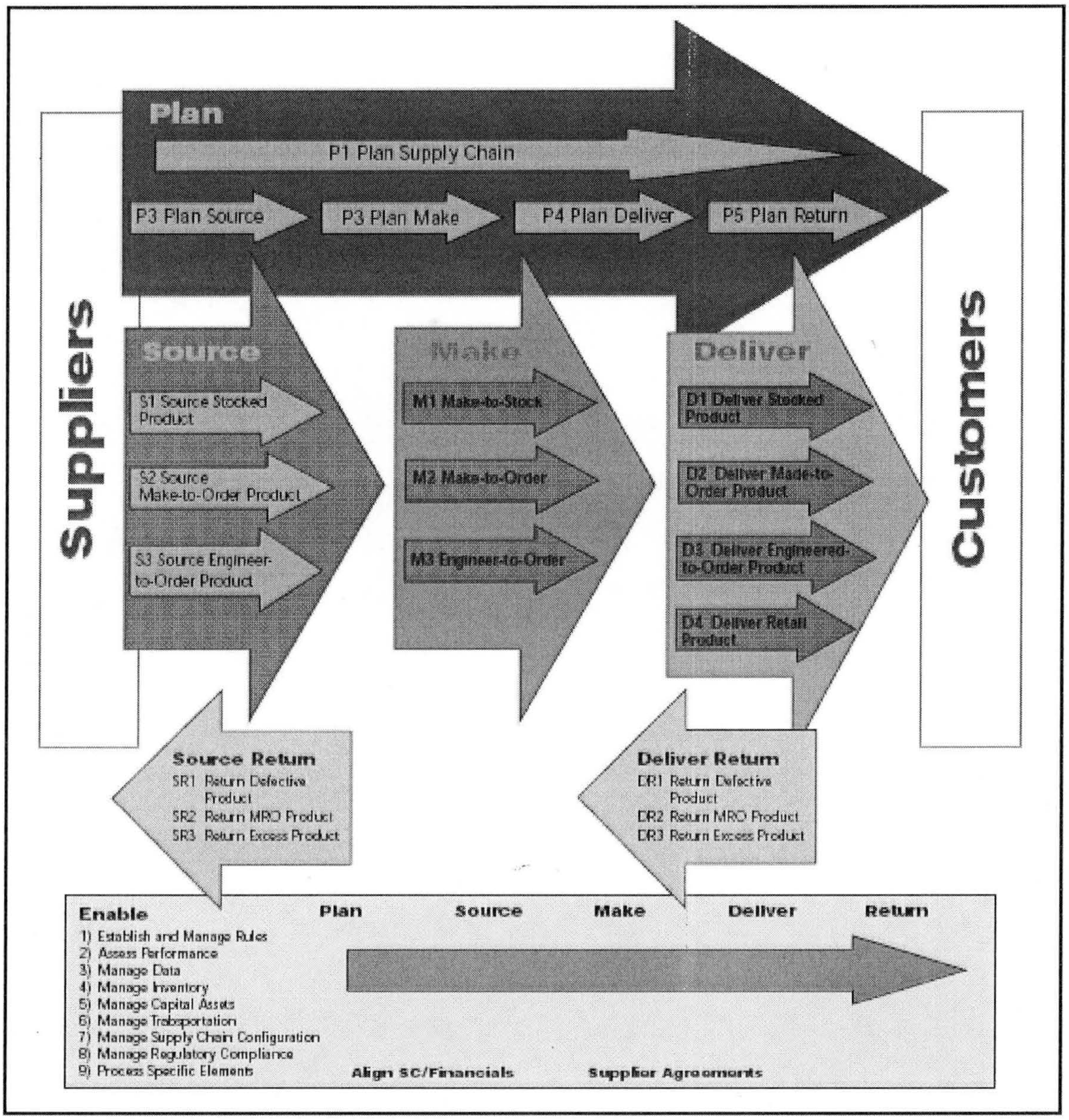

Figure 33: SCOR Level 2 process categories

7.6.3 SCOR process modelling data requirements

A SCOR model is made up of the standard SCOR process blocks described above, combined with supply chain specific descriptions and non-standard blocks. It also includes the geographic structure of the supply chain, that is, supply chain nodes and product flows. The functions responsible for the various processes are also indicated. *Table 15* provides a summary of the data requirements for constructing a SCOR process model. It should be noted that the interaction of supply chain processes should involve an extensive work-shopping with all role-players.

Table 15: SCOR process model data requirements

Supply chain element	Attributes	Description
SUPPLY CHAIN NODE	Supply chain node Name	Unique, descriptive name of a supply chain node (either supplier, manufacturer, distribution, customer).
	Supply chain node type	Type of node (supplier, manufacturer, distribution, storage, customer).
	Location	Longtitude, Latitude, City, Country, Region.
	Supply chain node picture	A picture associated with this node type.
	SCOR processes	The SCOR level 2 supply chain processes that take place at this node. Each process should have an associated function or organisational unit that takes responsibility for this task.
SUPPLY CHAIN ARC	Product Name	Product name moved on this arc.
	Origin Node Name	Relates to the node of origin.
	Destination Node Name	Relates to the node of destination.
	Supply Chain arc type	Type of arc (forward or reverse flow of product).

7.7 Financial modelling requirements

Physical supply chains are paralleled in all firms by financial supply chains involving decisions about capital investments, borrowing, dividends, and other factors under the control of the firms' financial managers (Shapiro 2001:391). The two chains are inextricably linked, especially on the strategic level of planning.

7.7.1 Financial modelling problem description

Optimisation models offer an appealing framework for analysing corporate financial decisions and constraints as well as for integrating them with supply chain decisions and constraints. For this reason, the financial modelling problem is not seen as a separate modelling exercise, but rather as an enhancement of the strategic supply chain network modelling as discussed in chapter 7.

The financial flow model (FFM) of Shapiro (2001: 408) offers an effective integration of supply chain and financial models for one product over multiple periods for a multi-national corporation. The model in words is as follows:

Maximise:

the net present value of earning in each period of the planning horizon in all entities

subject to the following constraints[20]:

- demand constraints;
- manufacturing sourcing constraints;
- inventory balance equations;
- supply revenue constraints (min, max);
- royalty (trademark, patent and know-how) constraints (min,max);
- income equations;
- retained earnings balance equations;
- changes in working capital;
- interest rate constraints (min,max);
- debt/equity constraints;
- minimum dividend requirements;
- minimum earnings constraints;
- minimum taxes paid constraints; and
- tax credit equations.

These objectives and constraints are integrated with the supply chain network model constraints (as set out in paragraph 7.1). The key control variables in the integrated model are:

- primary component of transfer prices;
- royalties (trademark, patent and know-how) rates;
- dividends;
- loan quantities;
- loan interest rates; and
- product flows.

---

[20] Note that these constraints only refer to the financial model, and not the physical supply chain network model as described in chapter 7.

7.7.2 Financial modelling data fundamentals

Since the financial model makes use of the same mathematical modelling technique as discussed in the 7.1.2, the discussion will not be repeated here. It is only necessary to mention the three types of information needed for each legal entity in each country to be modelled, which includes product-, financial- and tax information. More detail will follow in paragraph 7.8.3.

7.7.3 Financial modelling data requirements

Table 16 includes the information required to build a complete financial flow model. This information is needed for each legal entity in each country included in the model. Please note that only the additional information required will be mentioned here, it needs to be integrated with the data requirements for the network model in paragraph 7.1.3.

Table 16: Financial model data requirements

	Element	Description
PRODUCT	Manufacturing cost	Manufacturing cost to produce intermediate product.
	Customer Demand	Demand of each customer node for final product.
	Affiliate Demand	Demand of each affiliate node for product.
	Distribution Cost	Cost of distributing one unit on a supply chain arc.
	Intermediate product Selling Price	The price at which one node sells product to another (affiliate).
	Final product Selling Price	The price at which any node sells final product to customer.
	Marketing & Sales cost	Marketing and sales cost for marketing final product to customer.
FINANCIAL	Inventory ratio to sales	Requirement for min max ratio between inventory and sales.
	Trade receivables ratio to sales	Requirement for min max ratio between trade receivables and sales for affiliates and third parties.
	Current liabilities ratio to cost of goods manufactured	Requirement for min max ratio between current liabilities and cost of goods manufactured (payable to affiliates, third parties and other payables).
	Cash and return on investments	Required rate of return for investments.
	Cost of debt financing	Interest rates for debt at affiliates and third parties.
	Initial equity accounts	Initial equity accounts for capital stock and retained earnings.
	Debt to equity constraints	Requirement for min max ratio between debt and equity.
	Cross-border financial flow constraints	Restrictions on flow of money between entities due to government regulations or exchange controls.
	Initial cash and investment balances	Initial cash and investment balances (at start of planning horizon).
	Initial debt obligations	Initial debt obligations (at start of planning horizon).
	Component supply price	Min max constraints for supply price of primary components.
TAX	Local income tax rate	Tax rate at the country of the supply chain node.
	Import taxes and duties	Tax rate to import to the country of the supply chain node.
	Export taxes and duties	Tax rate for exporting from the country of the supply chain node.
	Minimum entity profitability	Minimum profitability (profit) for a supply chain node.
	Local withholding tax rates	Local withholding tax rates on dividends, royalties, and interest payments between pairs of entities.

7.8 Forecasting modelling requirements

Marketing science has evolved as a discipline that is primarily concerned with maximising sales of the firm's products. It is often ignorant to the implications that changes in demand patterns can have on the harmony of the supply chain. For this reason it has become crucial to include demand planning and supply chain planning in an integrated approach.

Marketing models are concerned with constructing descriptive models that forecast or otherwise project future demand for finished products, ideally as functions of marketing and sales decisions. This research will focus on some of the forecasting techniques available to model future demand.

7.8.1 Forecasting modelling problem description

Statistical forecasting incorporates information on the history of a product/item in the forecasting process for future figures. This research will focus on ***time-series analysis***, which assumes that demand follows a specific pattern. Therefore, the task of the forecasting method is to estimate the pattern from the history of observations. The most common demand patterns include 1) level demand, 2) trended demand, and 3) seasonal demand.

Demand can be forecasted on various levels of abstraction, that is, a forecast can be created per product for global sales, or alternatively split between regions, customers or other groupings. Similarly, forecasts are created for different time horizons, be it yearly, quarterly, monthly, weekly.

7.8.2 Forecasting modelling data fundamentals

The time-series forecasting techniques that this research is concerned with, are relatively simple in that they make use of historic demand or sales and project future values based on some mathematical equations.

For illustration a simple moving average example can be discussed in the strategic supply chain context. The forecasts are input for the supply chain network model that was discussed in paragraph 7.1, and is typical in the same time horizon for planning. Thus, if the network model will optimise the network for the next year, a yearly demand figure would be required from the forecasting model. Say, for example, that a supply chain concerns sales of a product X to global customers. From history, the sales figures for product X per customer are available for the past 3 years (*Figure 34*). Choosing N as 3 years, moving average theory states that the following year's forecast will be the average of the last N observations (in our case N=3). Similarly, the expected sales for the period here after can also be forecast with the last 3 observations (see *Figure 34*). Note that the choice of forecasting technique will depend on the trend in the historic sales data.

YEAR	ACTUAL SALES	FORECASTED SALES
-5	60	---
-4	55	---
-3	65	---
-2	70	---
-1	50	---
1	62	62
2	61	61
3	57	57

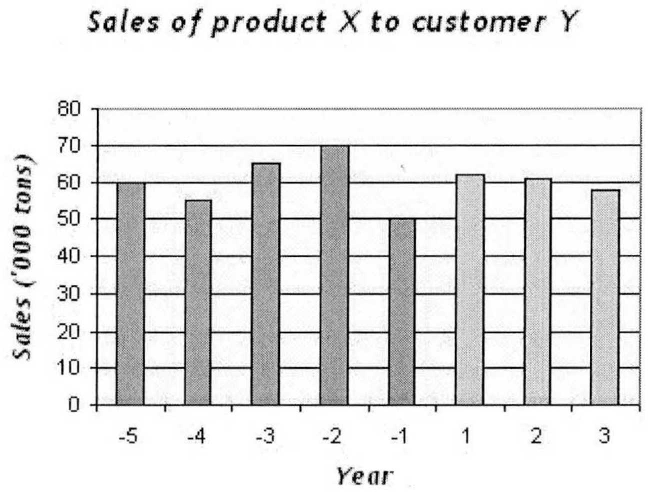

Figure 34: Sales forecast

7.8.3 Forecasting modelling data requirements

The data requirements for forecasting models are relatively simple, and basically involves the demand patterns per product per customer (or customer group) per period. Since this study is concerned with strategic supply chain planning, the time horizon is usually in years. *Table 17* summarises the data requirements for strategic demand forecasting models.

Table 17: Forecasting model data requirements

Element	Description
Customer Name	Unique, descriptive name of a specific customer.
Parent Company Name	Relates to a high level customer (parent company).
Customer Type	Describe type of customer (*e.g.* intermediate, strategic, *etc.*).
Location	Longtitude, Latitude, City, Country, Region.
Product Name	Product X delivered to this customer.
Historic demand	Historic yearly sales of product X to this customer. As many historic years as possible (minimum 1 year).
Supply Chain Name	Relates to a specific supply chain.

7.9 Strategic supply chain data requirements analysis

Now that the requirements for each of the strategic supply chain modelling techniques have been established, an analysis of these requirements follows. It is evident that a great number of the data elements are common for different modelling techniques. Consistent with the supply chain decision database concept discussed in paragraph 6.4.2, it is intended to establish the appropriate data requirements for a shared supply chain data repository. This involves a matrix formulation of all requirements discussed before, followed by an analytical approach to decide which data elements are sufficiently overlapping to include in the data repository.

