PREFACE

This research report on improving the customer-perceived value of supply with just-in-time production of specialty chemicals is the result of my internship at a chemicals company and the final work of my masters in Systems Engineering, Policy Analysis and Management.

My journey started with an internship. I'm very grateful for the opportunity I had to experience the complex world of chemicals production. First of all I was provided with professional feedback and coaching by my supervisor and mentor, this gave me valuable insights in the project and my own performances. Next the insight in the daily business at the supply department, regular visits to the sales department and a series of site visits gave me clear insight in the processes and made this experience very valuable.

After the experience in the chemicals business I returned back to the faculty of Technology, Policy and Management. The faculty at which I've spend most time of my studies and always has been a very pleasant place to study. The support that I've received from my graduation committee helped me a lot to shape and craft my work. Next the numerous discussions with fellow students made me able to reflect better on the graduation process.

Looking back at this experience I conclude that I've learned a lot about dealing with complex matters, not only in an academic way or in the company but also in organizing my own work.

I would like to thank all people that contributed to this valuable experience. I would like to thank my supervisors from the university for the provided assistance: Mamadou Seck , Scott Cunningham and graduation professor Alexander Verbraeck. And my supervisor and mentor from the company: Mijndert van der Spek and Nelke van de Ven.

I hope you all enjoy reading the results,

Manuel Harmsen.

EXECUTIVE SUMMARY

In many consumer markets lead-time is no longer the outcome of a process of planning, producing and delivery. Many companies have gained competitive advantage through shortening the lead-time. In achieving this, next to the introduction of more flexibility in their own operations, companies are looking for more flexible suppliers. Traditionally uncertainty in supply was mitigated through high inventories. Next to the costs involved in keeping these inventories, they also delay the demand information and thereby create volatility, called the bullwhip effect. That is why various industries have put efforts in lowering the inventories and increasing flexibility.

Introducing flexibility in production is rather controversial in the chemicals industry. Economies of scale and low margins nurture the emphasis on plant utilization. This drives ever lower margins, hence an even higher emphasis on plant utilization. The 24-hour operation leaves no flexibility to respond to a changing demand or to compensate for downtime.

The company that initiated this research and offered the facilities to perform a desk study and provided the data to build a simulation model is active in the chemicals industry. During the recession of 2008 the company was confronted with a decrease in demand. In 2010 a quick recovery of the market was experienced, accompanied with several assets failing this caused large disruptions in the supply to customers. The reliability of supply was perceived too low at the commercial interface. This made the company look for ways to improve the customer-perceived value of supply.

In this report a strategic audit is proposed. The objective of this audit is to align the company's competitive strategy and operations strategy. The competitive strategy considers the market the company is active in and its value proposition to its customers. In this research this was done though the Industry Trends Analysis and the Customer Value Analysis. The market view was applied, which starts at the market and ends in recommendations for the operations. This audit structured the answering of the following research question:

How can chemicals companies delivering to intermediate markets, improve the customer-perceived value of the supply in a cost-effective way?

Increasing volatility in the demand on consumer markets makes that requirements of the industries downstream of the chemicals industry include the responsiveness to this volatile demand. As a consequence this also influences the customer-perceived value of the manufacturer's supply. The commoditization in the downstream markets increases the need for agile operations and make that customers focus more on service-aspects like lead-times.

Through a structured survey customers were asked to indicate the importance of, and performances on, supply chain related aspects. These aspects were based on the four guiding principles for supply chain managers: responsiveness, reliability, resilience and relationships and the three of the four elements of customer value: quality, service and timing (cost was excluded to prevent strategic answers).

Besides a confirmation of some characteristics of the industry like the low importance of customized solutions and the high emphasis on quality the survey also resulted in new insights. The results especially represent the CASE[1] customers, a segment in which the company wants to grow and where customers on average are smaller and deliver to industries where just-in-time practices are more common. In contrast with Flexibles[2] customers these customers value responsiveness more than reliability. Reliability was valued high and performances where rated high. For responsiveness the importance was indicated to be high, while the performances where rated amongst the lowest.

The challenge for the company will be to become less dependent on forecasts and increase the agility of operations while sustaining the current level of reliability. As part of the strategic audit, the competency gap was specified by defining key performance indicators that the company should improve. The objective of the system should be to limit the lead-times, achieve a high order fulfilment rate and keep appropriate inventory levels.

The company currently applies a hybrid form of make-to-order (MTO) and make-to-stock (MTS) operations regime. The regime is based on forecasts that are facilitated by the monthly repeated S&OP process. The focus is in the first place on optimizing production, which leads to varying availability of products and a long planning horizon. The delay in information between the complex production chain and demand management makes that inventory levels vary a lot and consequentially order fulfilment is compromised.

It is advised to implement the just-in-time (JIT) regime. This regime has the prospect of shorter lead-times, more stable inventory levels which lead to less variation in product availability and thereby increases order fulfilment. The only downside is that this compromises the production capacity used on short term as this is adaptive to the demand, which is counter intuitive regarding the current KPI's which focus on the occupancy of assets. The prospect is that production capacity is only used for producing the right products at the right time and higher sales margins due to more stable operations.

The production processes and assets were successfully represented in a simulation model, which delivered valuable insights for the industry. The chemicals industry is characterized by a bill of materials that decomposes a few raw materials into many finished products. This makes that the chemicals industry has one of the most complex production chains. In this thesis an object oriented representation of the system was proposed. The relations between objects describe the bill of materials, thereby enabling the simulation of the complex production chain.

Experiments based on the sales of 2010 and disruptions based on historical data from 2005 to 2011 excluding the force-majeure[3] situations showed that the JIT regime is successful in fulfilling the orders with short lead times and low inventory levels. It is important to note that the sales represent a managed demand. Due to the inflexible capacity this managed demand is considered an important requirement for the system to work. Next to an improved order fulfilment, the model showed that JIT allows lower inventory levels. Finally JIT makes the impact of disruptions more predictable, which enables the company to develop calculated responses to these situations.

[1] CASE is a product segment that finds its application in Coatings, Adhesives, Sealants and Elastomer.
[2] Flexibles is a product segment that finds its application among others in mattresses and car seats.
[3] When a company isn't able to fulfil its delivery promises for an extended amount of time it will declare force majeure, legal arrangements will determine the distribution to customers in such an event.

TABLE OF CONTENTS

APPENDICES

1 INTRODUCTION

1.1 Introduction

In consumer markets many companies try to respond to the demand of the customer as quickly as possible. Lead-time no longer is the outcome of a process of planning, producing and delivery, but in many markets has given companies a competitive advantage.

In order to become agile enough to respond to the demand of their customers in ever shorter time-frames, flexibility is introduced in the production capacity. Low inventories are kept to decrease the working capital and part of the solution is found in more flexible suppliers. These suppliers on their turn are confronted with more volatility in the demand and take measures to improve their agility. Traditionally the uncertainty of supply was mitigated by keeping higher inventories. The bullwhip-effect shows the negative effects of this strategy. The bullwhip-effect describes the effect of information delay that rises from keeping inventories.

This thesis will focus on the chemicals industry, where assets are relatively inflexible (Consultants 2002). In this industry the economies of scale and low margins nurtures the emphasis on plant utilisation. This drives ever lower margins (Louw 2006), hence an even higher emphasis on plant utilisation. The 24 hour operation leaves no flexibility to respond to a changing demand or to compensate for downtimes.

The company that initiated this research and offered the facilities to perform a desk study and provided the data to build a simulation model is active in the chemicals industry. During the recession of 2008 the company was confronted with a decrease in demand. In 2010 a quick recovery of the market was experienced, accompanied with several assets failing this caused large disruptions in the supply to customers. The reliability of the supply was perceived too low at the commercial interface. This made the company look for ways to improve the customer-perceived value of the supply.

This thesis provides a framework which helps companies to assess their competitive strategy and align this with their operations strategy. The framework proposes a strategic audit that is executed for the assessed company. The audit starts in the market where the trends in the industry are identified and it is researched how customers value the supply. This is translated into recommendations for the company’s operations.

The internal supply chain of the company is rather complex due to the diverging bill of materials (BTS 2002). The bill of materials describes the ingredients of the products. Most products have a common raw material, but need to follow several process steps. Each product can be used in several other products or blends, which makes that there are many dependencies in the production. The effects of changes in the operations are not trivial. That is why a simulation will be built to experiment with the system and research the effect on the key performance indicators.

1.2 Structure

The next chapter will define the research into more detail. Chapter 4 discusses the literature about Supply Chain Management. A framework containing both competitive and operations strategy will be constructed and discussed in Chapter 4. Also the motivation for the methods used will be found in Chapter 4. Among them are an Industry Trends Analysis, a Customer Value Analysis and a Simulation Model Analysis. The Customer Value Analysis will be discussed in Chapter 5 and the Simulation Model Analysis in Chapter 6. Chapter 7 contains the conclusions and recommendations. Finally a reflection on this Master Thesis will be shared in Chapter 8.

2 RESEARCH DEFINITION

2.1 Introduction

2.1.1 Context

Today's markets are increasingly volatile. Many companies are struggling with this increasing volatility and try to find strategies to cope with the consequential fluctuations in demand. The recession that initiated a fast decrease in demand in the last quartile of 2008 and the quick recovery of the markets in the beginning of 2010 made that many manufacturers were confronted with their limited agility. In order to be agile on the markets, flexibility in operations is becoming increasingly important. Facilitating this flexibility is costly, but proven beneficial in many consumer markets, where commoditization makes that clients tend to buy substitute products when lead-times are too long. Many companies serving consumer markets are part of a complex supply network, where components from varying suppliers are assembled into the final product. These suppliers commonly are part of one or more supply chains that produce the raw materials for these components. Companies investing in flexible operations commonly pass part of the solution towards agility on to their suppliers, demanding more flexibility in supply. For these suppliers the key question now is how to assess the need of flexibility on the demand side and how to obtain this through their operations in a cost-effective way.

2.2 Research Motivation

2.2.1 Commercial motivation

This research was initiated after the recovery from the recession in the beginning of 2010. During the recession many industries were confronted with a decrease in demand, customers going bankrupt or becoming less trustworthy. This was also experienced at the company assessed (further referred to as 'the company'). One of their key propylene customers went bankrupt, resulting in a decrease of propylene production of about 60%. The recession caused a consequential underutilization in the rest of the company's supply network, among which the polyols units. In 2010 a quick recovery of the market was experienced, accompanied with several assets failing this caused large disruptions in the supply to customers. The reliability of supply is perceived too low at the commercial interface. This made the company look for ways to improve the customer-perceived value of the supply.

2.2.2 **Scientific motivation**

Literature about supply chain management is biased to the 'fast moving consumer goods'-markets and answers how companies in these markets can cope with the increasing need for agility. Little attention is addressed to the companies that are upstream of these markets and are at the start of these supply chains. Further on a comprehensive method that links observations in the market and the required changes in the operations of a manufacturers is lacking.

2.2.3 **Problem statement**

Taking both motivations in consideration, the following two problem statements can be extracted:

2.2.3.1 *Practical problem statement*

At the company the reliability of supply is perceived too low at the commercial interface and wants to how to improve this customer-perceived value of the supply through its operations.

2.2.3.2 *Scientific problem statement*

A clear scientific method that links developments in the market with the required changes in the operations of a manufacturer is lacking in literature.

2.2.4 **Research objective**

The objective of this research is twofold. First a method will be provided that links market developments with the required changes in the operations of a manufacturer. Next to that this method will be used to advise the company in their quest to improve the customer-perceived value of the supply.

2.3 Research Questions

2.3.1 **Main question**

Based on the research objective and the problem statements the key research question in this research is defined as:

How can chemicals companies delivering to intermediate markets, improve the customer-perceived value of supply through their operations?

2.3.2 **Sub questions**

In order to answer the main question, sub-questions are devised.

2.3.2.1 *Sub question 1: How do the trends in the chemicals industry affect the customer-perceived value of the manufacturer's supply?*

In order to improve the customer-perceived value there is a need to understand the environment of the company and the relation between supplier and customer. The trends in this industry are of special interest because these will set the upcoming changes. Making improvements in line with these trends will secure sustainability of related investments.

2.3.2.2 *Sub question 2: What is the customer-perceived value of the manufacturer's supply?*

In order to improve the customer-perceived value there is a need to understand how the customers currently value certain aspects of the supply. This question will give insight in the aspects that a customer uses to evaluate the supply of its suppliers, how these values can be measured and what the specific values are for the assessed company.

2.3.2.3 *Sub question 3: How can the customer-perceived value of the manufacturer's supply be improved on the commercial interface?*

In order to address the recommendations for improvements to the right department within the company, this question will answer what the sales department can do in order to improve the customer-perceived value.

2.3.2.4 *Sub question 4: How can the customer-perceived value of the manufacturer's supply be improved through its operations?*

In order to address the recommendations for improvements to the right department within the company, this question will answer what the supply and manufacturing department can do in order to improve the customer-perceived value.

2.3.2.5 *Sub question 5: What is the effect of the suggested operational improvements?*

In order to secure the applicability of the suggested improvements, the effects on the operations and supply of the company will be modelled. This question will answer what the effect of the suggested operational improvements is.

2.3.3 Research approach

The approach to answer these questions is to view the interaction of companies with their customers from a supply chain perspective and linking the company's market position with its operations. The research is framed by a combined framework, based on competitive strategy (Porter 1980), operational strategy (Mieghem 2008) and supply chain management literature, mainly based on the work of Christopher (Christopher 2011) . A desk study at a large chemicals company facilitated a case study and is used to enrich this research with the practical application of the proposed assessment. The methods proposed and applied are data analysis, literature studies, a workshop, a survey and a simulation model.

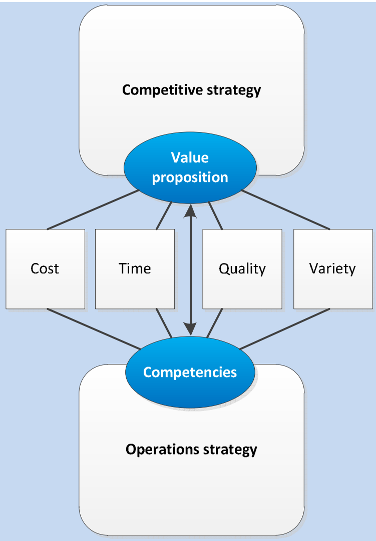
2.4 Research Framework

2.4.1 Introduction

The research framework introduced in this section combines both the competitive and operations frameworks and guides the answering of the research questions. This section gives an introduction to this framework and shows how it structures the answering of the questions. In Chapter 4, the framework will be discussed in more detail.

2.4.2 Competitive- and operations strategy

In Chapter 4 it will be argued that both the frameworks of competitive strategy and operations strategy are needed to fully capture the scope of the main question. Both frameworks aim to optimize the value that a company is able to create for its customers. Competitive strategy seeks to accomplish this by deciding which markets to enter and which value proposition to offer to its customers (Porter 1985). Operations strategy is a plan for developing an operational system with competencies that maximize net present value (Mieghem 2008). The two frameworks are respectively looking to the external position and internal operations of the company. The frameworks are connected through the value proposition (Mieghem 2008). Figure 2-1 shows how competitive strategy and operations strategy are connected though the value proposition and the competencies.



Competitive strategy meets operations strategy

The research fields meet each other in the aspects that characterize the value proposition (cost, time, quality and variety) as defined in the competitive strategy and the aspects that characterize the competencies (cost, time, quality and flexibility / variety) as defined in the operations strategy.

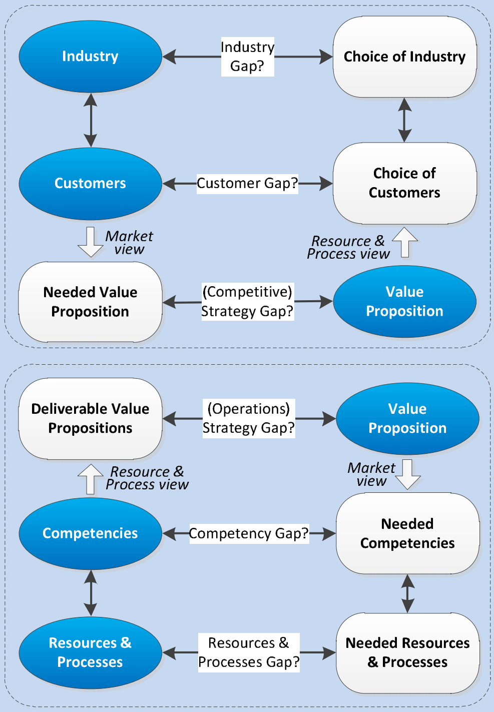
Figure 2-1: Competitive strategy meets Operations strategy

2.4.3 Relation with Supply Chain Management

Stevens (Stevens 1989) identified four stages regarding Supply Chain Management starting at the point where the supply chain is a function of fragmented operations within the individual company and ending in supply chain integration with suppliers and customers. Considering the research question, the broader interpretation will be related to the competitive strategy while the final recommendations will focus on the more pragmatic interpretation. In this interpretations supply chain management is a function to the company, which considers the company as a set of production echelons. Known as the multi-echelon context (Sherbrooke 2004). In the broader interpretation Supply Chain Management considers the management of upstream and downstream relationships with suppliers and customers in order to deliver superior customer value at less cost to the supply chain as a whole (Christopher 2011). The philosophy behind supply chain management is to extend the internal activities by embracing an inter-enterprise scope, bringing trading partners together with the common goal of optimization and efficiency (Harwick 1997). Where competitive and operations strategy seek to optimize the value of one organization, the broader interpretation of supply chain management considers the entire supply chain.

2.4.4 Strategic Audit

In operational strategy (Mieghem 2008) a strategic operation audit is described to assess the current operational system and the gaps between the current state and the needed state to ensure strategic alignment between the competencies and the value proposition. The in this thesis proposed strategic audit additionally audits the fitness of the value proposition with respect to the competitive arena which is considered in the competitive strategy. As discussed in Chapter 4, the market view contributes most to answering the main question of the research. The market view starts at the market and results in improvements in the resources and processes of the company. Figure 2-2 shows the strategic audit.



Strategic audit

The in this thesis proposed strategic audit is a gap analysis to assess the degree of alignment and to develop improvement actions.

Figure 2-2: Strategic audit

Applying the market view starts at the upper left corner with "industry" and ends in the lower right corner with "needed resources & processes". In order to be able to assess the strategic alignment, the following gaps have to be identified:

- Industry Gap
- Customer Gap
- Competitive Strategy Gap
- Operations Strategy Gap
- Competency Gap
- Resource & Processes Gap

This inspired the design of the following analyses to assess these gaps:

- Industry Trends Analysis
- Customer Value and Satisfaction Analysis
- Simulation Model Analysis

Figure 2-3 shows how these frameworks, activities and the suggested analyses are related.