7.9.1 Supply chain data matrix

A high-level data matrix is formulated in *Table 18* by combining all of the previous data requirements, and mapping applicability to the different modelling techniques. The data in this table was grouped for ease of understanding, based on the detailed requirements in the previous paragraphs.

Legend for Table 18:

Models	
1	Network Modelling
2	Site Location (AHP)
3	Performance Evaluation (AHP)
4	Discrete event simulation
5	GIS
6	Supply chain schematic
7	SCOR
8	Financial Modelling
9	Forecasting

Colour Mapping	
2	Required
1	Optional
0	Not required

Table 18: Supply chain data matrix

Data Element	Description	Models								
		1	2	3	4	5	6	7	8	9
General Supply Chain										
Supply Chain Name	Unique name for the supply chain.	2	2	2	2	2	2	2	2	2
Company / Business Unit	Company / Business Unit.	2	2	2	2	2	2	2	2	2
Product	Specific product applicable.	2	2	2	2	2	2	2	2	2
Supply Chain Structure										
NODES	Details of all supply chain nodes.									
Manufacturing Facilities	Name & location of manufacturing facilities.	2	2	1	2	2	2	2	1	0
Storage Facilities	Name & location of storage facilities.	2	2	1	2	2	2	2	1	0
Distribution Facilities	Name & location of distribution facilities.	2	2	1	2	2	2	2	1	0
Suppliers	Name & location of suppliers.	2	2	1	2	2	2	2	1	0
Customers	Name & location of customers.	2	2	1	2	2	2	2	1	2
Inter-modal Nodes	Name & location of inter-modal nodes.	2	2	1	2	2	2	2	1	0
ARCS	Detail of supply chain arcs per transport mode & transportation format.									
Supplier Arcs	Arcs between supplier and manufacturing nodes	2	2	1	2	2	2	2	1	0
Inter-facility Arcs	Arcs between facilities.	2	2	1	2	2	2	2	1	0
Customer Arcs	Arcs between facilities & customers.	2	2	1	2	2	2	2	1	0
Supply Chain Activities / Processes										
LOGISTICS ACTIVITIES	Detail of logistics activities and process per node.									
Manufacturing	Detail of manufacturing processes.	0	0	1	2	0	2	2	0	0
Storage	Detail of storage processes.	0	0	1	2	0	2	2	0	0
Loading	Detail of loading processes.	0	0	1	2	0	2	2	0	0
Offloading	Detail of offloading processes.	0	0	1	2	0	2	2	0	0
Surveying	Detail of surveying processes.	0	0	1	2	0	2	2	0	0
Quality Control	Detail of quality control processes.	0	0	1	2	0	2	2	0	0
Drumming	Detail of drumming processes.	0	0	1	2	0	2	2	0	0
Containerisation	Detail of containerisation processes.	0	0	1	2	0	2	2	0	0
Weighing	Detail of weighing processes.	0	0	1	2	0	2	2	0	0
Documentation	Detail of documentation processes.	0	0	1	2	0	2	2	0	0
SCOR PROCESSES	Detail of SCOR level 1 & 2 processes per node.									
Plan	Plan processes.	0	0	2	1	0	1	2	0	0
Source	Source processes.	0	0	2	1	0	1	2	0	0
Make	Make processes.	0	0	2	1	0	1	2	0	0
Deliver	Deliver processes.	0	0	2	1	0	1	2	0	0
Return	Return processes.	0	0	2	1	0	1	2	0	0
SCOR METRICS	Detail of SCOR metrics.									
Delivery Reliability	Metrics applicable to delivery reliability.	0	1	2	1	0	0	2	0	0
Responsiveness&Flexibility	Metrics applicable to responsiveness & flexibility	0	1	2	1	0	0	2	0	0
Cost	Metrics applicable to cost.	0	1	2	1	0	0	2	0	0
Assets	Metrics applicable to assets.	0	1	2	1	0	0	2	0	0
PROCESS TIMES	Detail on the time it takes for activities/processes.									
Process Times	Time it takes per activity.	0	0	1	2	0	0	1	0	0
Transportation Format										
Loose Drums	Product transported in loose drums.	1	0	0	2	1	2	1	0	0
Containerised Drums	Product transported containerised drums.	1	0	0	2	1	2	1	0	0
Dry Bulk	Product transported in dry bulk.	1	0	0	2	1	2	1	0	0
Dry Packaged Goods	Product transported as dry packaged goods.	1	0	0	2	1	2	1	0	0
Bulk Liquid	Product transported as bulk liquid.	1	0	0	2	1	2	1	0	0
Container	Product transported in containers.	1	0	0	2	1	2	1	0	0
Tank Container	Product transported in tank containers.	1	0	0	2	1	2	1	0	0

Supply chain data matrix (...continued)

Data Element	Description	Models								
		1	2	3	4	5	6	7	8	9
Logistics Service Providers										
ARCS	Service providers & internal capabilities per arc.									
Road	Detail on road service providers.	2	1	1	2	2	1	2	0	0
Rail	Detail on rail service providers.	2	1	1	2	2	1	2	0	0
Marine	Detail on marine service providers.	2	1	1	2	2	1	2	0	0
Barge	Detail on barge service providers.	2	1	1	2	2	1	2	0	0
Pipeline	Detail on pipeline service providers.	2	1	1	2	2	1	2	0	0
NODES	Service providers & internal capabilities per node.									
Supply Chain Activities	Detail on service providers for SC activities.	2	1	1	2	2	1	2	0	0
Supply Chain Capabilities										
NODES	Detail on SC capabilities per node (internal & external).									
Manufacturing Capacity	Detail on manufacturing capacity.	2	2	0	2	2	2	2	2	0
Storage Capacity	Detail on storage capacity.	2	2	0	2	2	2	2	2	0
Distribution Capacity	Detail on distribution capacity.	2	2	0	2	2	2	2	2	0
Supply Capacity	Detail on supply capacity.	2	2	0	2	2	2	2	2	0
ARCS	Detail on SC capabilities per arc (internal & external).									
Lead Times	Lead times for transportation on SC arcs.	1	1	2	2	0	0	2	0	0
Transportation Capacity	Detail on transportation capacity.	2	2	0	2	2	2	2	2	0
SC ACTIVITIES	Detail on capabilities per activity (internal & external).									
Capacity per SC Activity	Detail on capacity per SC activity.	1	1	0	2	2	0	2	1	0
Product										
Raw Materials	Detail on raw materials applicable to the SC.	2	2	0	2	2	2	2	2	1
Intermediate Products	Detail on intermediate products applicable.	2	2	0	2	2	2	2	2	1
Final Products	Detail on final products applicable to the SC.	2	2	0	2	2	2	2	2	1
Material Balance	Material balances at supply chain nodes.	2	0	0	2	0	0	0	2	0
Product Type	Detail on product type classification.	1	1	0	1	2	1	1	1	1
Product Family	Detail on product family classification.	1	1	0	1	2	1	1	1	1
Countries / Locations										
Political Climate	Detail on political climate per SC node.	0	2	0	0	0	0	0	0	0
Economic Conditions	Detail on economic conditions per SC node.	0	2	0	0	0	0	0	0	0
Business Environment	Detail on business environment per SC node.	0	2	0	0	0	0	0	0	0
Resource Availability	Detail on resource availability per SC node.	0	2	0	0	0	0	0	0	0
Financial & Tax										
FINANCIAL	Financial detail per legal entity & SC affiliate.									
Financial ratio's	Detail on financial ratio's and requirements.	0	0	0	0	0	0	0	2	0
Financial Flow Constraints	Detail on financial flow constraints.	0	0	0	0	0	0	0	2	0
Initial Financial Position	Detail on initial financial position.	0	0	0	0	0	0	0	2	0
Debt to equity Constraints	Detail on debt to equity constraints..	0	0	0	0	0	0	0	2	0
ROI Requirements	Detail on ROI requirements.	0	0	0	0	0	0	0	2	0
Cost of Debt	Detail on cost of debt.	0	0	0	0	0	0	0	2	0
TAX	Tax detail per legal entity & SC affiliate.									
Local Income Tax	Detail on local income tax.	2	2	0	0	0	0	0	2	0
Import and Export Tax	Detail on import & export taxes and duties.	2	2	0	0	0	0	0	2	0
Supply Chain Product Flow										
Sales History	Detail on sales history per customer.	0	2	2	2	2	2	1	0	2
Sales Forecast	Detail on sales forecast per customer.	2	2	1	2	2	2	2	2	2
Flow Design	Detail on SC design of product per arc.	2	2	1	2	2	2	2	2	2

Data Matrix (...continued)

Data Element	Description	Models								
		1	2	3	4	5	6	7	8	9
Supply Chain Triggers & Info										
Arrival & Departure Rates	Detail on arrival & departure rates of transport.	0	0	0	2	0	0	2	0	0
Order Triggers	Detail on triggers for SC processes & orders.	0	0	0	2	0	0	2	0	0
Supply Chain Resources										
People	Detail on internal & external SC resources.	0	0	0	2	0	0	2	0	0
Equipment	Detail on SC equipment reliability.	0	0	0	2	0	0	2	0	0
Up-times	Detail on human and equipment shifts & up-times.	0	0	0	2	0	0	2	0	0
Supply Chain Costs & Income										
Supply Chain Activities	Detail on SC activity costs per activity.	2	2	2	2	2	1	2	2	1
Transportation Cost	Detail on SC transportation costs per arc.	2	2	2	2	2	1	2	2	1
Storage Cost	Detail on storage costs per storage node.	2	2	2	2	2	1	2	2	1
Manufacturing Cost	Detail on manufacturing costs per manuf. node.	2	2	2	2	2	1	2	2	1
Inventory Cost	Detail on inventory costs per node and arc.	2	2	2	2	2	1	2	2	1
Supply Cost	Detail on supply costs per raw material.	2	2	2	2	2	1	2	2	1
Selling Price	Detail on selling price per customer.	2	2	2	2	2	1	2	2	1
Supply Chain Pictures & Symbols										
Nodes	Pictures/symbols for SC nodes.	0	0	0	2	2	2	2	0	0
Modes	Pictures/symbols for SC modes.	0	0	0	2	2	2	2	0	0
Parcel Format	Pictures/symbols for SC parcel format.	0	0	0	2	2	2	1	0	0
Supply Chain Activities	Pictures/symbols for SC activities.	0	0	0	2	2	2	2	0	0

7.9.2 Data analysis

The supply chain data matrix is analytically analysed by assigning a numeric value to each of the colour mappings. *"Required"* data (green blocks) are assigned a value of 2. *"Optional"* data is assigned a value of 1, and data *"not required"* a value of 0.

7.9.2.1 Extent of data needs for various modelling techniques

The extent of data needed for each of the modelling techniques is summarised in *Figure 35*. Values are expressed as percentage of the total possible data, where 100% means that all the data expressed in *Table 18* is required for building the model. From the graph it is evident that SCOR and discrete-event simulation require the most data (85% and 83% respectively). The least data is required for a forecasting model (24%).

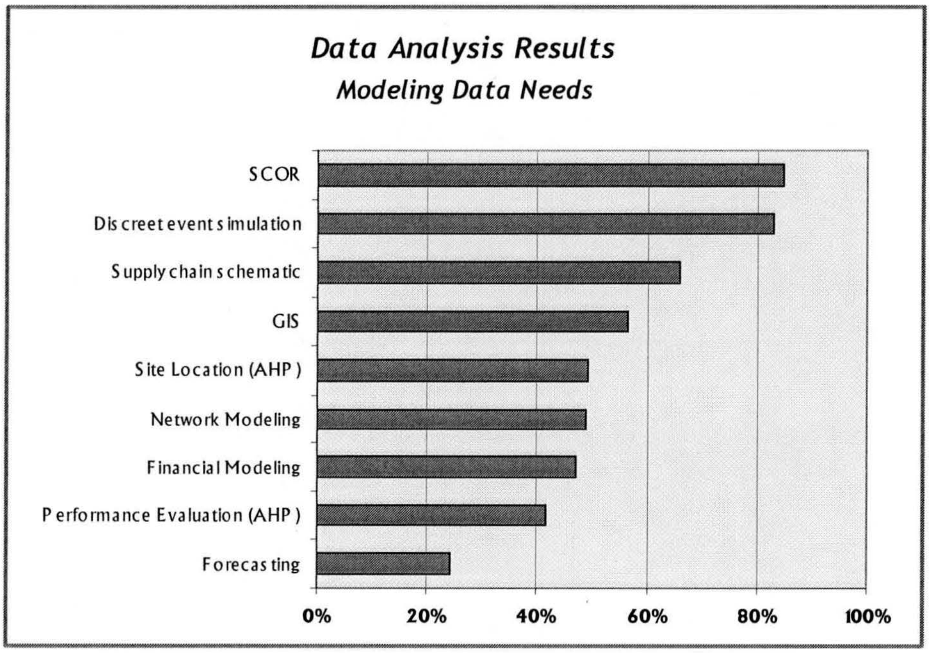

Figure 35: Extent of data needs per modelling technique

7.9.2.2 Data mapping

Next, the extent to which categories of data are applicable to the modelling techniques is considered. Values are expressed as percentage of total possible application, where 100% indicates that these data are required for all 9 modelling techniques. The results are summarised in the graph in *Figure 36*. In this graph, data categories are classified as either red (with common data more than 60%), and blue (with common data less than 60%). These results will be the basis for the supply chain decision database design (following in the next chapter).