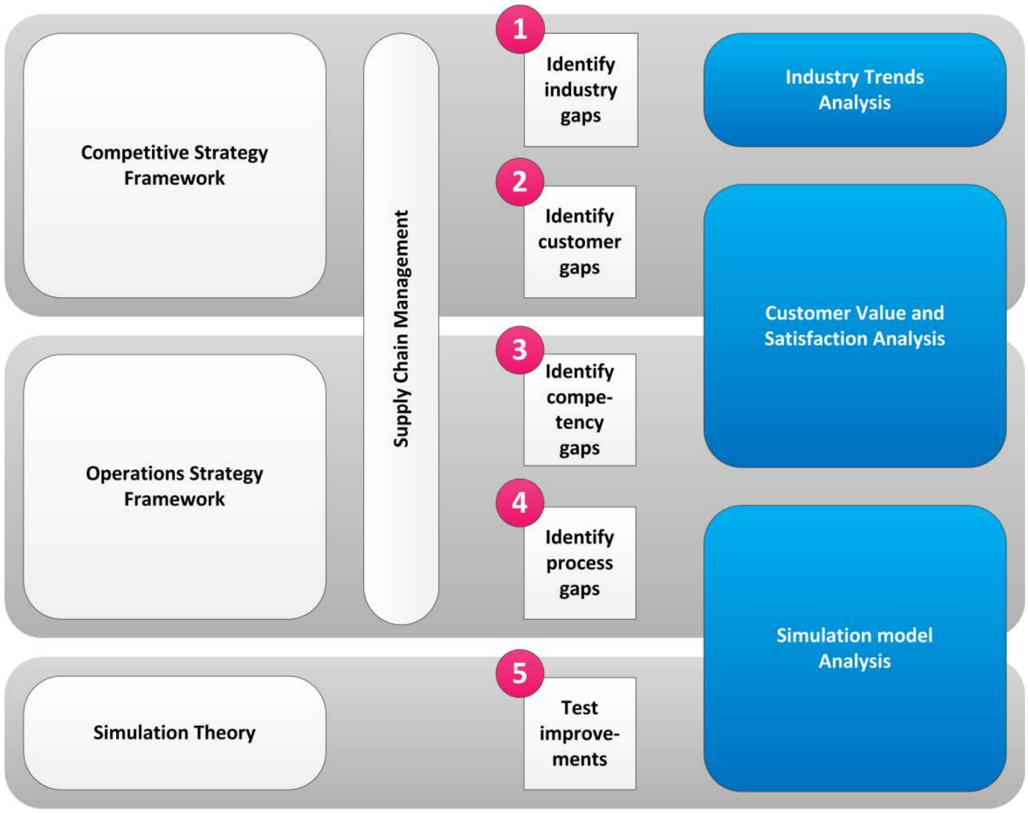


Figure 2-3: Relations between frameworks, activities and analyses.

A detailed description of the analyses can be found in Chapter 4. The methods used in the analyses and the relation with the sub questions is summarized in Table 2-1.

Analysis	Methods	Sub Question
Industry Trends Analysis	Literature review, Workshop	1. How do the trends in the industry affect the customer-perceived value of the manufacturer's supply?
Customer Value Analysis	Literature review, Online Survey, AHP	2. What is the customer-perceived value of the manufacturer's supply? 3. How can the customer-perceived value of the manufacturer's supply be improved on the commercial interface?
Simulation Model Analysis	Data Analysis, Simulation Model	4. How can the customer-perceived value of the manufacturer's supply be improved through its operations? 5. What is the effect of the suggested operational improvements?

Table 2-1: Relation between Analyses and Sub Questions

3 SUPPLY CHAIN MANAGEMENT

3.1 Introduction

3.1.1 Relevance

Supply Chain Management considers the management of upstream and downstream relationships with suppliers and customers in order to deliver superior customer value at less cost to the supply chain as a whole (Christopher 2011). This makes supply chain management a promising approach in answering the research question that aims at improving the customer-perceived value of the manufacturer's supply in a cost-effective way. The relevance of supply chain management in the chemical industry is also affirmed in literature. Whitfield found that Supply Chain Management is growing in importance in the chemical industry (as cited by Louw 2006). Louw even takes it a step further by claiming that Supply Chain Management needs to become the backbone of the chemical business where logistics costs can be greater than manufacturing costs (excl. raw materials) (Louw 2006).

3.1.2 Structure

In this chapter two methods to guide the supply chain manager will be presented. First a set of guiding principles regarding four themes identified by Christopher will be presented. Secondly it will be argued that uncertainty should be reduced through decreasing eight complexities found in supply chains. These methods will be enriched by relating them to the characteristics of the chemicals industry as presented in Appendix A. Finally a series of general trends identified in supply chains will be presented. In Appendix B the applicability of these trends to the company assessed will be researched.

3.2 Guiding principles

3.2.1 Introduction

In his work Christopher describes how industries move into the era of supply chain competition and how a set of principles emerges to guide the supply chain manager. These are referred to as the 4R's; responsiveness, reliability, resilience and relationships. In the following paragraphs these principles will be discussed and related to the characteristics of chemicals industry.

3.2.2 Responsiveness

3.2.2.1 *Definition by Christopher (Christopher 2011)*

Responsiveness concerns the ability to respond to customers' requirements in ever-shorter time-frames. In general customers are demanding shorter lead-times, more flexibility and increasingly customized solutions. Key in improving responsiveness is agility. Agility considers the ability of the supplier to meet the customers' demand sooner. In a fast-changing market place agility is even more important than long-term planning in its traditional form. Because future demand patterns are uncertain, by definition this makes planning more difficult and, in a sense hazardous. In the future, organizations must be much more demand-driven than forecast-driven. This transition can be achieved through agility, not just within the company but across the supply chain. Responsiveness also implies that the organization is close to the customer, hearing the voice of the market and quick to interpret the demand signals it receives.

3.2.2.2 *Responsiveness in the chemicals industry*

The characteristics of the chemicals industry are discussed in detail in Appendix A. In this paragraph their implications for the responsiveness will briefly be discussed. The products are commodities, which makes that there is a limited need for customized solutions. There are though opportunities for suppliers to differentiate on other aspects than quality: in business-to-business and industrial markets it seems that product or technical features are of less importance in winning orders than issues such as delivery lead-times and flexibility (Christopher 2011). The inflexible capacity and emphasis on plant utilization make that flexibility is not found in the capacity used, but rather in the market price. The 24 hour operations make proper planning and forecasting critical (Louw 2006), customers are required to nominate their demand on long horizons, hence long lead-times. The silo and secrecy mentality in petrochemical enterprises makes it hard to hear the voice of the market. Further on the chemicals industry is a producers market, where the relative small customers have less bargaining power than the producers. This makes that flexibility is commonly pushed towards the customers. Finally the laboratory lead-times and slow bulk transit modes cause long delivery lead-times.

It can be concluded that the characteristics of the chemicals industry make that there is a limited need for customized solutions and customers' requirements are not responded on quickly, in other words the responsiveness of this industry is low.

3.2.3 Reliability

3.2.3.1 *Definition by Christopher (Christopher 2011)*

One of the main reasons why any company carriers safety stock is because of uncertainty. This can be uncertainty about the future demand, the ability of a supplier to meet delivery promises, or about the quality of materials. Significant improvements in reliability can only be achieved through re-engineering the processes that impact performance. Manufacturing managers long ago discovered that the best way to improve product quality was not by quality control through inspection but rather to focus on process control. The same is true for logistics reliability. One of the keys to improving supply chain reliability is through reducing process variability. Methods like 'six sigma' and related tools are designed to enable variability in a process to be reduced and controlled.

3.2.3.2 *Reliability in the chemicals industry*

The chemicals industry functions in a commodity market, which causes prices to be volatile and cyclical (Louw 2006). This makes that customers prices cannot be relied on. At the company assessed, the demand is perceived more certain than the production. This view might be biased by the market power that lies with the suppliers, the price fluctuations that influence the demand and the lack of actual information on the demand. In the production complex production chains (BTS 2002) induce many sources for variability. The numerous sources for variability makes it hard to mitigate them in order to obtain reliable operations. Also interdependencies make that the effects of disruptions are not evident, making it hard to identify the real causes of unreliability and eliminate them. This makes that suppliers often are not able to meet delivery promises. In other words the uncertainty in production makes that the reliability of delivery is low. Next to that the long distance between supply chain partners and slow modes of transportation induce a high variability of transportation times (Hussain 2006). The manufacturing processes have matured over time to reduce variability in quality with a high investment in quality control processes (Louw 2006). In other words the quality of materials is reliable.

It can be concluded that in the chemical industry the prices are rather unreliable. At the company assessed the demand is perceived more certain than the production. Delivery is unreliable due to uncertainties in production and transportation. Quality though is reliable.

3.2.4 Resilience

3.2.4.1 *Definition by Christopher (Christopher 2011)*

Today's marketplace is characterized by higher levels of turbulence and volatility. The wider business, economic and political environments are increasingly subjected to unexpected shocks and discontinuities. As a result, supply chains are vulnerable to disruption and, in consequence, the risk to business continuity is increased. Whereas in the past the prime objective in supply chain design was probably cost minimization, the emphasis today has to be upon resilience. Resilience refers to the ability of the supply chain to cope with unexpected disturbances. There is evidence that the tendencies of many companies to seek out low-cost solutions because of pressure on margins may have led to leaner, but more vulnerable, supply chains. Resilient supply chains may not be the lowest-cost supply chains but they are more capable of coping with the uncertain business environment. The most important characteristic of such supply chains is the business-wide recognition of where the supply chain is at its most vulnerable. Other characteristics are the recognition of the importance of strategic inventory and the selective use of spare capacity to cope with surge-effects.

3.2.4.2 *Resilience in the chemicals industry*

In the chemical industry production is rather uncertain. The effects are amplified by the high emphasis on plant utilization, leaving no spare capacity to catch up when production units fail. The complex bill of materials and related complex production chains (BTS 2002) make that production units are interdependent. The inflexible assets make changing the production plan difficult. The complex production chains, the inflexible assets and emphasis on plant utilization make that the failing of one production unit, easily causes consequential downtime in another production unit that uses products of the first unit. Quite often suppliers have to declare a 'force-majeure', which indicates that they are not able to meet the promised deliveries to any of their customers for a significant period of time. The increasing volatility in the market is not felt to the full extend. The market power that lies with the suppliers probably prevents this, combined with a volatile market price that tempers the demand fluctuations.