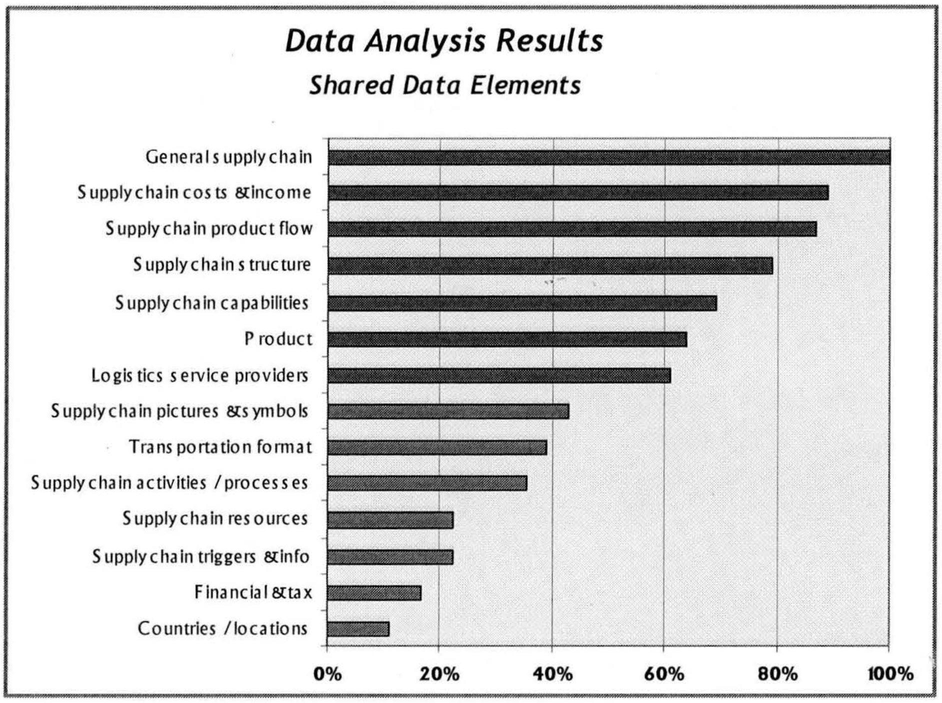

Figure 36: Shared data elements

7.10 Concluding chapter 7

This research is particularly interested in strategic supply chain planning problems, and in this chapter the detailed analytical data requirements for each of the chosen decision-making modelling techniques were examined. This includes mathematical programming of network models, AHP for site selection and performance evaluation, discrete-event simulation models of supply chain strategies, GIS to implement geographical models, schematic models, process models utilising the SCOR methodology, financial models, and forecasting models for demand planning. For each of the techniques, three areas of interest were discussed: 1) the strategic supply chain problem description, 2) the data fundamentals of the particular tool, and 3) the specific data requirements for implementing the supply chain model concerned. An analysis of all these data requirements followed, by mapping the requirements in a data matrix. In this way, the data intensive modelling techniques were identified, as well as the most important shared data categories among the different models. This now forms the basis for the detailed ***supply chain analytical data repository*** (SCADR) specification that will follow in the next chapter.

Chapter 8

The supply chain data and modelling framework

Following the motivation for an integrated approach, this chapter will elaborate on the supply chain data and modelling framework, by discussing all of the elements needed for successful implementation. It builds on the data requirements as discussed and analysed in the previous chapter in order to specify the requirements for the supply chain analytical data repository (SCADR), a database containing the most important and involved data elements needed for the supply chain data and modelling framework.

8.1 Motivation for an integrated approach

Following the detailed discussion of strategic supply chain modelling techniques in chapter 5, as well as an extensive data requirements analysis for each of these techniques in chapter 7, an integrated supply chain data and modelling framework will now be presented.

Perhaps the biggest hurdle in the continual use of modelling techniques that support strategic supply chain decision-making, is the extent of the data gathering phase in any such project. Note the use of the word *"project"*. Supply chain models are usually developed on an *ad hoc* project basis, each time requiring extensive data gathering and analysis from transactional data systems. The reason for this is twofold: 1) transactional data are not configured to meet the analytical data requirements of supply chain models, and 2) projects are often done in isolation, resulting in supply chain data that end up in spreadsheets and point solutions.

This research proposes an integrated framework, that aspire to the sustainable use of supply chain data, and continual use of modelling techniques to support strategic supply chain decision-making. The intent of the framework is twofold: 1) to enable the design of new supply chains, and 2) to ensure a structured approach for capturing historical supply chain activities for continued review and optimisation.

8.2 Overview of the supply chain data and modelling framework

An overview of the supply chain data and modelling framework is presented. It should be noted that the aim of this research is not to develop software tools, but rather to conceptually design an integrated space in which supply chain modelling techniques can compliment each other to support supply chain decision-making. The *"integrated space"* supports the idea of using supply chain data in a sustainable way, versus *ad hoc* analytics and repetitive data gathering. This will enable the use of multiple modelling applications drawing data from the same standarised set of supply chain information, and should promote the continual use of modelling for supply chain decision-support.

Figure 37 illustrates the proposed ***supply chain data and modelling framework***. Structural and managerial supply chain data are manually captured with the ***supply chain modelling editor (SCME)***, which serves as a user interface with the ***supply chain analytical data repository (SCADR)***. Alternatively, historical supply chain data can also be automatically transformed from the organisation's transactional databases and legacy systems. The SCADR is a relational database, and stores all supply chain related data for all supply chains in the organisation. Depending on the supply chain problem at hand, an applicable filter is then applied to extract the relevant data from the SCADR. The extracted data then serve as input for the chosen supply chain modelling analysis.

The forward and backward data integration of the elements in the supply chain data and modelling framework relies on the design of converters and filters to make the different systems and/or applications communicate with each other. Each element of the framework will be discussed at length in the subsequent paragraphs.

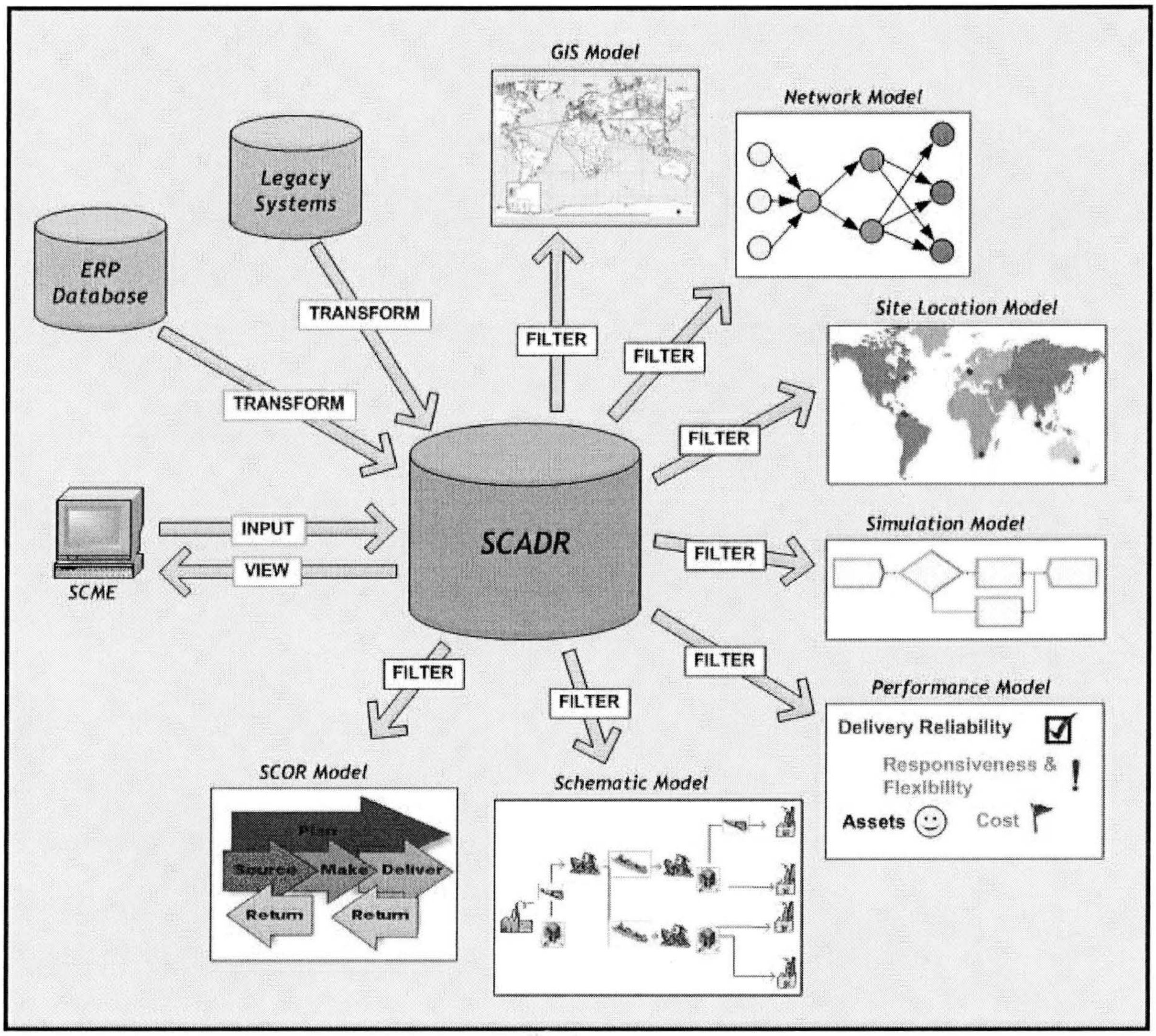

Figure 37: Supply chain data & modelling framework

8.3 Supply chain analytical data repository

At the heart of the framework is the supply chain analytical data repository (SCADR), following from Shapiro's supply chain decision database (SCDD) discussed in paragraph 6.4.2. The SCADR maintains supply chain structural and managerial information in a structured approach. The motivation behind developing a database structure for storing supply chain data is that a standard encoding method encourages data sharing among different applications and analysts. It allows for a supply chain to be analysed by multiple people with multiple models and methodologies.

8.3.1 Relational data modelling

Data modelling is a technique for organising and documenting a system's DATA. The data model is notated in the form of an entity relationship diagram, or ERD, which depicts the data in terms of the entities and relationships described by the data. A few key concepts are explained with the help of Whitten *et al.* (2001):

- An ***entity*** is a class of persons, places, objects, events, or concepts about which we need to capture and store data.
- An ***attribute*** is a descriptive property or characteristic of an entity.
- The ***data type*** for an attribute defines what type of data can be stored in that attribute.
- A ***primary key*** is an attribute, or a group of attributes, that assumes a unique value for each entity instance. An entity instance is a single occurrence of an entity. A ***foreign key*** is a primary key of one entity that is duplicated in another entity to identify instances of a relationship. A foreign key in a child entity always matches the primary key in a parent entity.
- A ***relationship*** is a natural business association that exists between one or more entities. The relationship may represent an event that links the entities or merely a logical affinity that exists between the entities.
- ***Normalisation*** is a data analysis technique that organises data attributes such that they are grouped to form non-redundant, stable, flexible, and adaptive entities. This normally requires a few additional tables (entities) to avoid redundancy.

8.3.2 The SCADR Data Model

The most important data requirements from paragraph 7.9 are included in the data model. This includes data categories with significant overlap from the data analysis of paragraph 7.9.2, which are:

- supply chain activities / processes;
- transportation format;
- supply chain pictures & symbols;
- logistics service providers;
- product;
- supply chain capabilities;
- supply chain structure;
- supply chain product flow;

- supply chain costs & income; and
- general supply chain.

For each of these categories, the detail data requirements (as listed in the data matrix in *Table 18*) are implied.

The entity relationship diagram (ERD) for the SCADR is illustrated in *Figure 38*. The ERD shows the relationships between entities in the normalised database structure. Normalisation tables are used to ensure referential integrity, and to avoid data duplication and redundancy. An example of a normalised entity is the table "Supply Chain Node", which links a specific "Supply Chain" with a specific "Node", without duplicating data.

Each of the entities illustrated in *Figure 38* is defined in *Table 19*. Logically, the data design includes the following main groups of entities:

- ***products*** – containing the detail of a specific product to be included in a supply chain, including the product type, parent product, and product family;
- ***nodes*** – containing the detail of a specific node to be included in a supply chain, including node type and location (site → city → province/state → country → region);
- ***arcs*** – containing the detail of a directional link on which product flow is to be included, as well as the possible transport mode and transport format;
- ***node processes & activities*** – containing the detail of activities and SCOR processes in a supply chain;
- ***supply chain entities*** – a number of normalised entities are used to define a specific supply chain, including supply chain, supply chain products, supply chain nodes, supply chain arcs, supply chain node capacity, supply chain node activities, supply chain node SCOR processes, and supply chain flows.

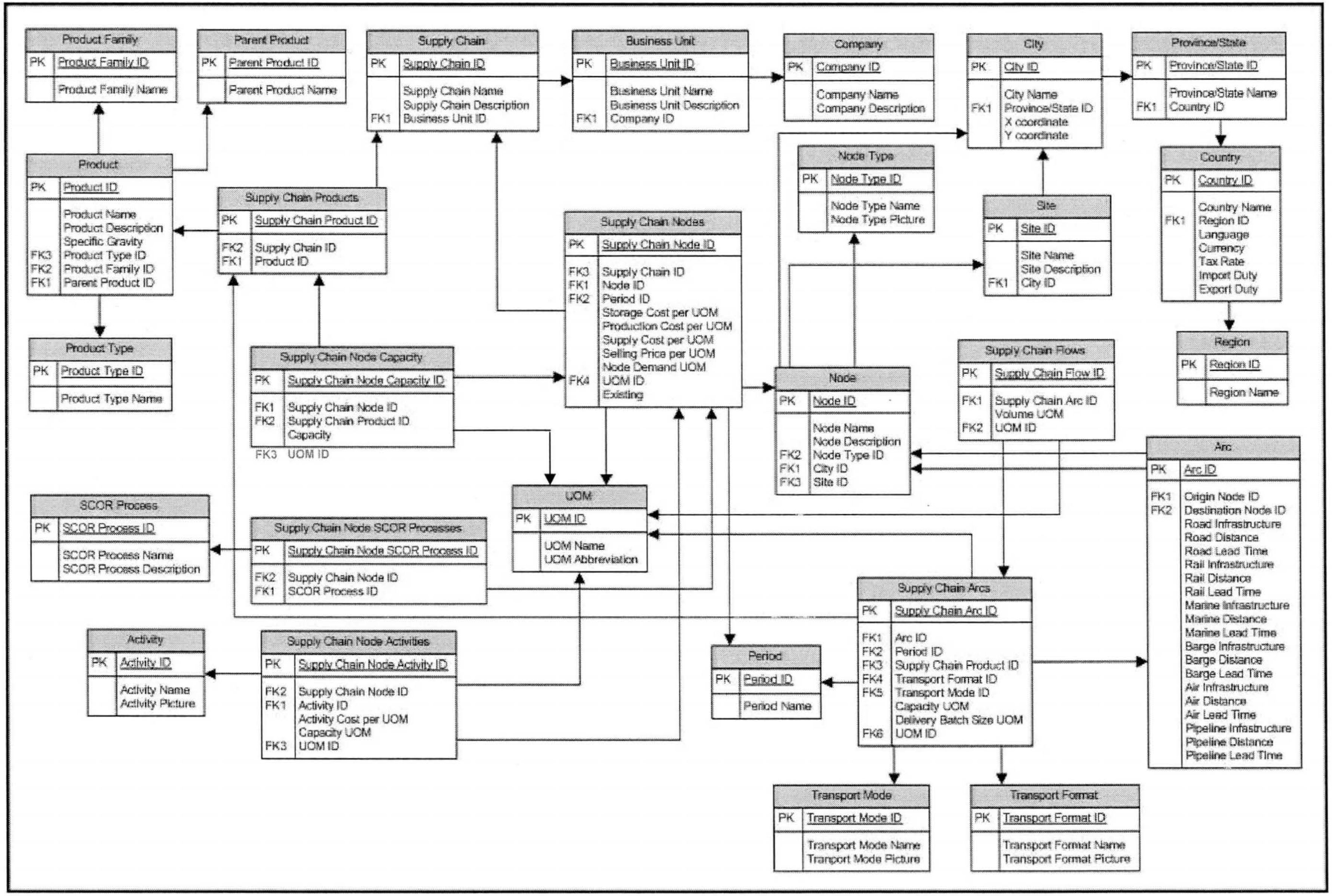

Figure 38: Entity relationship diagram (ERD) for SCADR

Table 19: SCADR list of entities

CATEGORY	ENTITY	DESCRIPTION
SUPPLY CHAIN	Supply Chain	Contains data describing a certain supply chain.
	Business Unit	Contains a list of Business Units and their attributes.
	Company	Contains a list of companies and their attributes One company will have many Business Units.
PRODUCT	Product	Contains data specific to a product. Can be a raw material, intermediate product or final product. A product will have a parent product, which will be part of a product family.
	Product Type	Contains a list of the possible product types: raw material, intermediate product or final product.
	Product Family	Contains data related to a product family, which is the first level of the product hierarchy.
	Parent Product	Contains data related to a parent product, which is the second level of the product hierarchy.
NODE	Node	Contains data related to a supply chain node. A node is specified as a specific type, i.e. supplier, storage facility, production facility, inter-modal facility or customer.
	Node Type	Contains a list of possible node types: supplier, storage facility, production facility, inter-modal facility, customer.
LOCATION	Site	Contains data specific to a site. A site might have multiple supply chain nodes, like storage facilities, multiple production facilities, etc.
	City	Contains data related to a specific city. A city will be part of a province / state, which forms part of a country, which forms part of a region.
	Province/State	Contains data related to a specific province or state.
	Country	Contains data related to a country, including tax and duty information.
	Region	Contains data related to a specific region.
ARC	Arc	Contains data related to a supply chain arc, which links two supply chain nodes together. Information includes the logistics infrastructure available on this link, with travelling lead time.
	Transport Mode	Contains a list of possible transport modes: road, rail, air, barge, marine, pipeline.
	Transport Format	Contains a list of possible transport formats: dry bulk, liquid bulk, drummed products, etc.
OTHER	UOM	Contains a list of Unit of Measures: cubic metre, litres, kilograms, etc.
	Activity	Contains a list of the supply chain node activities: manufacturing, weighing, storing, drumming, etc.
	SCOR Process	Contains a list of the SCOR processes: plan, source, make, deliver, return, enable, etc.
	Period	Contains data related to a specific period. This is used to differentiate the same supply chain in different periods.
SUPPLY CHAIN SPECIFIC	Supply Chain Products	Relates a specific supply chain with specific products in a specific period.
	Supply Chain Nodes	Relates a specific supply chain with specific nodes in a specific period.
	Supply Chain Node Capacity	Contains data regarding the capacity of specific products at specific nodes.
	Supply Chain Node Activities	Relates a specific supply chain node to specific activities.
	Supply Chain Node SCOR Processes	Relates a specific supply chain node to specific SCOR processes.
	Supply Chain Arcs	Relates a specific supply chain to a specific arc in a specific period.
	Supply Chain Flows	Contains the product volume that flowed on a specific supply chain arc.

8.3.3 Data dictionary

The detailed attributes for each of the entities of the SCADR are defined in *Table 20*. It includes a description of the attribute, the data type of the attribute and whether the attribute is a primary or foreign key.

Table 20: SCADR data dictionary

ENTITY	ATTRIBUTE	DESCRIPTION	DATA TYPE	KEY
Activity				
	Activity ID	Unique identifier for an activity.	Long Integer	PK
	Activity Name	Name of activity.	Text	
	Activity Picture	Picture associated with activity.	OLE Object	
Arc				
	Arc ID	Unique identifier for a directional arc.	Long Integer	PK
	Origin Node ID	Node ID of node of origin.	Long Integer	FK
	Destination Node ID	Node ID of node of destination.	Long Integer	FK
	Road Infrastructure	Does road infrastructure exist in this arc?	Yes/No	
	Road Distance	Road distance of arc.	Long Integer	
	Road Lead Time	Lead time of transportation on this arc by road.	Long Integer	
	Rail Infrastructure	Does rail infrastructure exist in this arc?	Yes/No	
	Rail Distance	Rail distance of arc.	Long Integer	
	Rail Lead Time	Lead time of transportation on this arc by rail.	Long Integer	
	Marine Infrastructure	Does marine infrastructure exist in this arc?	Yes/No	
	Marine Distance	Marine distance of arc.	Long Integer	
	Marine Lead Time	Lead time of transportation on this arc by marine.	Long Integer	
	Barge Infrastructure	Does barge infrastructure exist in this arc?	Yes/No	
	Barge Distance	Barge distance of arc.	Long Integer	
	Barge Lead Time	Lead time of transportation on this arc by barge.	Long Integer	
	Air Infrastructure	Does air infrastructure exist in this arc?	Yes/No	
	Air Distance	Air distance of arc.	Long Integer	
	Air Lead Time	Lead time of transportation on this arc by air.	Long Integer	
	Pipeline Infrastructure	Does pipeline infrastructure exist in this arc?	Yes/No	
	Pipeline Distance	Pipeline distance of arc.	Long Integer	
	Pipeline Lead Time	Lead time of transportation on this arc by pipeline.	Long Integer	
Business Unit				
	Business Unit ID	Unique identifier for a business unit.	Long Integer	PK
	Business Unit Name	Name of business unit.	Text	
	Business Unit Description	Description of business unit.	Memo	
	Company ID	ID of company associated with this business unit.	Long Integer	FK

Table 20: SCADR data dictionary (...continued)

ENTITY	ATTRIBUTE	DESCRIPTION	DATA TYPE	KEY
City				
	City ID	Unique identifier for a city.	Long Integer	PK
	City Name	Name of city.	Text	
	Province/State ID	ID of province/state associated with this city.	Long Integer	FK
	X coordinate	X coordinate of city.	Long Integer	
	Y coordinate	Y coordinate of city.	Long Integer	
Company				
	Company ID	Unique identifier for a company.	Long Integer	PK
	Company Name	Name of company.	Text	
	Company Description	Description of company.	Memo	
Country				
	Country ID	Unique identifier for a country.	Long Integer	PK
	Country Name	Name of country.	Text	
	Region ID	ID of region associated with this country.	Long Integer	FK
	Language	Primary language of country.	Text	
	Currency	Currency of country.	Text	
	Tax Rate	Primary tax rate of country.	Decimal	
	Import Duty	Import duty of country.	Decimal	
	Export Duty	Export duty of country.	Decimal	
Node				
	Node ID	Unique identifier for a node.	Long Integer	PK
	Node Name	Name of node.	Text	
	Node Description	Description of node.	Memo	
	Node Type ID	ID of node type associated with this node.	Long Integer	FK
	City ID	ID of city associated with this node.	Long Integer	FK
	Site ID	ID of site associated with this node.	Long Integer	FK
Node Type				
	Node Type ID	Unique identifier for a node type.	Long Integer	PK
	Node Type Name	Name of node type.	Text	
	Node Type Picture	Picture associated with node type.	OLE Object	
Parent Product				
	Parent Product ID	Unique identifier for a parent product.	Long Integer	PK
	Parent Product Name	Name of parent product.	Text	
Period				
	Period ID	Unique identifier for a period.	Long Integer	PK
	Period Name	Name of period.	Text	
Product				
	Product ID	Unique identifier for a product.	Long Integer	PK
	Product Name	Name of product.	Text	
	Product Description	Description of product.	Memo	
	Specific Gravity	Specific gravity of product.	Long Integer	
	Product Type ID	ID of product type associated with this product.	Long Integer	FK
	Product Family ID	ID of product family associated with this product.	Long Integer	FK
	Parent Product ID	ID of parent product associated with this product.	Long Integer	FK

SCADR data dictionary (...continued)

ENTITY	ATTRIBUTE	DESCRIPTION	DATA TYPE	KEY
Product Family				
	Product Family ID	Unique identifier for a product family.	Long Integer	PK
	Product Family Name	Name of product family.	Text	
Product Type				
	Product Type ID	Unique identifier for a product type.	Long Integer	PK
	Product Type Name	Name of product type.	Text	
Province/State				
	Province/State ID	Unique identifier for a province/state.	Long Integer	PK
	Province/State Name	Name of province/state.	Text	
	Country ID	ID of country associated with this province/state.	Long Integer	FK
Region				
	Region ID	Unique identifier for a region.	Long Integer	PK
	Region Name	Name of region.	Text	
SCOR Process				
	SCOR Process ID	Unique identifier for a SCOR process.	Text	PK
	SCOR Process Name	Name of SCOR process.	Text	
	SCOR Process Description	Description of SCOR process.	Memo	
Site				
	Site ID	Unique identifier for a site.	Long Integer	PK
	Site Name	Name of site.	Text	
	Site Description	Description of site.	Memo	
	City ID	ID of city associated with this site.	Long Integer	FK
Supply Chain				
	Supply Chain ID	Unique identifier for a specific supply chain.	Long Integer	PK
	Supply Chain Name	Name of supply chain.	Text	
	Supply Chain Description	Description of supply chain.	Memo	
	Business Unit ID	ID of business unit associated with this supply chain.	Long Integer	FK
Supply Chain Arcs				
	Supply Chain Arc ID	Unique identifier for a specific supply chain arc.	Long Integer	PK
	Arc ID	ID of arc associated with this supply chain arc.	Long Integer	FK
	Period ID	ID of period associated with this supply chain arc.	Long Integer	FK
	Supply Chain Product ID	ID of supply chain product associated with this supply chain arc.	Long Integer	FK
	Transport Format ID	ID of transport format associated with this supply chain arc.	Long Integer	FK
	Transport Mode ID	ID of transport mode associated with this supply chain arc.	Long Integer	FK
	Capacity UOM	Capacity of supply chain arc.	Long Integer	
	Delivery Batch Size UOM	Batch size of deliveries for supply chain arc.	Long Integer	
	UOM ID	ID of UOM associated with capacity & batch size.	Long Integer	FK
Supply Chain Flows				
	Supply Chain Flow ID	Unique identifier for a specific supply chain flow.	Long Integer	PK
	Supply Chain Arc ID	ID of supply chain arc associated with this supply chain flow.	Long Integer	FK
	Volume UOM	Volume flow on this supply chain arc.	Long Integer	
	UOM ID	ID of UOM associated with volume.	Long Integer	FK

SCADR data dictionary (...continued)