It can be concluded that the on the production side complex production chains, the inflexible assets and emphasis on plant utilization make the supply chain vulnerable, in other words the resilience is low. On the market side volatility is not felt to the full extend, probably due to the high market power of suppliers.

3.2.5 Relationships

3.2.5.1 *Definition by Christopher (Christopher 2011)*

Increasingly companies are discovering the advantages that can be gained by seeking mutually beneficial, long-term relationships with suppliers. It is usually suggested that the benefits of such practices include improved quality, innovation sharing, reduced costs and integrated scheduling of production and deliveries. Consequentially customers are seeking to reduce their supplier base. From the suppliers' point of view, such partnerships can prove formidable barriers to the entry for competitors. The more that processes are linked between the supplier and the customer the more the mutual dependencies increase and hence the more difficult it is for competitors to break in. Successful supply chains will be those that are governed by a constant search for win-win solutions based upon mutuality and trust. This is not a model of relationships that has typically prevailed in the past. It is one that will have to prevail in the future, as supply chain competition becomes the norm.

3.2.5.2 *Relationships in the chemicals industry*

The perceived product equality due to the commodity products makes that customers don't face high switching costs and thus can easily switch between suppliers. The chemicals industry can be characterized as a suppliers' market, where the relative big suppliers have most market power. As a result, the smaller customers have low market power. Due to this low market power and the high chance that suppliers will not deliver as promised, commonly a mix of suppliers secures the supply. The complex bill of materials and related broad range of end-markets make it hard for suppliers to understand the wishes of the customer or to foresee in the specific preferences. The chemicals industry is characterized by vertically integrated firms (Waller 1999), which makes that the supplier is commonly a company that is within the same enterprise. The chemicals industry is also characterized by its functional silo's and secrecy mentality (Louw 2006). This complicates cooperation both within the enterprise and with customers. Next to that the long distance between supply-chain partners make that cultural differences may play a role in the relationship between parties.

It can be concluded that relationships play a big role in the chemical industry, though functional silo's, the secrecy mentality and the suppliers' market complicate cooperation between supplier and customer.

3.3 Complexities

3.3.1 Introduction

Another guidance coming from supply chain management next to the previously discussed guiding principles are complexities. Complexity considers the interconnectedness and interdependency across a network. The outcome of complexity in a supply chain, is uncertainty and with that uncertainty comes an increased likelihood that forecast error will increase in line with complexity (Christopher 2011). A growing uncertainty brings with it a serious challenge to the classic practice of running the business on the basis of forecasts (Christopher 2011). Davis also describes this relation: one key issue known to impact on the effectiveness of a supply chain is that of uncertainty (Davis 1993). It logically follows that decreasing the complexity in the end also decreases the uncertainty, thereby increasing the accuracy of forecasts. Despite similarities the petroleum supply chain shares with those in other industries, it is still one of the most complex industry supply chains (Kafoglis 1999). Next to that the 24-hour operations make proper planning and forecasting critical (Louw 2006). Hence the urgency to limit complexity where possible. This section will discuss the sources of complexity and relates them to the practices in the chemical industry.

3.3.1.1 *Network complexity*

The network complexity rises by the number of nodes that exists in a network. As a result of outsourcing non-core activities many companies are today much more reliant on external suppliers of goods and services. These suppliers have to be managed. In the chemical industry this is seen through the outsourcing of transportation and partnerships for instance to serve a specific group of customers. Next to that parties common cooperate closely with competitors.

3.3.1.2 *Process complexity*

The process complexity comes with lengthy processes with multiple steps, often performed in series contributing to the complexity of operations. In the chemical industry the complex bill of material causes long and complex production chains with many steps to be performed in series.

3.3.1.3 *Range complexity*

The range complexity rises with the range of products sold. Though the products in the chemicals industry are commodities which indicate a low product range, the many end-markets makes it tempting to introduce more products in order to serve specific customer groups.

3.3.1.4 *Product complexity*

Product complexity is caused by a large number of ingredients and low commonality across the bill of materials. The chemicals industry is characterized by its complex bill of materials which increases the product complexity but also by a high commonality across the bill of materials, mitigating the complexity.

3.3.1.5 *Customer complexity*

Non-standard service options or customized solutions contribute to the customer complexity. In the chemicals industry the market power that lies with the suppliers make that many solutions are standardized. The complexity rises tough through the number of end-markets served. In the specialty chemicals typically a broad range of end-markets is served.

3.3.1.6 *Supplier complexity*

The supplier complexity rises with the size of the supplier base and related relationships that have to be managed. The vertical integration in the chemicals industry indicates a low supplier complexity, though this complexity is increased through the functional silos. The market power that lies with the suppliers prevents customers to seek reduction of their supplier base.

3.3.1.7 *Organizational complexity*

The organizational complexity can be increased by the number of functions and departments within the organization. In the chemicals industry the vertical integration can be argued to simplify the complexity, though functional silo's and secrecy mentality in fact increases the organizational complexity.

3.3.1.8 *Information complexity*

The information complexity rises by the volume of data. The antidote for information complexity is firstly a reduction in the other seven sources of complexity as well greater visibility. In the chemicals industry there is a high emphasis on data gathering (Louw 2006), but the secrecy mentality prevents information sharing and thereby visibility.

3.4 Trends

3.4.1 Introduction

In this section the trends in supply chain management will be discussed. Supply chain management literature mainly focuses on the markets directly serving the consumers, little attention goes to the supply chains delivering the raw and intermediate materials (Hussain 2006). Though the trends can be seen as one direction the world's industries are moving to, for analysis purposes, an artificial separation was made. In Appendix B, it will be researched to which extend these trends are also applicable to the chemicals industry and their impact.

3.4.2 Trends

3.4.2.1 *From focus on strong brands to capabilities and competencies*

In the past the ground rules for marketing success were obvious: strong brands backed up by large advertising budgets and aggressive selling. Now companies recognize that increasingly it is through their capabilities and competencies that they compete (Christopher 2011).

3.4.2.2 *Moving towards commoditization*

There is an inexorable transition towards 'commodity' type of markets (Christopher 2011). This makes service aspects like availability increasingly important. This trend towards the service-sensitive customer is as apparent in industrial markets as it is in consumer markets (Christopher 2011).

3.4.2.3 *Downward pressure on price*

Most markets are increasingly price competitive (Christopher 2011). This is caused by new global competitors with low-cost manufacturing bases, hence the rise China. This has led to overcapacity in many industries (Christopher 2011).

3.4.2.4 *Moving to outsourcing*

A growing number of large firms are rationalizing and decentralizing their operations by retaining core skills and drawing their additional needs from the market place. In the process they are moving to a more distributed method of production, encompassing all activities from upstream raw material input to downstream distribution of final goods, commonly referred to as, for example, extended enterprise, supply chain tunnels, lean production, and supply chain network (Wynarczyk 2000).

3.4.2.5 *Customers taking control*

As more and more markets become in effect 'commodity' markets, the need for the creation of differential advantage through added value (Christopher 2011). Increasingly a prime source of this added value is through customer service (Christopher 2011). Customers are increasingly looking for close cooperation with their suppliers (Christopher 2011).

3.4.2.6 *From 'stand-alone' competition to supply-chain rivalry*

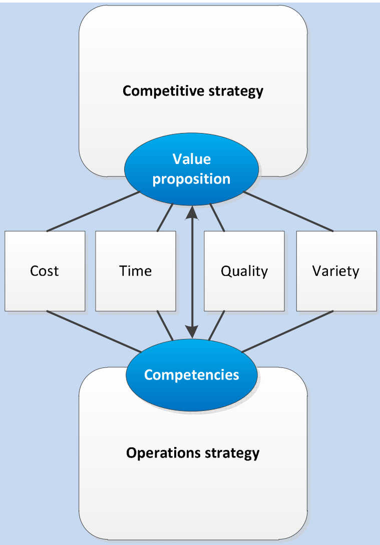
According to AMR, the basis of competition for winning companies in today's economy has become supply chain superiority (Friscia 2004). We are now entering the era of 'network competition', where leading organizations are those that can better structure, coordinate and manage the relationships with their partners in a network committed to delivering superior value in the final market place (Christopher 2011).

4 ANALYSIS FRAMEWORK

4.1 Introduction

4.1.1 Introduction

As discussed in the introduction, the objective of the framework is to structure the research to answer the main question. The main question reflects both the interests of the customer and the company, as the question is how to improve the customer-perceived value, with the constraint that such should occur in a cost-effective way for the company. Ultimately, the value of an organization stems from the value it is able to create for its customers over time minus the firm's cost of providing it, commonly operationalized as net present value (Mieghem 2008). There are two complementary frameworks that obtain to optimize this value; competitive strategy and operations strategy. Competitive strategy seeks to accomplish this by deciding which markets to enter and which value proposition to offer to its customers (Porter 1985). Operations strategy is a plan for developing an operational system with competencies that maximize net present value (Mieghem 2008). The two frameworks are respectively looking to the external position and internal operations of the company. In this chapter it will be argued that both competitive and operations strategy are needed to fully capture the scope of the main question. Figure 4-1 shows how competitive strategy and operations strategy are connected through the value proposition, defined in the competitive strategy, and the competencies, defined in the operations strategy.



Competitive strategy meets operations strategy

The research fields meet each other in the aspects that characterize the value proposition (cost, time, quality and variety) as defined in the competitive strategy and the aspects that characterize the competencies (cost, time, quality and flexibility / variety) as defined in the operations strategy.