ENTITY	ATTRIBUTE	DESCRIPTION	DATA TYPE	KEY
Supply Chain Node Activities				
	Supply Chain Node Activity ID	Unique identifier for a specific supply chain node activity.	Long Integer	PK
	Supply Chain Node ID	ID of supply chain node associated with this supply chain node activity.	Long Integer	FK
	Activity ID	ID of activity associated with this supply chain node activity.	Long Integer	FK
	Activity Cost per UOM	Cost of activity.	Currency	
	Capacity UOM	Capacity of delivering this activity at this node.	Long Integer	
	UOM ID	ID of UOM associated with activity cost & capacity.	Long Integer	FK
Supply Chain Node Capacity				
	Supply Chain Node Capacity ID	Unique identifier for a specific supply chain node capacity.	Long Integer	PK
	Supply Chain Node ID	ID of supply chain node associated with this supply chain node capacity.	Long Integer	FK
	Supply Chain Product ID	ID of supply chain product associated with this supply chain node capacity.	Long Integer	FK
	Capacity	Capacity for the period under review.	Long Integer	
	UOM ID	ID of UOM associated with capacity.	Long Integer	FK
Supply Chain Node SCOR Processes				
	Supply Chain Node SCOR Process ID	Unique identifier for a specific supply chain node SCOR process.	Long Integer	PK
	Supply Chain Node ID	ID of supply chain node associated with this supply chain node SCOR process.	Long Integer	FK
	SCOR Process ID	ID of SCOR process associated with this supply chain node SCOR process.	Text	FK
Supply Chain Nodes				
	Supply Chain Node ID	Unique identifier for a supply chain node.	Long Integer	PK
	Supply Chain ID	ID of supply chain associated with this supply chain node.	Long Integer	FK
	Node ID	ID of node associated with this supply chain node.	Long Integer	FK
	Period ID	ID of period associated with this supply chain node.	Long Integer	FK
	Storage Cost per UOM	Storage cost at supply chain node.	Currency	
	Production Cost per UOM	Production cost at supply chain node.	Currency	
	Supply Cost per UOM	Supply cost at supply chain node.	Currency	
	Selling Price per UOM	Selling price at supply chain node.	Currency	
	Node Demand UOM	Demand at supply chain node.	Long Integer	
	UOM ID	ID of UOM associated with this costs.	Long Integer	FK
	Existing	Is this an existing (vs new) supply chain node?	Yes/No	
Supply Chain Products				
	Supply Chain Product ID	Unique identifier for a supply chain product.	Long Integer	PK
	Supply Chain ID	ID of supply chain associated with this supply chain product.	Long Integer	FK
	Product ID	ID of product associated with this supply chain product.	Long Integer	FK
Transport Format				
	Transport Format ID	Unique identifier for a transport format.	Long Integer	PK
	Transport Format Name	Name of transport format.	Text	
	Transport Format Picture	Picture associated with transport format.	OLE Object	

SCADR data dictionary (...continued)

ENTITY	ATTRIBUTE	DESCRIPTION	DATA TYPE	KEY
Transport Mode				
	Transport Mode ID	Unique identifier for a transport mode.	Long Integer	PK
	Transport Mode Name	Name of transport mode.	Text	
	Tranport Mode Picture	Picture associated with transport mode.	OLE Object	
UOM				
	UOM ID	Unique identifier for a Unit of Measure (UOM).	Long Integer	PK
	UOM Name	Name of UOM.	Text	
	UOM Abbreviation	Abbreviation of UOM.	Text	

The SCADR data model described in this paragraph was successfully implemented and validated with Microsoft Access.

8.4 Supply chain modelling editor

The supply chain modelling editor (SCME) acts as primary interface between the analyst and the SCADR. It provides a user-friendly method to capture structural and managerial supply chain data, which is stored in the correct format in the SCADR for future analysis.

The SCME is an object-orientated application, which aims to make the manual capturing of especially supply chain structural information more effective. This interface will be used to initially set up a supply chain structure, and then to manually enter supply chain flow information if required.

Although the programming and development of the SCME falls outside the scope of this research, the conceptual design is presented. There are 5 "tabs" used for different views to enter various attributes. These are:

- Supply Chain
- Products
- Nodes
- Arcs
- Other

8.4.1 Supply Chain Tab

The *"Supply Chain"* tab is the primary interface and is illustrated in *Figure 39*. The information is entered through building a supply chain schematic model in the SCME interface. A new supply chain is defined by entering the **Supply Chain Name** and **Description**, as well as choosing the relevant **Business Unit** and **Period**. The supply chain structure is then built by using the objects (nodes and arcs) on the right side tabs. These objects are dragged and dropped in the modelling space, after which the attributes of the new objects are defined in the appropriate tabs.

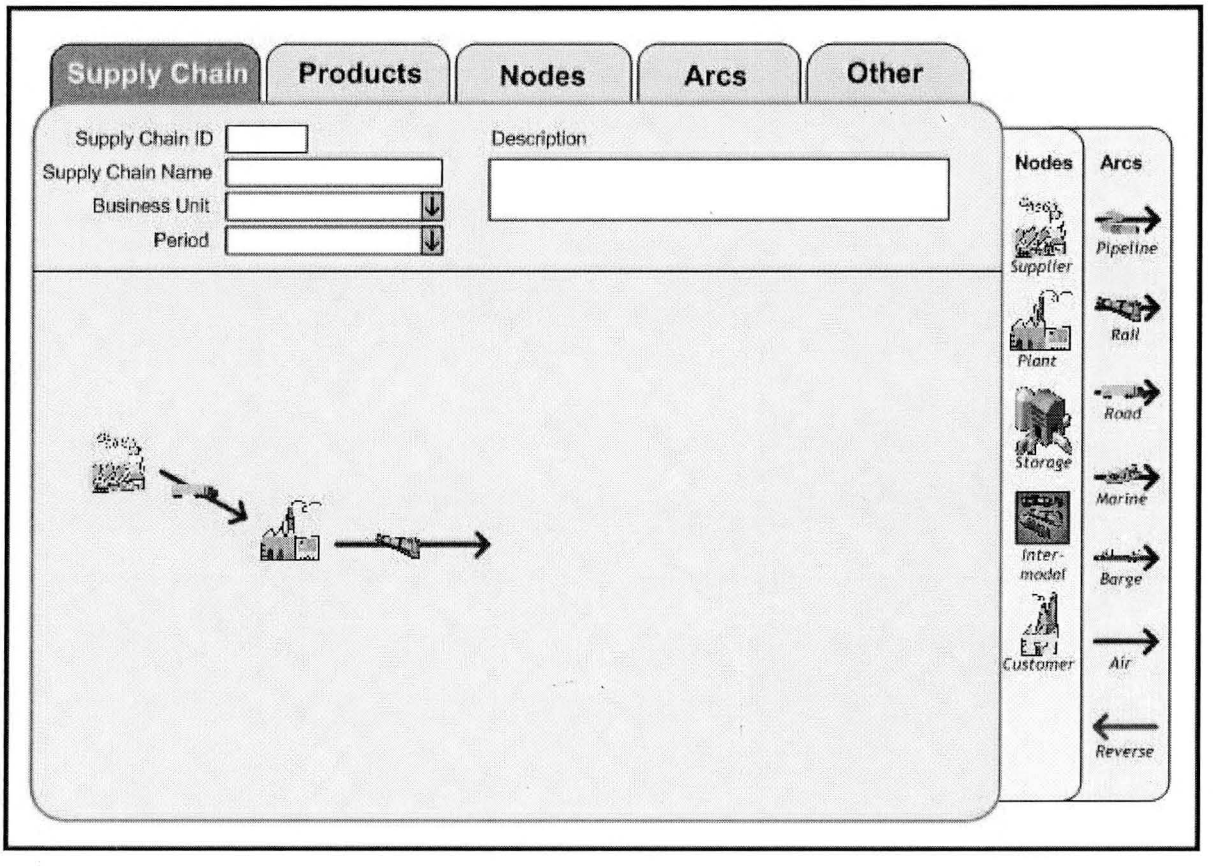

Figure 39: SCME - Supply Chain Tab

8.4.2 Products Tab

The ***"Products"*** tab is used to define the products relevant to this supply chain (*Figure 40*). This includes all products, *i.e.* raw materials, intermediate products and final products. It can be defined by either choosing the products already in the database, or alternatively, by creating a new product. The data entered include **Product Name**, **Product Description**, **Specific Gravity**, as well as choosing the relevant **Product Type**, **Product Family** and **Parent Product**. The relationship between the supply chain entity and the product entity is implied in the data structure in the *"supply chain product"* entity.

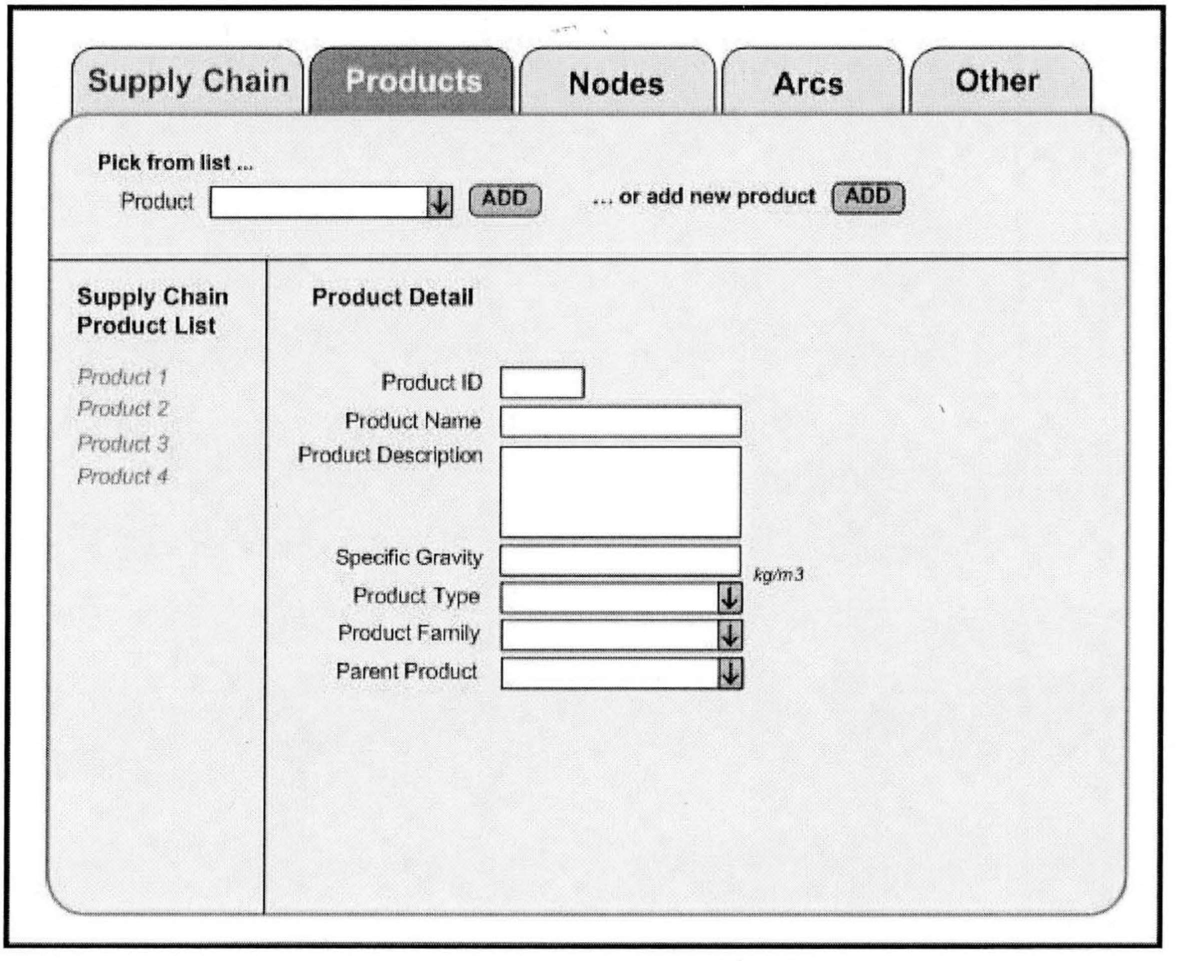

Figure 40: SCME - Products Tab

8.4.3 Nodes Tab

Once the user drags and drops a node in the network design window, he/she has to define the attributes of that node in the ***"Nodes"*** tab (*Figure 41*). It can be defined by either choosing from the nodes already in the database, or alternatively, by creating a new node. The data entered include 5 categories:

- ***Node Detail*** – the detail of the node (not supply chain specific) as illustrated in *Figure 41*, including attributes like Node Name, Node Description, Node Type, City and Site.
- ***Supply Chain Node Detail*** – the detail of the node (specific to this supply chain) as illustrated in *Figure 41*, including attributes like Cost, UOM and specifying whether this node is existing (part of the supply chain), or new (to be considered as potentially part of the supply chain).

- ***Supply Chain Node Activities*** – the activities that take place at this node for this supply chain as illustrated in *Figure 42*, including attributes like Cost and UOM.
- ***Supply Chain Node SCOR processes*** – the SCOR processes that take place at this node for this supply chain as illustrated in *Figure 42*.
- ***Supply Chain Node Capacities*** – the capacities for the different products at this node for this supply chain as illustrated in *Figure 43*.

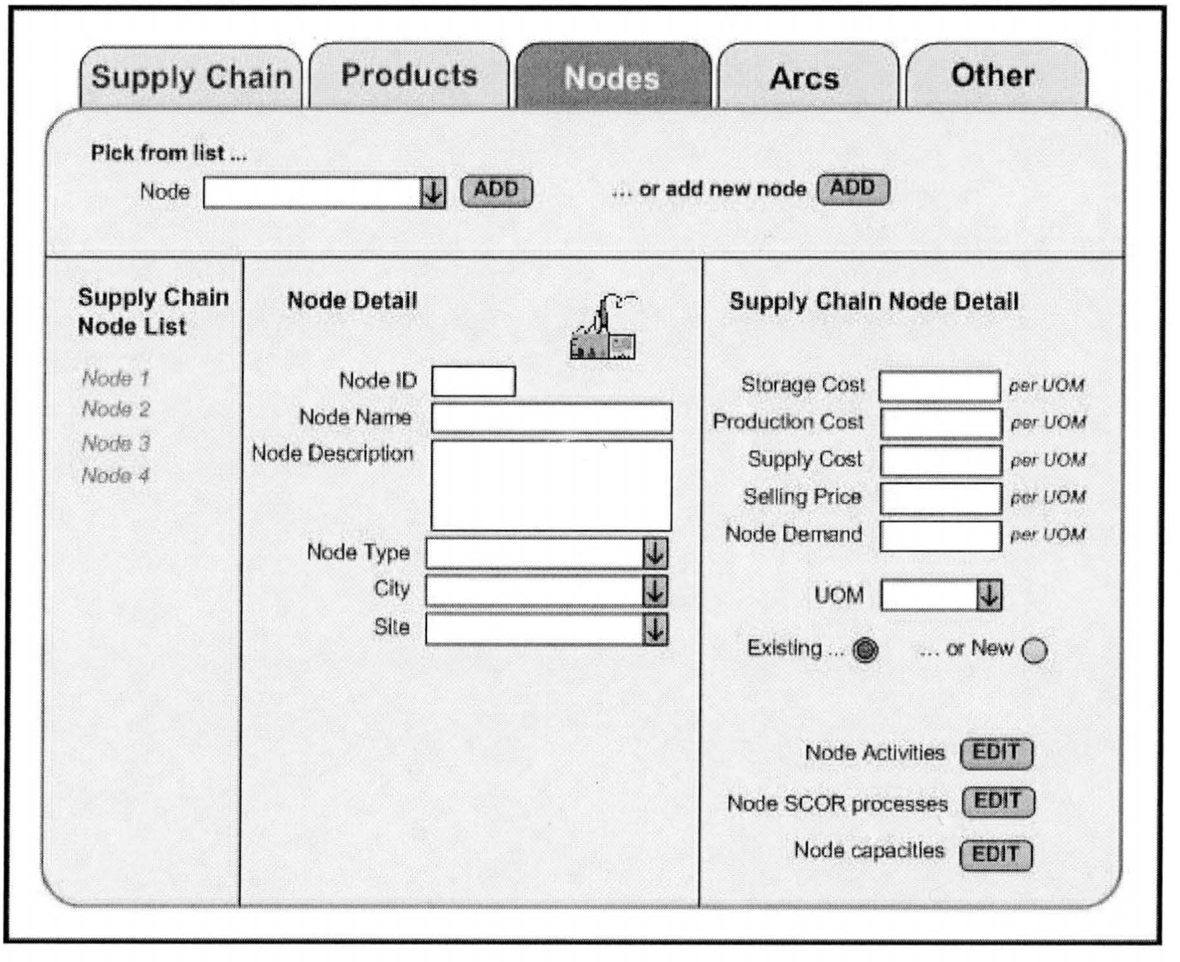

Figure 41: SCME - Nodes Tab (1)

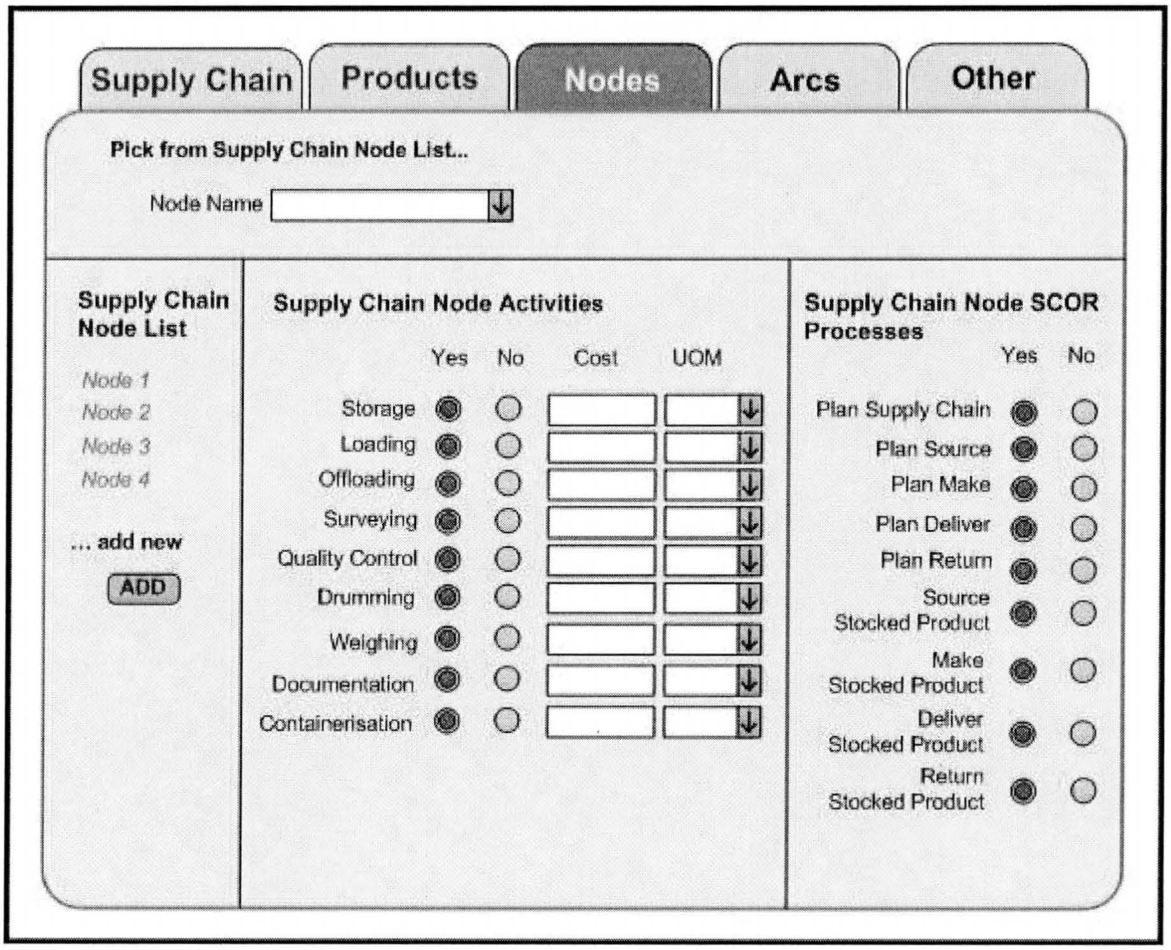

Figure 42: SCME - Nodes Tab (2)

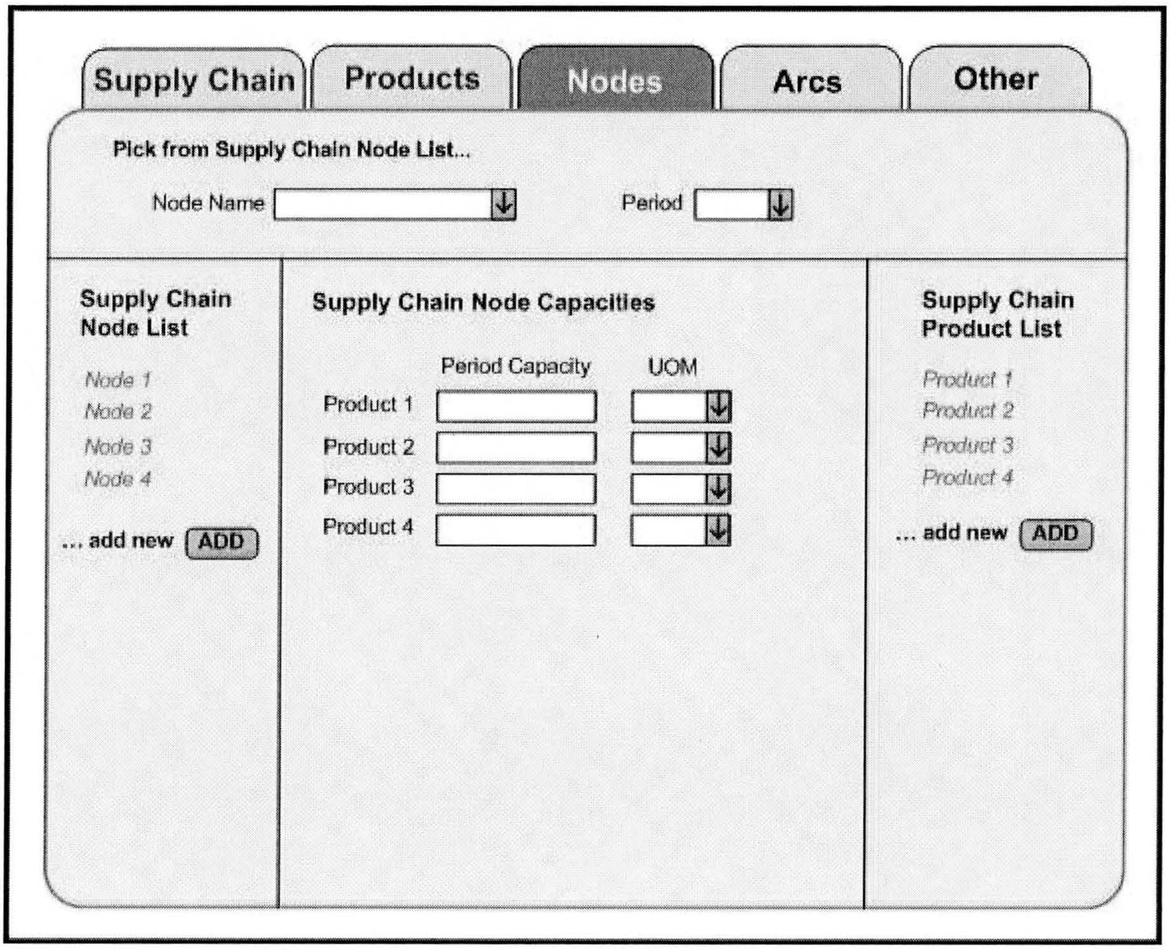

Figure 43: SCME - Nodes Tab (3)

8.4.4 Arcs Tab

Once the user drags and drops an arc in the network design window, he/she has to define the attributes of that arc in the *"Arcs"* tab. This can be done by either choosing from arcs already in the database, or alternatively by creating a new arc. The data entered include 3 categories:

- ***Arc Detail*** – the detail of the arc (not supply chain specific) as illustrated in *Figure 44*, including attributes like Origin Node, Destination Node, and Infrastructure information.
- ***Supply Chain Arc Detail*** – the detail of the arc (specific to this supply chain) as illustrated in *Figure 45*, including attributes like Transport Mode, Transport Format and Capacity.
- ***Supply Chain Arc Flows*** – the flow of material on this arc of this product during this period as illustrated in *Figure 45*.

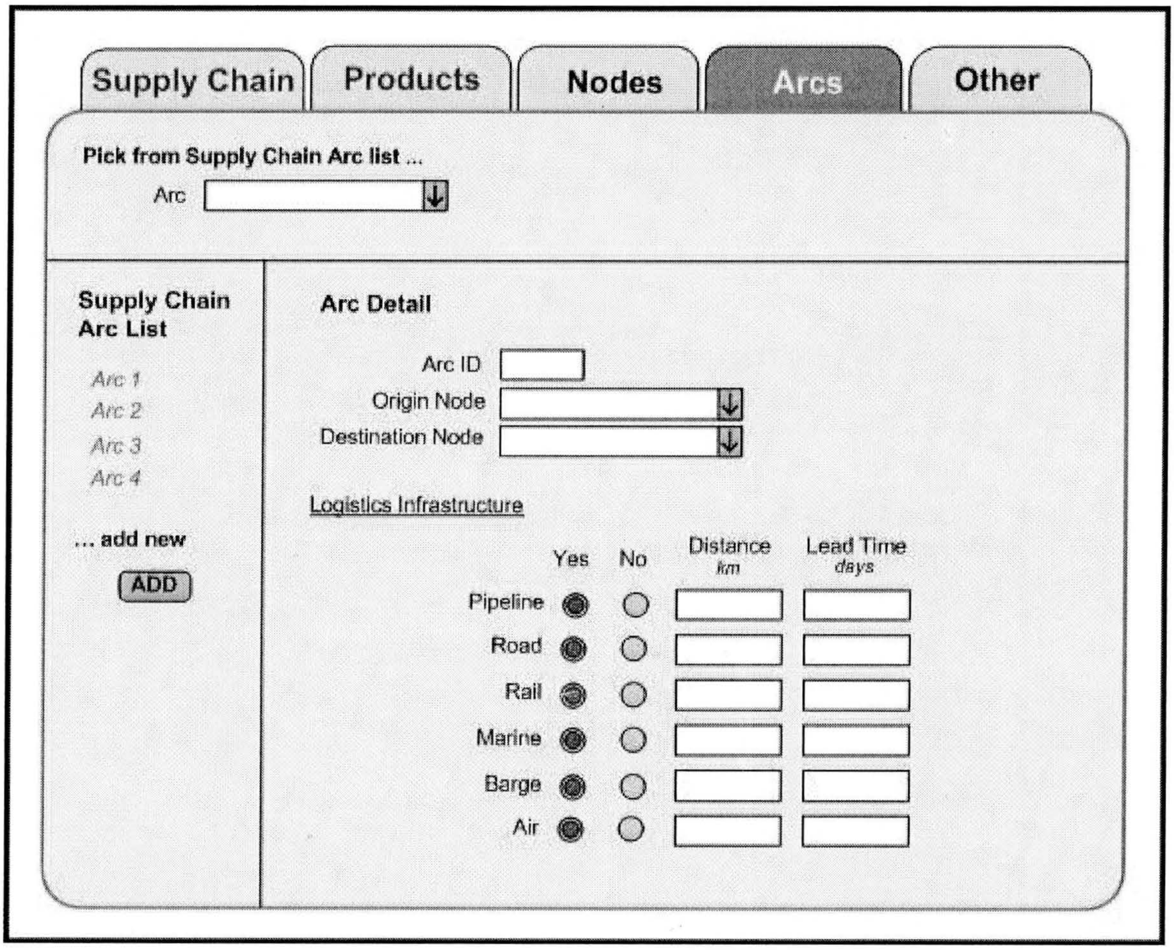

Figure 44: SCME - Arcs Tab (1)