Figure 4-1: Competitive strategy meets Operations strategy

4.1.2 Objective

The objective of this research is to improve the customer-perceived value of the supply in a cost effective way. Improving the customer-perceived value can be obtained through two exercises. First the value proposition should reflect best the customer value. Secondly the competencies should be aligned with the value proposition. Means to perform these exercises are found in respectively the competitive strategy and the operations strategy frameworks. The cost effectiveness of proposed changes is discussed in the operations strategy framework and will be the topic of further analysis.

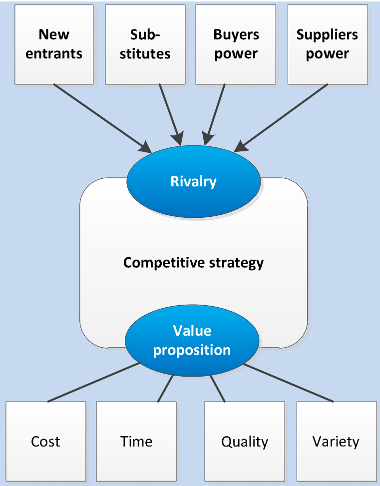
4.1.3 Structure

In this chapter, combining the competitive strategy- and operations strategy frameworks will be the starting point of constructing a framework which guides the research in a structured way to answer the main question. First the separate frameworks will be discussed. Secondly "strategic audit" will be provided that will set a series of analysis that will be executed in this research. Then each analysis will be discussed in detail.

4.2 Competitive strategy Framework

4.2.1 Introduction

Competitive strategy considers the drivers for competition in a market or potential market, how to react on actions that competitors take or might take, and how the industry evolves (Porter 1980). The objective is to position the firm best to compete in the long run, accomplish maximization of net present value of a firm by deciding which markets to enter and which value proposition to offer to its customers.



Competitive strategy

The threat of new entrants and substitute products or services and the bargaining power of suppliers and buyers shape the rivalry among existing firms (Porter 1980). The value proposition is built of a set of benefits that the firm offers the customers (cost, time, quality and variety).

Figure 4-2: Competitive strategy, adapted from Porter.

4.2.1.1 *Structure*

Though the focus in this research is more on the value proposition and its relation to the operations, this section starts with a brief notion of the concepts involved in rivalry. Secondly the value proposition will be discussed.

4.2.2 The competitive arena

The competitive arena ("Rivalry" in Figure 4-2), describes the forces that drive the rivalry among existing firms. These forces will be discussed in the following paragraphs.

4.2.2.1 *Threat of new entrants*

The threat of new entrants ("New entrants" in Figure 4-2) is a function of both barriers to entry a market and the reaction from existing competitors. The threat of new entrants in the chemicals industry is low because of the high entry barriers. Most dominant are the high investments needed, the high asset specificity and the low margins. For the customers of the company, the threat of new entrants recently increased as some of their suppliers are downwards integrating and thereby compete on the same markets as their customers.

4.2.2.2 *Pressure from substitute products*

The pressure from substitute products relates to the competition with industries producing substitute products. The polyols products find their application among others in the insulation industry where many alternatives are available.

4.2.2.3 *Bargaining power of suppliers and buyers*

Bargaining power of the suppliers and buyers (respectively "suppliers power" and "buyers power" in Figure 4-2) considers the power that the suppliers and buyers have in the competitive area. The conditions making suppliers powerful tend to mirror those making buyers powerful (Porter 1980). In Appendix A the circumstances that influence the buyer's and supplier's power in the industry were discussed in detail. In Table 4-1 these circumstances are summarized and divided in positive and negative circumstances for the company with respectively low and high buyer's power.

Positive circumstances (lower buyer's power)	Negative circumstances (higher buyer's power)

Buyers purchase low volumes relative to seller	Significant fraction of buyer's cost
High switching costs for the buyer	Commodity products
No credible threat of backward integration and credible threat of forward integration	Low profits in the buyer's industry
Quality is important to the buyer's products	Presence of retailers influence the demand
No information transparency for buyers	

Table 4-1: Bargaining power of suppliers and buyers

The bargaining power of suppliers and buyers is mainly set by the industry and out of reach for the company to change. Though the choice of buyer groups to sell to should be viewed as a crucial strategic decision (Porter 1980).

4.2.3 The value proposition

Besides choosing an attractive competition arena (which isn't in the scope of this research), choosing an attractive position within that industry is the second topic discussed in competitive strategy. Positioning can be described in terms of the customer value proposition. As discussed in the introduction of this chapter, the objective is to align the value proposition with the competencies of the company. The value proposition is built of a set of benefits that the firm offers the customers. The purchase decision of the customer depends on the value of the benefits relative to the costs. In the following paragraph the value proposition of the company will be discussed respectively to the costs and benefits.

4.2.3.1 *Customer value proposition*

The company sees itself as the commoditizer of the industry and tries to keep costs low by seeking economies of scale. For most industries their customers are active in require high quality products, the quality is considered a requirement rather than a benefit. By their choice to be the commoditizer, there is less space for variety. The company offers a limited portfolio of products. Production is forecast based and customers are asked to announce their orders long before the actual delivery. A summary of the customer value proposition is presented in Table 4-2.

Category	Ranking in Customer Value Proposition
Cost	High: Cost leadership
Time	Medium: No attention
Quality	High: High quality (requirement)
Variety	Medium: Commoditizer

Table 4-2: Customer Value Proposition

4.2.3.2 *Proposition of supply chain related themes*

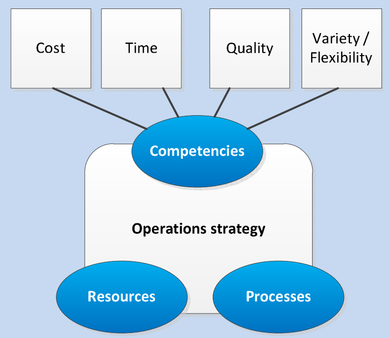
As discussed in Chapter 3 the activities of the company regarding supply chain management can be summarized in four principles: reliability, responsiveness, resilience and relationships (Christopher 2011).

In the company, special attention goes to the reliability as this is considered to be of high value for the customers, where an unreliable supply can lead to underutilization of their assets. There is low attention to responsiveness as the company seeks cost reductions in high asset utilization economies of scale. In order to obtain this, customers are asked to announce their orders long before the actual production and delivery. No special attention goes to resilience. Much attention goes to the relationship with the customer.

4.3 Operations strategy Framework

4.3.1 Introduction

Operations strategy is a plan for developing an operational system with competencies that maximize net present value (Mieghem 2008). While competitive strategy is about positioning the company best by means of formulating a value proposition, operations strategy focuses on enabling the execution of the strategy on how to best deliver this value proposition.



Operations strategy

Operations strategy focuses on developing resources and configuring processes. These resources and processes shape the set of competencies (cost, time, quality and flexibility).

Figure 4-3: Operations strategy (Mieghem, 2008).

4.3.1.1 *Structure*

A company's competencies are developed through its resources and processes. First the choices that a company should assess regarding its resources will be discussed. Secondly the choices regarding its processes will be discussed. Thirdly the current competencies of the company will be discussed. This section ends with a description of the strategic operational audit that aims to identify improvements in aligning the operational strategy with the competitive strategy.

4.3.2 Resource view

The resource view considers any organization as a bundle of real assets (Mieghem 2008). The resource strategy of a company considers four questions that characterize the capacity portfolio regarding sizing, timing, type and location. In Table 4-3 these four questions and the relevant industry characteristics and company specific characteristics are shown. The industry characteristics are discussed in detail in Appendix A.

Theme	Question	Industry characteristics	Company specific characteristics
Sizing	How many resources should we invest in?	Low margins make that resources are commonly not over-sized.	Selling more than 100% to assure assets utilization.
Timing	When should we increase or reduce	Long pay-back period and high sunk	Need has to be proven by means of a

	resources?	costs: conservative.	detailed business case.
Type	What kinds of resources are best?	The low margins increases the need for economies of scale, thus large installations.	Company aims to commoditize products in order to obtain economies of scale.
Location	Where should resources be located?	Global coverage	Global coverage, with global optimization activities.

Table 4-3: Resource-view themes, questions and characteristics

Regarding this research changing the resources is out of scope.

4.3.3 Process view

The process view considers an organization to be an activity network or a collection of processes (Mieghem 2008). By necessarily starting with inputs (expressed customer demands) and ending with outputs (served customer demands), the process view is compatible with a customer-centric view of the world (Mieghem 2008), which reflects the ambition of the company to become more customer-centric.

Processes can be either explicit or implicit. Explicit processes are well documented and can be captured in for instance a process flow diagram. Implicit processes are poorly documented and mainly depend on the tacit knowledge of the employees executing them. In order to evaluate and improve processes, it is important to formalize them.

A company's process strategy must answer four questions regarding supply, technology, demand and innovation. These questions will be discussed in more detail in the following paragraphs, where first a definition of the process will be given, followed by the characteristics of the industry and the company specific characteristics.

4.3.3.1 *Supply: Which activities are outsourced and how to manage suppliers?*

The supply or strategic sourcing process characterizes the interfaces and relationships with suppliers.

In the industry most functions are internal, except for the transport, which is commonly outsourced. Managing the suppliers is of high importance in order to assure the utilization of the assets.

The company is integrated upstream, which isn't the case for most competitors. This enables the production of certain products in continuous-mode, supporting their cost-leadership ambition. Further the company has a partnership in order to serve a group of smaller customers that doesn't fit in the profile the company is used to serve.

4.3.3.2 *Technology: Which technologies do our processes need?*

Technology characterizes how inputs are processed into outputs.