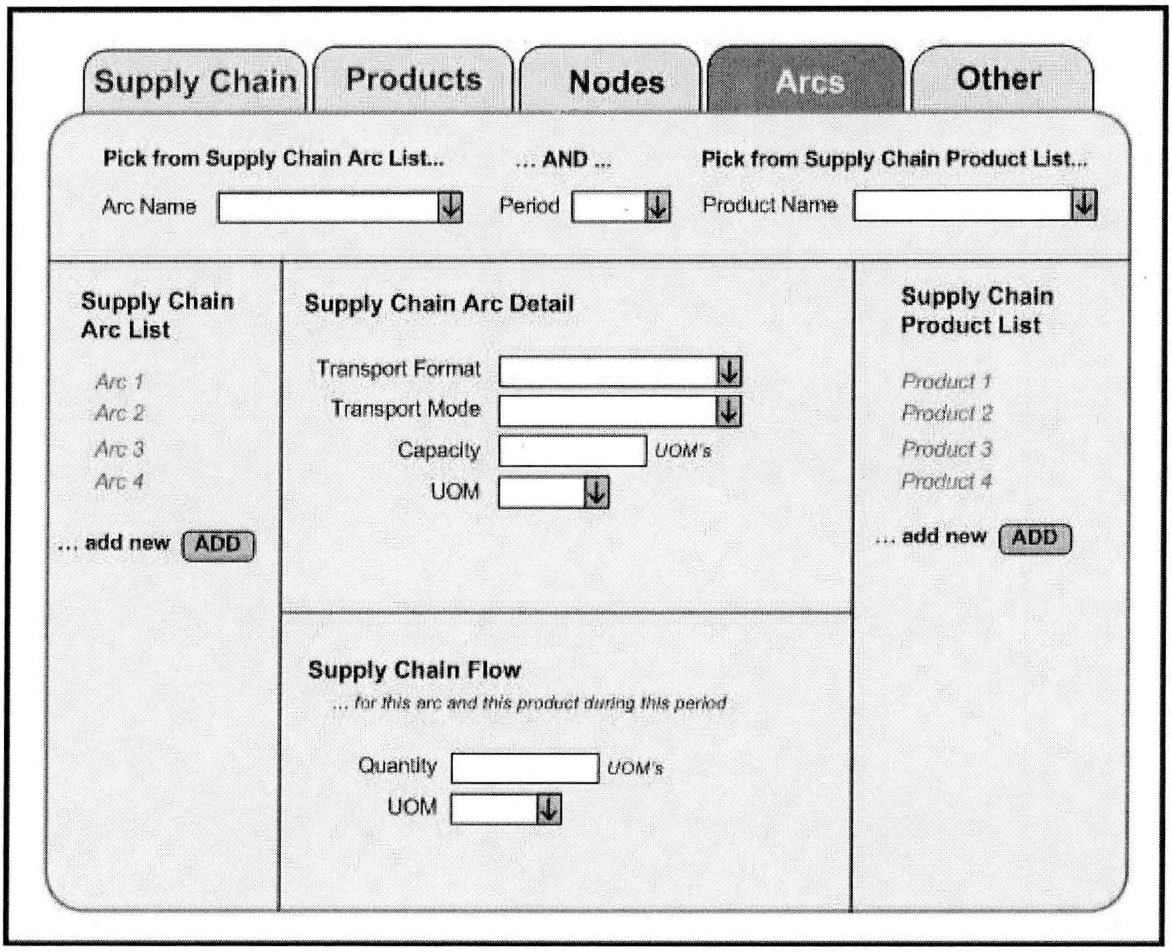

Figure 45: SCME - Arcs Tab (2)

8.4.5 Other Tab

The *"Other"* tab is used to define and update all other data in the database. Two examples are illustrated: **Activities** in *Figure 46* and **Countries** in *Figure 47*. For **Activities** the following attributes are required: Activity Name and Activity Picture. For **Countries** the following attributes are required: Country Name, Region, Language, Currency, Tax Rate, Import Duty and Export Duty. All other entities follow the same principle, and require all of the attributes stated in the ERD.

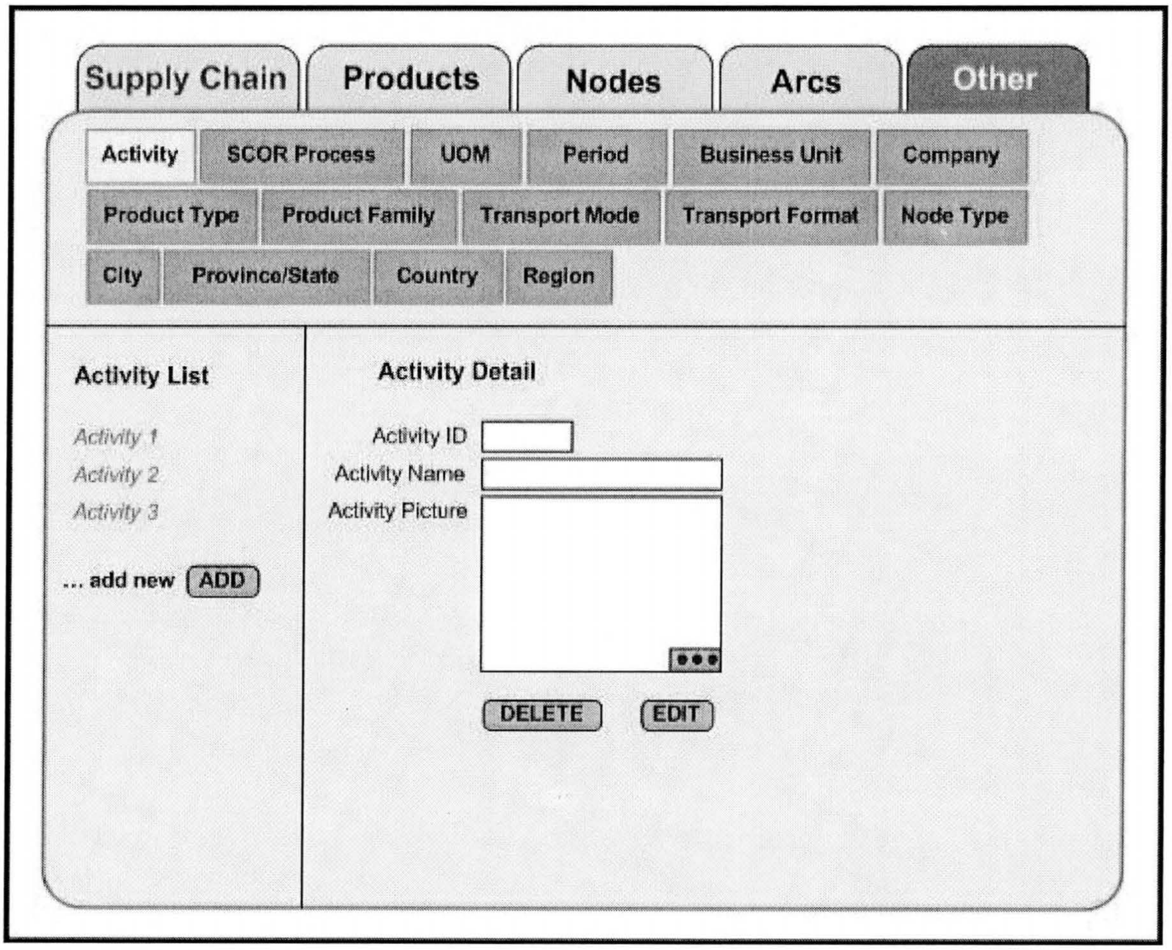

Figure 46: SCME - Other Tab (1)

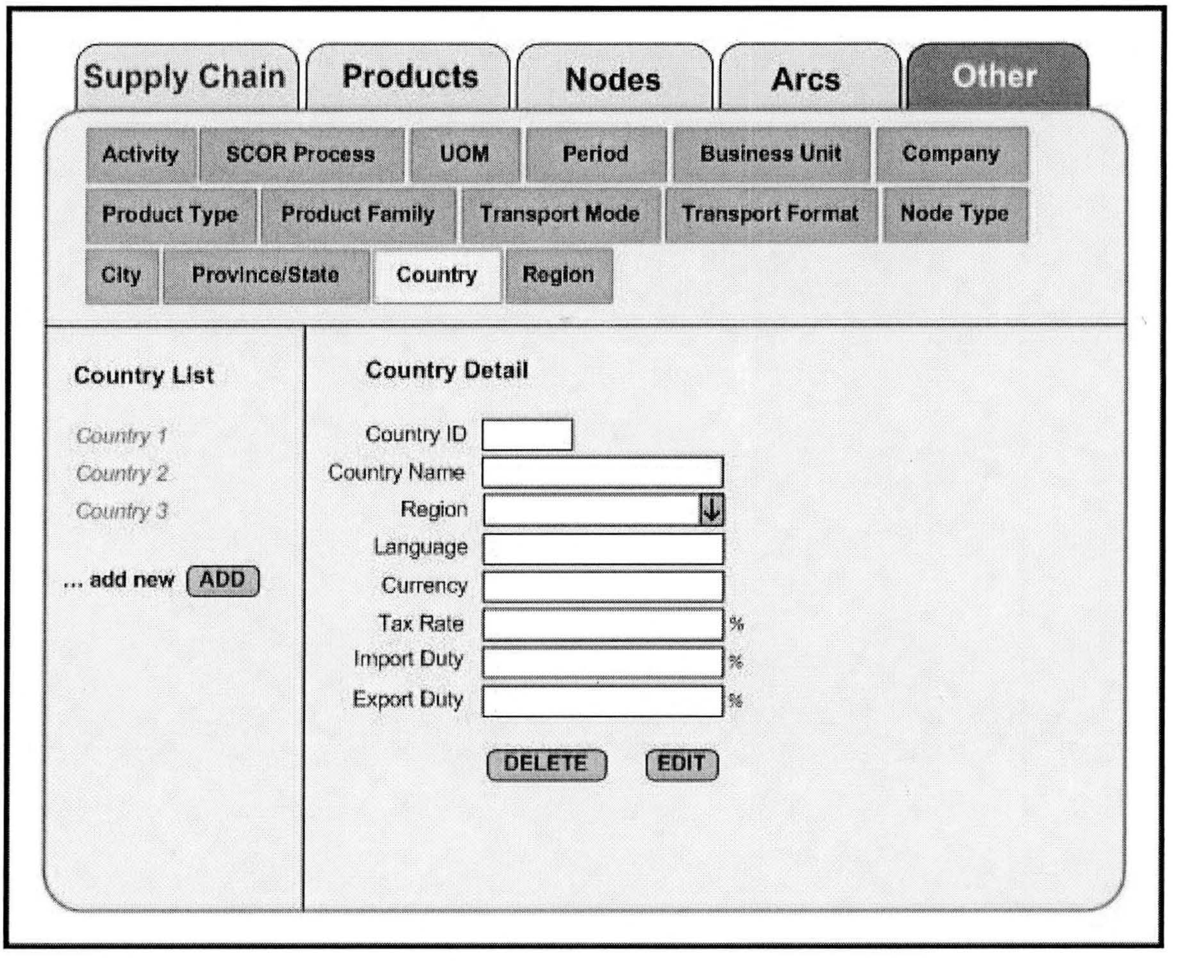

Figure 47: SCME - Other Tab (2)

8.5 Interaction with transactional database systems

8.5.1 Motivation for automated data transfer

The key to the sustainable use of the SCADR is in keeping the analytical supply chain data up to date. This allows for the frequent use of strategic modelling techniques to regularly review the firm's supply chains.

The analyst will be interested in understanding the change in supply chains over time, and for this reason, the SCADR allows for entering supply chain information for multiple historical periods. It will not be practical to manually enter the supply chain data for each period and each supply chain in an environment where hundreds of supply chains exist. For this reason, an automated process of updating the supply chain data for each historical period is necessary.

8.5.2 Interface solution

The solution for automating the flow of data from the company's transactional system(s) to the SCADR is provided by Enterprise Application Integration (EAI) as well as Extraction, Transformation, and Loading (ETL) tools. These tools interface to source and target systems, as described in paragraph 6.6, and provide the "middleware" layer necessary to perform the required data transformations and aggregations for use in the SCADR.

8.5.3 Master supply chain data management

The prevalent challenge in utilising the firm's transactional database is that transactional data often needs clean-up due to a lack of consistency and format. It will be impossible to integrate the SCADR with transactional systems if the integrity of the data from the transactional systems can not be guaranteed. This is where Master Data Management (MDM), described in paragraph 6.6, offers a solution.

For clarity, the definition of MDM as stated in paragraph 6.6 is repeated. Swanton & Samaraweera (2005) define master data management as *"a system of business processes and technology components that ensures information about business objects, such as materials, products, employees, customers, suppliers, and assets, is current, consistent, and accurate wherever they are used inside or exchanged outside the enterprise."* The reader is referred to *Figure 25* for an illustration of the master data management framework of Swanton & Samaraweera (2005). It consists of a 1) master data architecture (data modelling), and 2) MDM components and services.

Establishing a supply chain master data architecture involves defining the supply chain data taxonomy and relationships similar to that used in the SCADR. A standard master data set is maintained for suppliers, customers, locations and products across different business units. This is still a titanic challenge since all business units in a large multi-national will probably not work from the same ERP system. Using the same master data set across multiple business units (and potentially across different partners in the supply chain) will significantly simplify the transformation of transactional data into analytical data, and will make the vision of regular strategic supply chain reviews possible. This vision is not an unrealistic one, but would require buy-in into the potential benefit of using this approach.

This research proposes that the data model for a MDM framework be based on the data model as defined in the SCADR. It would require that the inherent network structure of the supply chain be maintained in the SCADR architecture. New nodes or arcs will be updated in the SCADR, which act as the primary master data model controlling transactions in the ERP. Product flow transactions in the ERP system is thus directly linked to specific arcs in the supply chain network (as specified in the SCADR).

8.6 Interaction with modelling application systems

An extensive discussion on the data fundamentals and requirements has been presented in chapter 5 and chapter 7, and will not be repeated here. The interaction between the SCADR and each of the modelling techniques will be discussed briefly.

In essence, the extraction of data from the SCADR for modelling applications relies on queries. Creating a query on a data model extracts only specified data based on certain pre-defined parameters and conditions. An example would be to only extract the data for products of the product type "raw material".

Specific customised queries would thus be required for each of the modelling techniques, based on its specific data requirements as discussed in chapter 7. These queries will be specific to a modelling application, and can span any dimension of the data model, *e.g.* supply chain, period, business unit, *etc.*

It is important to note that only the data that overlap with multiple modelling techniques have been included in the SCADR. For this reason, additional model-specific data would be required to complete any specific model.

8.6.1 Network model interaction

The data required for a network model is essentially about the network structure (*i.e.* nodes and arcs) and the capabilities of the supply chain elements, which include both existing and potential new structural elements. This data is easily queried from the SCADR and can be exported to an Excel spreadsheet, for further use in the linear programming software application. The data flow can be automated programmatically.

8.6.2 Site location model interaction

Since site location modelling will not be a regular exercise, and most of the data required for this type of modelling does not overlap with other modelling techniques, it has not extensively been included in the SCADR. Most of the data will be a once-off requirement for the specific analysis, but the analyst can make use of structural supply chain information already in the SCADR. This data can be queried from the SCADR and used on an *ad hoc* basis for site location analysis.

8.6.3 Performance model interaction

The supply chain performance model requires supply chain flow and cost information. The SCOR metrics used for performance evaluation are based on these data. This data is easily queried from the SCADR and can be exported to an Excel spreadsheet, for further use in the modelling application. The data flow can be automated programmatically.

8.6.4 Simulation model interaction

A supply chain simulation model, in essence, requires structural and process data relevant to the supply chain. The SCADR can be queried for the relevant supply chain structure, activities and process times (including transportation lead times and node activity times). Completing the simulation model would further require extensive additional model-specific data. The transfer of data from the SCADR to the simulation application would not be easily automated, and would therefore mainly be a manual exercise.

8.6.5 GIS model interaction

Because the geo-database used for a GIS model is also a relational database, it is relatively easy to construct a GIS model from the SCADR. The exact same data model of the SCADR can be used for the geo-database, with the only difference in the actual data extracted to the GIS model. The analyst will specify the relevant supply chain for the analysis, perform a query on the SCADR for a supply chain dimension, and then transfer only the relevant data to the geo-database used for creating the GIS model. Once the data is in the geo-database, the analyst can manipulate the appearance of the data in any way, as well as adding other geographical layers like countries, cities, *etc.* Most GIS applications have advanced database functionalities, making the import of existing database models (in this case the SCADR) possible.

8.6.6 *Schematic model interaction*

Since the SCME is used to define the supply chain network structure, it is already available from the SCADR (refer to *Figure 39*). It would however be required to additionally store the x y screen locations of nodes and arcs as displayed in the SCME in the SCADR. This is a programmatic issue that will not be discussed here.

8.6.7 *SCOR model interaction*

The SCADR stores the SCOR processes applicable at each node. Building a SCOR model would therefore rely on querying the supply chain structural data as well as the SCOR processes from the SCADR. This data can be used to include in a SCOR model, either in geographic or schematic format.

8.7 Data & Modelling process

The chapter is concluded with a data and modelling process to assist analysts in implementing the supply chain data and modelling framework (illustrated in *Figure 48*).

The first step is to set up the SCADR based on the data model presented in this research. Although the aim was to capture the essence of supply chain analytical data in the SCADR, the specific environment will probably require some customisation. Once a data model has been established, it forms the basis of implementing a master supply chain data management (MSCDM) framework. This in itself is a major project, and relies heavily on the maturity of the environment. It is however believed that it is key to ensuring the integrity of analytical data in the SCADR.

The second phase entails the capturing of the structure of supply chains in the SCADR with the help of the SCME. Due to the resource intensity of the process, it will not be a once-off initiative, and be done as and when required. The Pareto principle can be applied to identify the most important supply chains to start with. The vision is however that all supply chains in the organisation are formally captured in the SCADR.

Once the supply chain structure is captured in the SCADR, it needs to be kept up to date with product flow data for each period (typically a period equals one year).

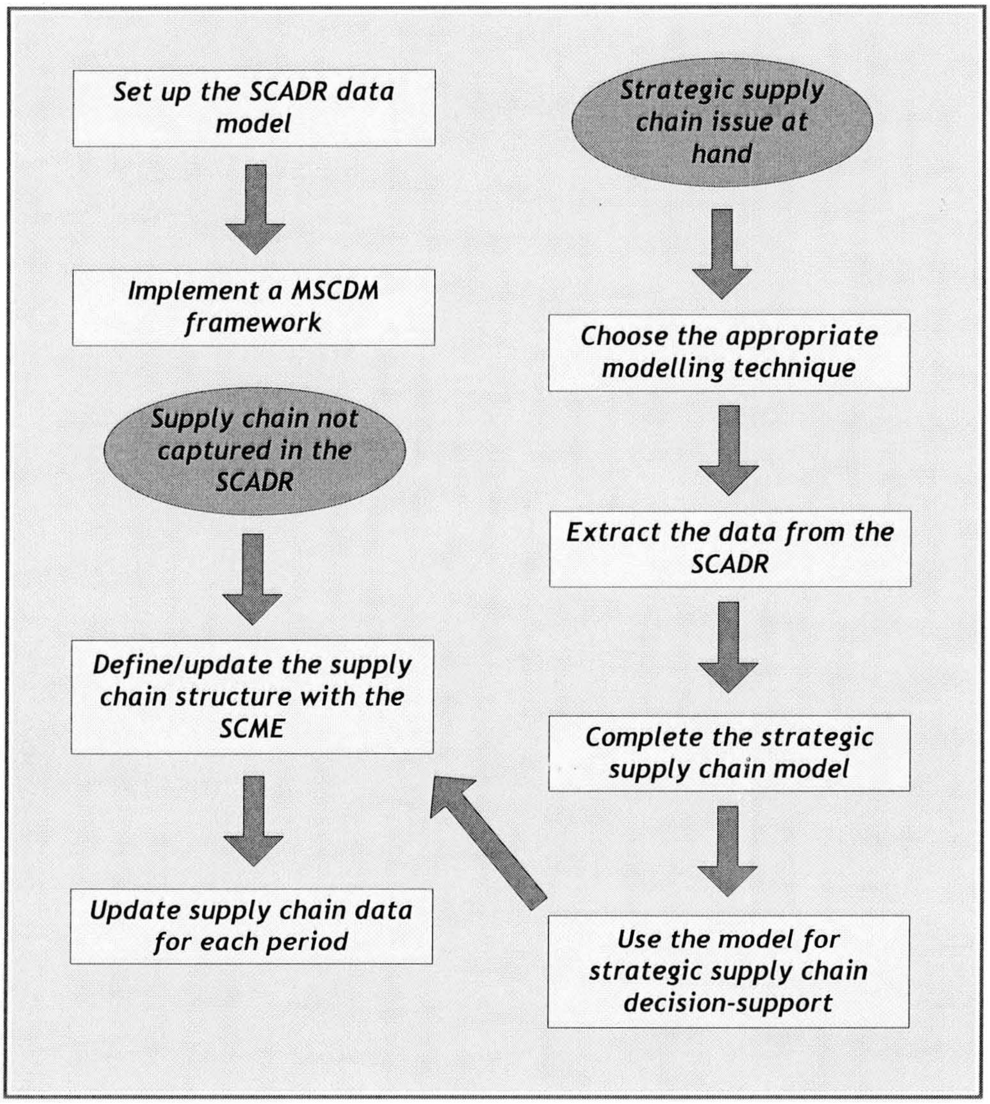

Figure 48: Supply chain data & modelling process

The modelling phase will be triggered by a specific supply chain issue or optimisation opportunity, and the process is as follows. Firstly, an appropriate modelling technique must be chosen. *Table 21* aims to assist the analyst in deciding on the appropriate model. Note that theses modelling techniques are not used mutually exclusively, as each addresses different supply chain issues. It would however be possible to use all of these models in different phases of supply chain design and optimisation. After the modelling technique is chosen, the relevant data is extracted from the SCADR (refer to chapter 7 for data requirements on each modelling technique). The model is then constructed (with additional data as required), and used in aiding supply chain decision-making. Any changes in the supply chain structure are to be updated in the SCADR.

Table 21: Choice of modelling technique

MODELLING TECHNIQUE	*WHEN TO USE*
Network Model	For optimising a supply chain network structure. Will provide the optimal flow of product in a supply chain for maximum benefit.
Site Location Model	When choosing a new location for a site, whether it is production, storage, *etc.*
Performance Model	For evaluating the performance of a supply chain against SCOR metrics.
Simulation Model	To model the process dynamics due to randomness and variability in the supply chain. To ensure a robust supply chain and evaluate the impact of eventualities.
GIS Model	For a geographical map of the structure and flow of a supply chain.
Schematic Mode	For a schematic presentation of the structure of a supply chain.
SCOR Model	To evaluate the essential SCOR processes at different nodes / locations in the supply chain, and how these processes integrate.

8.8 Concluding chapter 8

Chapter 8 presented the supply chain data and modelling framework - an integrated framework for the sustainable use of strategic supply chain data and modelling. The supply chain analytical data repository (SCADR) and the supply chain modelling editor (SCME) were presented, followed by proposals for interfacing with transactional data systems and modelling applications. Lastly, a practical data and modelling process were presented to assist the analyst in implementing this framework.

Chapter 9

Conclusion and Recommendations

This chapter will conclude the research document by presenting a synopsis of the research and final thoughts on the proposed solution. The next steps identified at the end of the research will aim to steer future research, followed by recommendations on the practical implementation of the framework.

9.1 Concluding the research

The research was initiated by an opportunity within Sasol to explore, improve and integrate various analytical techniques used in the modelling, design and optimisation of supply chains on a strategic level. The aim of the research was not to develop a lot of software, but rather to conceptually design an integrated space in which modelling and optimisation enablers can complement each other to facilitate superior strategic supply chain decision-making. The following main deliverables were met:

- a review of the strategic supply chain problem space (chapters 2, 3 and 4);
- a literature review of various supply chain modelling methodologies and tools (chapters 5 and 6);
- an analytical analysis of the data requirements for the various modelling techniques (chapter 7);
- an integrated modelling framework (chapter 8);
- a supply chain data model and information system (chapter 8); and
- a supply chain editor tool as user interface to the repository (chapter 8).

9.2 Recommendations

Moore (1996) stated that companies will no longer ensure their market position solely by their own functional excellence...that in the new economy, whole business ecosystems will compete against each other for global survival. This poses an enormous challenge to companies on how they manage their global supply chains, and makes the strategic review and optimisation of supply chains a continual rather than a once-off process. It challenges companies to make use of more advanced analytical tools available to their disposal to support their strategic supply chain decision-making on a regular basis. These modelling initiatives are traditionally done as once-off projects in isolation, which motivates the need for the integrated supply chain data and modelling framework presented in this research. It is recommended that companies adopt these modern technologies, or alternatively suffer the consequences of them being outplayed by the more sophisticated players. Especially in the petro-chemical industry, there seems to be a lot of scope for improvement and maturity when it comes to strategic supply chain planning.

Although the framework presented here is only a conceptual one, its practical feasibility has been tested and confirmed. The next step will be to programmatically develop the software tools based on the functional requirements expressed in this research.

Future research could explore the possibilities of fully integrating different modelling technologies in one system, with automatic model building. The student however believes that this may be a little premature, considering the flexibility that the analyst typically requires when developing models for supply chain issues.

9.3 Final thoughts

The research document was introduced with a quote from Owens (1998:xiii), that is particularly applicable to the objective of this research:

> *"Perhaps the biggest breakthrough in prospect lies in achieving truly integrated decision support systems that link all the parties along a particular supply chain. A comprehensive supply chain information system will make visible to managers all the opportunities to improve performance along the length and breadth of the network, ensuring that all parties improve their decision - making and their capacity to contribute to, and benefit from, the optimum supply chain."*

It is believed that this research has brought this vision a little closer to home, by introducing an integrated supply chain data and modelling framework, aiming to make the use of advanced modelling techniques more regular and making it quicker and easier to implement. In an era of advancements in information technology and advanced analytical methodologies, the supply chain should embrace the application of these techniques to aid their strategic decision-making for the optimal benefit.

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