The process technology is mainly driven by the bill of material of the products produced. Products in this industry are mainly commodities, but offering specific features to customers offers some competitors an advantage as customers are locked in to one supplier. Transportation between parties is mainly done by road or bulk tankers, the typical long distances make transport lead-times uncertain. Internal transportation is done through pipe-lines with the advantage of continuous operations and low variations in transport lead-times.

The products the company focuses on are a limited set of products with an integrated bill of material that finds broad application in order to spread seasonality influences. The internal supply through pipe-lines makes supply lead-times more certain.

4.3.3.3 *Demand: How do we match demand and available supply?*

The demand management process characterizes the interfaces and relationships with customers.

In the industry coordination is mainly done through forecasting. Demand management is an important driver because of inflexible supply processes that cannot quickly adapt to changes in demand. There is limited sight on the demand of the end-user. This in contrast with companies like Dell. Here end-user marketing plays an important role in managing the demand of components upstream in the supply-chain.

The company has an S&OP process in place to facilitate the forecasting process which coordinates operations. The company has to deal with highly inflexible assets due to the focus on economies of scale. Especially the continuous processes but also the batch processes have to cope with large batch-sizes. The company invests heavily in customer relation management in order to facilitate these inflexible assets. The sight on the end-user market is even more blurred when traders block information from the markets and play with demand information in order to obtain higher margins, taking away the margins of the company.

4.3.3.4 *Innovation: How and when do we improve and innovate?*

Improvement and innovation characterize the processes and incentives to improve and innovate products and processes.

In the industry there is limited product development due to the high changing costs involved in introducing new products to existing customers. Also process developments are rare as there is limited spare capacity, making testing complicated and hazardous as every disruption is immediately felt by the customers.

The company hosts a 'performance excellence' team that evaluates processes and procedures in the organization. This team is mainly focused on the manufacturing processes rather than the order processes. Many innovations are taking place, mainly focussed on the technology.

4.3.3.5 *Summary*

The previous paragraphs give a rough impression of the processes in the company. In Table 4-4 these four questions and the relevant industry characteristics and company specific characteristics are summarized. The industry characteristics are discussed in detail in Appendix A.

Theme	Question	Industry	Company

Supply	Which activities are outsourced and how to manage suppliers?	Supplier management, Transport outsourced	Upstream integrated enterprise, Partnership for 'Rigids'
Technology	Which technologies do our processes need?	Driven by bill of materials, long transport lead-times	Limited set of products (commoditizer)
Demand	How do we match demand and available supply?	Forecasting, limited sight on demand end-user.	Coordination through S&OP process.
Innovation	How and when do we improve and innovate?	Limited developments (conservative).	Focused on manufacturing and technology rather than order fulfilment

Table 4-4: Process-view themes, questions and characteristics

4.3.4 Competency view

The competency view characterizes the abilities of the ensemble of the organization's resources, processes, and values. To determine an organization's competencies the categories cost, time, quality and flexibility are considered. In the following paragraphs these competencies will be discussed.

4.3.4.1 *Cost: What is the total cost operating, including variable and fixed costs?*

The industry is characterized by commodity products, which indicates that there are limited possibilities to differentiate than through price. Hence the low margins on these products. This effect is increased by the emphasis on asset utilization. This makes that the supply doesn't reflect the demand at all moments, pressing the price downwards. In the industry there are specialty products with a lower demand where higher margins can be obtained.

The company's ambition is cost-leadership, which they accomplish through economies of scale. Offering only the products with high demand and balancing the utilization of their assets by serving varying markets enables the company to maximize their asset utilization and obtain the needed economies of scale to offer the products for the best price.

4.3.4.2 *Time: What is the total response or lead time?*

The industry is characterized by large production installations that produce with large batch-sizes and installations capable of producing multiple products commonly have to cope with long campaign lengths in order to obtain economies of scale and prevent cross-contamination. The emphasis on asset utilization drives producers to long forecasting horizons and make that operations are not agile, in other words not able to quickly respond on changing demand (either quantity or product type). The lead-time, the time between planning and delivery, are in general several weeks.

In the company there is no special attention to the lead-time of orders. Customers are asked to nominate their orders long in advance and the actual time between ordering and delivery is fuzzy due to the negotiation taking place before the order is actually inserted in the system. This makes measures regarding the actual lead-time and order fulfilment rather difficult.

4.3.4.3 *Quality: What is the ability to deliver quality outputs?*

In the industry delivering quality is a requirement, especially in the 'performance' markets. Customers are highly dependent on the quality their suppliers are delivering. The actual performance of the product is commonly visible when the products are foamed and there is no way back to another product source, making a constant quality very important.

In the company there is a high emphasis on the quality of the products. All products are tested in a lab before transport. Long campaign lengths are in place in order to prevent cross-contamination.

4.3.4.4 *Flexibility: What is the operations' flexibility to change inputs, activities, volumes or outputs?*

The industry is characterized by the quality requirements and dependence of customers on this quality. This makes that the recipes of products are followed strictly to prevent quality issues, making the inputs inflexible. The emphasis on asset utilization makes that the volumes produced are rather inflexible as there is low spare capacity. There is some flexibility in the outputs, especially for the batch installations it is possible to switch to another type of product, though the danger of cross-contamination and long campaign lengths due to emphasis on economies of scale make that there is low range flexibility.

In the company recipes are also followed strictly and the bill of materials that is focused on a limited set of root products makes that inputs are not flexible. The emphasis on economies of scale has driven the company to continuous-mode production for some products, making it harder to switch between outputs.

4.3.4.5 *Summary*

In the previous paragraphs the competencies of the company were discussed.

Theme	Question	Industry	Company
Cost	What is the total cost operating, including variable and fixed costs?	Commodity products, pressing the margins.	Cost-leadership, emphasis on economies of scale.
Time	What is the total response or lead time?	Long forecasting horizons.	Fuzzy information about actual lead-time and order fulfillment.
Quality	What is the ability to deliver quality outputs?	Quality requirements are high, customers depend on them.	Emphasis on quality by lab testing and long production campaigns.
Flexibility	What is the operations' flexibility to change	Inflexible assets	Increased inflexibility due to emphasis on

	inputs, activities, volumes or outputs?	economies of scale.

Table 4-5: competency-view themes, questions and characteristics

4.3.5 Conclusion of resource-, process- and competency view

In the resource view it was explained that the resources were designed to support the cost leadership ambition of the company. Resulting in highly inflexible resources with high batch sizes due to the emphasis on economies of scale.

The processes also aim to sustain the cost leadership position and assure high quality products. In order to sustain the cost leadership position there is an emphasis on asset utilization, resulting in long campaigns and a need for long term forecasting.

The resources and processes set the competencies of the firm. The processes assure high quality products. Also the cost leadership position is sustained through the resources and processes in place. Cost leadership though highly compensates the responsiveness and flexibility.

4.3.6 Strategic operational audit

4.3.6.1 *Introduction*

A strategic operational audit "takes stock" of an organization's operation to assess its degree of fit with competitive strategy and to identify where improvements can be made (Mieghem 2008).

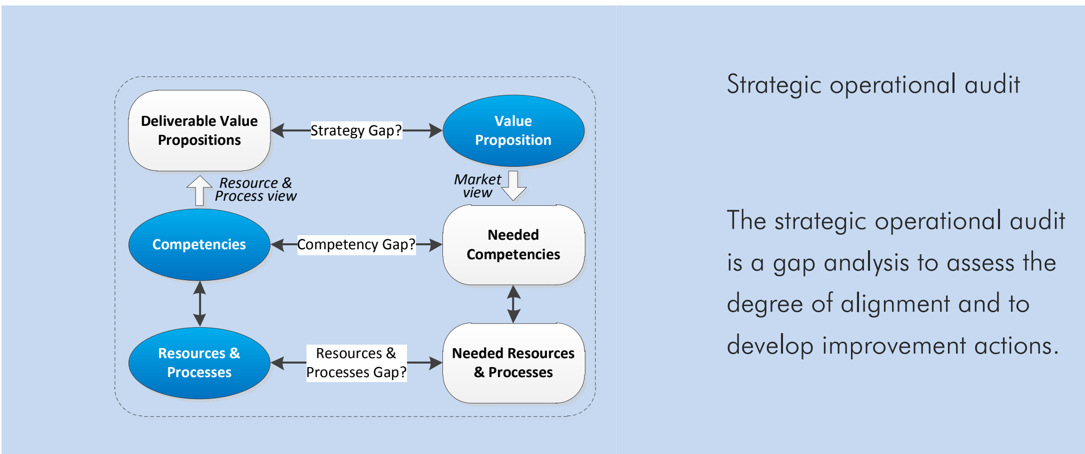


Figure 4-4: Strategic operational audit

4.3.6.2 *Market- and 'resource & process'-view*

There are two views that can be applied to assessing the fitness of an organizations' operation with its competitive strategy. The market view starts with the value proposition of the organization and determines the needed competencies and underlying resources and processes. The 'resource & process'-view starts with the current competencies and underlying resources and processed of the organization and determines the value proposition that can be delivered.

4.3.6.3 *Steps*

The strategic operational audit describes three steps to be taken in order to perform the audit:

1. Audit the current operational system: its resources, processes, and competencies. This step is represented by the three ovals in Figure 4-4.
2. Apply the 'resource & process'-views (bottom-up) to characterize the set of value propositions that current competencies can support well. Followed by the market view (top-down) perspective to specify the competencies needed to execute the current competitive strategy. This step is represented by the three rectangles in Figure 4-4.
3. Assess the gaps between the current state and the needed state to ensure strategic alignment.

Based on this assessment "gap reducing actions" can be developed. The strategic operational audit only considers changes that involve the internal operations of the company or its value proposition. It doesn't audit the fitness of the value proposition with respect to the competitive arena which is considered in competitive strategy. This inspired extending this audit with respect to the competitive strategy, which will be discussed after the next section.

4.4 Relation with Supply Chain Management

4.4.1 Introduction

Supply Chain Management considers the management of upstream and downstream relationships with suppliers and customers in order to deliver superior customer value at less cost to the supply chain as a whole (Christopher 2011). In chapter 3 two methods to guide the supply chain manager were discussed. This section relates supply chain management to the 'competitive strategy'- and 'operations strategy' framework. Figure 4-5 visualizes of how in supply chains for each company a competitive strategy and an operations strategy can be defined. The interaction between these strategies through the market and logistics will be discussed in the next section.

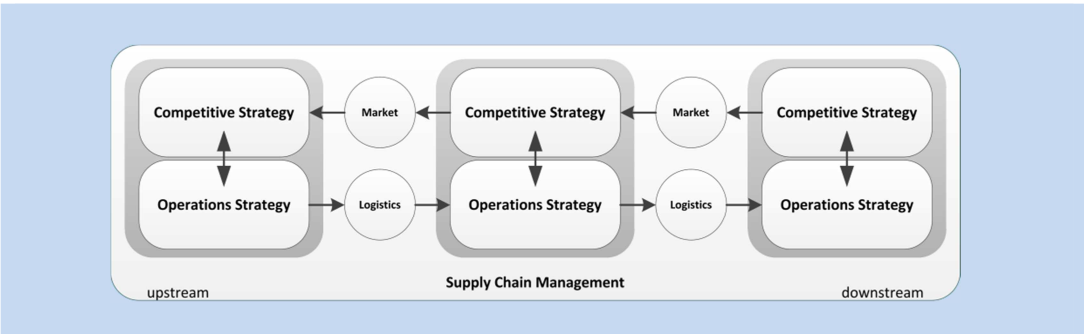


Figure 4-5: Company as a function to a supply chain

In literature there are two streams that have a different scope regarding the definition of Supply Chain Management. First there is the philosophy of supply chain management that considers the company as a function to the supply-chain. This extends the concept of partnerships into a multi-firm effort to manage the total flow of goods from the supplier to the ultimate customer (Ellram 1990). On the other hand there is the stream that considers supply chain management as a function to the company. Stevens (Stevens 1989) identified four stages regarding this view starting at the point where the supply chain is a function of fragmented operations within the individual company and ending in supply chain integration with suppliers and customers. Considering the research question, the focus in this research will be on the more pragmatic interpretation where supply chain management is a function to the company, which considers the company as a set of production echelons. Known as the multi-echelon context (Sherbrooke 2004).

4.4.2 Interaction

The philosophy behind supply chain management is to extend the internal activities by embracing an inter-enterprise scope, bringing trading partners together with the common goal of optimization and efficiency (Harwick 1997)). This efficiency is achieved through operations, materials and logistics management (Harwick 1997) . In Figure 4-5 operations and materials management are considered in the 'operations strategy', logistics is represented by both the inbound and outbound logistics of the company. The indicated relation between competitive and operations strategy was discussed in detail in the previous sections. Practitioners of supply chain management are looking for integration with their suppliers and their distribution functions. This is represented by the relations between the in- and outbound logistics, and the operations strategy of the focal firm in Figure 4-5. Competitive strategy considers the drivers for competition in a market (Porter 1980). The competitive strategy is focused on the downstream market, this is represented by the relation between the downstream market and the competitive strategy of the focal firm in Figure 4-5. A buyers' market is an ideal situation in which to develop long-term strategies with key suppliers because buyers have leverage in negotiating specialized processes for recurrent transactions (Ellram 1994). This indicates that the viability of supply chain cooperation is a function of the market conditions. The previously presented integration of competitive strategy and operational strategy discusses how in the end the operations are or are not adapted to the wishes of the downstream market.

The previously discussed operational audit will be extended to the strategic audit. The strategic audit is based both on operations and competitive strategy and helps companies in a supply chain to align the wishes of the downstream market with their operations.

4.5 Strategic audit

4.5.1 Introduction

4.5.1.1 *Competitive and operations strategy frameworks*

For the strategic audit, both the competitive and operations strategy framework are included. This chapter started with relating the research fields of competitive and operations strategy. The frameworks meet each other in the aspects that characterize the value proposition (cost, time, quality and variety) as defined in the competitive strategy and the aspects that characterize the competencies (cost, time, quality and flexibility / variety) as defined in the operations strategy. The two frameworks obtain to optimize the net present value of the company. Competitive strategy seeks to accomplish this by deciding which markets to enter and which value proposition to offer to its customers (Porter 1985). Operations strategy is a plan for developing an operational system with competencies that maximize net present value (Mieghem 2008). The two frameworks are respectively looking to the external position and internal operations of the company.

The strategic audit is an extended version of the strategic operational audit. The strategic operational audit "takes stock" of an organization's operation to assess its degree of fit with competitive strategy and to identify where improvements can be made (Mieghem 2008). The strategic operational audit only considers improvements that involve the internal operations of the company or its value proposition. It doesn't audit the fitness of the value proposition with respect to the competitive arena which is considered in competitive strategy. In order to find a value proposition that fits both the internal competencies and a profitable external proposition, both the competitive and operations strategy framework are needed.

A combination of the two frameworks makes that observations on the commercial interface can be interpreted along the entire scope from the competitive position through competitive strategy to operations strategy. This will show how resources and processes can reflect the competencies needed to fulfill a customer value proposition which assures a sustained profitable position in the competitive arena. Considering the entire scope of these two frameworks should prevent jumping into solutions that don't reflect a good position in the competitive arena or the company's competencies.

4.5.2 Framework extension

The strategic operational audit can be extended to reflect both the operational strategy as the competitive strategy. Competitive strategy considers the drivers for competition in a market or potential market, how to react on actions that competitors take or might take, and how the industry evolves (Porter 1980). The objective is to position the firm best to compete in the long run, accomplish maximization of net present value of a firm by deciding which markets to enter ("Choice of Industry" in Figure 4-6) and which value proposition to offer to its customers ("Value Proposition" in Figure 4-6). The drivers for competition are mainly set by this industry ("Industry" in Figure 4-6) and out of reach for the company to change. Though the choice of buyer groups to sell to ("Customers" and "Choice of Customers" in Figure 4-6) should be viewed as a crucial strategic decision (Porter 1980).

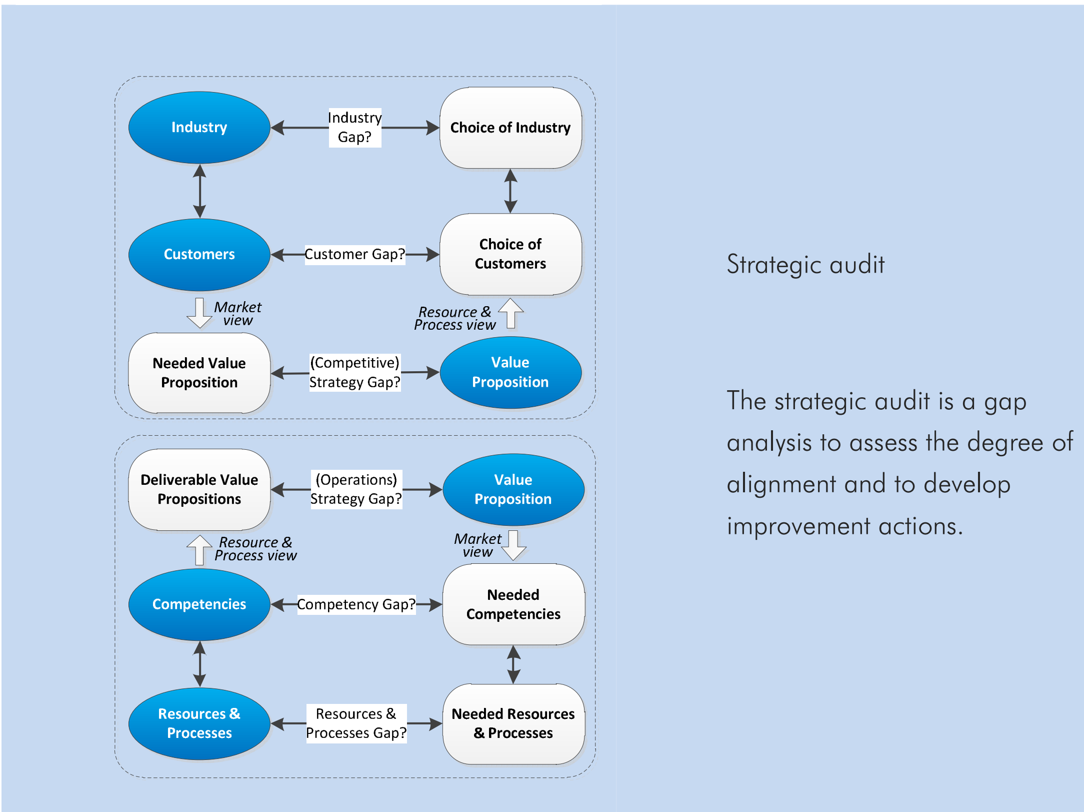


Figure 4-6: Strategic Audit

Similar to the strategic operational view, there are two views that can be applied to assess the fitness of an organizations' operations and competitive strategy. In the next section it will be argued why the market view is the appropriate view for this research. In the section thereafter the gaps that are pointed out in the strategic audit will inspire a series of analyses.

4.5.3 Market view

As discussed in the strategic operational audit, there are the 'market'-view and the 'resources & processes'-view that can be used to assess the fitness of the strategies. The problem statement discussed that the problem was felt at the commercial interface and the research was commissioned by the supply department. Therefor in this research the market view will be applied, starting at the 'market' and resulting in improvements in the resources and processes of which the supply department is responsible. In other words improving the customer-perceived value of the supply though the manufacturer's operations.

4.5.3.1 *Scope*

A full audit should include both views, but as a starting point this research will be limited to the market view. It is important to keep in mind that identified gaps can be mitigated by making improvements on the 'operations' side (by means of resources and processes) as well as on the 'market' side (by means of the choice of industry and customer selection).

4.5.4 Gaps

In the strategic audit, as shown in Figure 4-6, six potential gaps are identified, in the following paragraphs these gaps will be discussed and further analyses will be suggested.

4.5.4.1 *Industry Gap*

The industry gap indicates the deviation between the 'industry of choice' and the actual industry the company is active in. The 'industry of choice' is the industry that reflects the value proposition and underlying competencies best. The sunk costs of investments in the past make companies conservative regarding the industry they are active in. Even if leaving an industry is not a realistic scenario, it is important to know what drives the competition in the industry and how these determents are changing in the future. In many industries supply chain management is increasingly important for companies to gain competitive advantage and has influenced their operations and relationships with other parties in the supply chain (Christopher 2011).

In order to identify possible 'industry gaps', the trends in the industry will be researched. The identified trends in supply chain management will be used for this goal. In the industry trends analysis it will be analysed to what extend the trends in supply chain management are applicable to the polyols industry and what their implications are.

4.5.4.2 *Customer Gap*

The customer gap indicates the deviation between the 'customers of choice' and the actual customers. The 'customers of choice' are the customers that one would look for given the customer value proposition. In order to make strategic decisions on what buyer groups to serve, the company should understand the market into large extend. In this research the market view will be applied, which means that the customers will be considered a given. The remaining question then is what the needed value proposition is to serve these customers appropriate. As discussed before supply chain management and logistics is increasingly important and can be seen as leading in the way customers value the supply related aspects of their suppliers.

In order to identify possible 'customer gaps', the value that customers assign to supply related aspects and how they grade the current performances on these aspects will be researched in the customer value analysis.

4.5.4.3 *Competitive Strategy Gap*

The competitive strategy gap indicates the difference between the needed value proposition and the actual value proposition. The needed value proposition considers the most appropriate value proposition when looking at the current customers and industries the company is participating in. When there is a difference the underlying determinants should be changed, this gap can be identified based on the industry trends analysis and the customer value analysis.

4.5.4.4 *Operations Strategy Gap*

The Operations Strategy Gap indicates the difference between the 'deliverable value proposition' and the actual value proposition. The 'deliverable value proposition' is the proposition that reflects the company's competencies and underlying resources and processes best. When there is a gap, either the value proposition should be changed or the deliverable value proposition should be changed by means of changing the competencies.

4.5.4.5 *Competency Gap*

The competency gap considers the difference between a company's competencies and the needed competencies that fully reflect the value proposition. When applying the market-view, the 'needed value proposition' will set the needed competencies. These needed competencies will be leading in improving the underlying resources and processes.

The competencies of the company can be analysed by means of a customer satisfaction analysis. In this analysis the current competencies will be graded by the current customers. Combined with the customer value analysis this will give insight in the needed competency improvements.

4.5.4.6 *Resources & Processes Gap*

The 'resources & processes'-gap considers the difference between a company's current resources and processes and the needed resources and processes. When applying the market-view, the 'needed resources & processes' will be set by the 'needed competencies'.

Changing resources or processes can become rather expensive, substantive quantitative evidence is then needed to support the business plan needed to get funding for the needed investments. Testing the effect of changes in the resources and processes can be done through a simulation model analysis. A further argumentation for the use of a simulation model will be given in the chapter 6.

4.5.5 Analyses

Based on the competitive- and operations strategy, the strategic audit dictates gaps that need to be identified by means of a series of analyses. Figure 4-7 shows how these frameworks, activities and the suggested analyses are related. The steps inspired by the strategic audit are numbered 1 to 5.

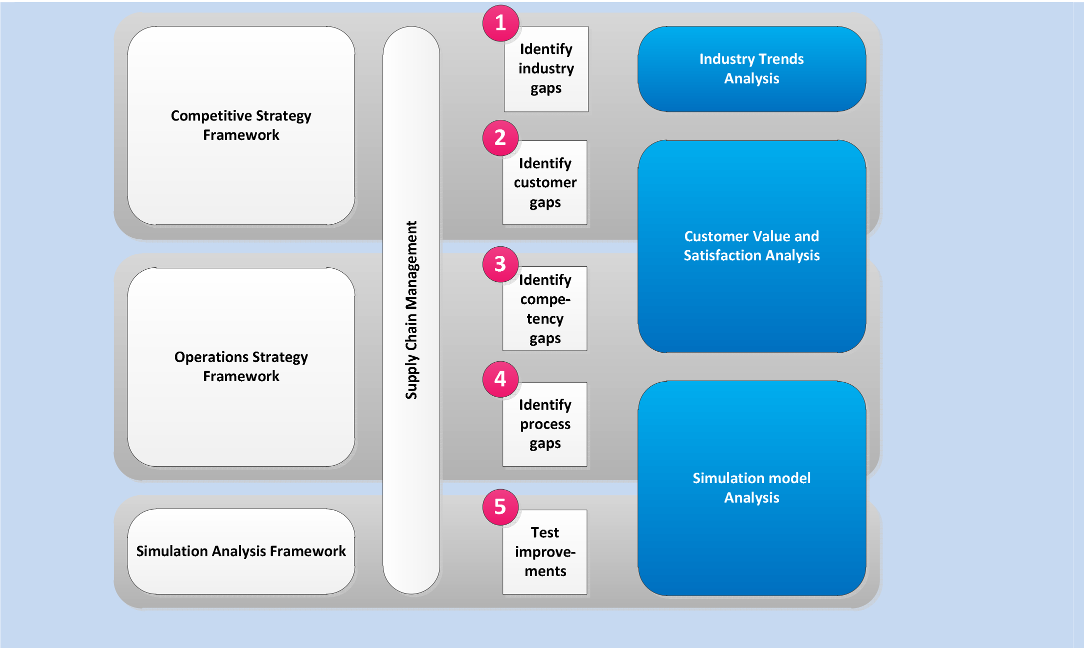


Figure 4-7: Relations between frameworks, activities and analyses.

In the following sections these analyses will be discussed in further detail. The Simulation Model Analysis will include the conclusions from the precursory analyses, that is why this analysis will not be explained in this chapter but after the results of the precursor analyses are discussed.

4.6 Industry trends analysis

4.6.1 Objective

The objective of the industry trends analysis is to identify trends in the industry that influence the customer-perceived value of operations.

4.6.2 Methodology

Supply Chain Management is considered increasingly important in the customer-perceived value. Supply Chain Management literature includes a series of trends that apply to companies that are part of a supply chain. Little literature is available about the trends in chemicals- and polyols industry. Therefor the methods used are a literature review on generic trends in supply chain management and a workshop to find out to which extend these generic trends are applicable to the chemicals industry.

4.6.3 Trends in supply chains

In Chapter 3 the trends in supply chain management were discussed. These trends consider general changes in the way supply chains are managed in varying industries. The extent to which a company experiences these trends depends on the competition playing field of the suppliers of the company, the competition playing field of the company itself and the competition playing field of the customers of the company.

A change in the configuration of one part of the supply chain commonly has an effect on the configuration of the neighbouring parts of the supply chain. As the business is integrated upstream, it makes sense to focus on the changes that occur downstream of the company, in other words the changes that their customers' experience, this is in line with the market-view discussed in the strategic audit.

4.6.4 Workshop

In order to find out to which extend the general trends apply to the company and their customers a workshop will be organized. In this workshop the trends are presented and discussed to a representative group of employees of the company.

4.7 Customer value analysis

4.7.1 Objective

The objective of the customer value analysis is to identify gaps between the customers deriving from the current value proposition and the actual customers that set the 'needed value proposition', see in Figure 4-6 (on page 36) how these terms relate to one each other.

4.7.2 Methodology

In order to identify the 'customer gap', it will be researched how the current customers value aspects the supply, called the importance, and how the company's current practices are valued, called the performance. The aspects that need most attention can be derived through the importance and performance. The aspects that need most attention are those that are of high importance but on which the customers indicate low performance. Customers will be asked to indicate the importance and performances on supply related aspects in an online survey. In order to determine the importance that customers assign to certain aspects of the supply the AHP will be used. The analytic hierarchy process (AHP) is an approach used to determine the relative importance of a set of criteria (Saaty 1994). The company's performance on the aspects will simply be determined through grading. This analysis will be executed in five steps:

- Step 1: Identify themes (literature review)
- Step 2: Identify industry-related aspects (literature review)
- Step 3: Collect data about performances and importance (survey)
- Step 4: Quantify importance of aspects (AHP)
- Step 5: Select aspects that need most attention (importance-performance analysis)

In the following paragraphs, these steps will be discussed in detail.

4.7.3 Step 1: Identify themes (literature review)

In order to cover the full range of aspects that can be considered by the customers regarding the company's supply, two perspectives are integrated: the supply perspective and the customer value perspective.

4.7.3.1 *Supply perspective*

For the supply perspective the guiding principles discussed in Chapter 3 will be used: responsiveness, reliability, resilience and relationships. These principles guide firms to improve their fitness in a supply chain and thereby clearly represent the supply perspective.

4.7.3.2 *Customer value perspective*

Customer value can be defined as the difference between the perceived benefits that flow from a purchase or a relationship and the total cost incurred (Johansson 1993). These benefits are expressed in the quality and the service, the total cost in the total cost of ownership and time. To go short, customer value can be expressed through cost, quality, service and timing.

4.7.4 Step 2: Identify industry-related aspects (literature review)

The previously two presented perspectives on supply and customer value will be used to identify a comprehensive set of aspects of the supply that can be considered by the customers. To prevent strategic behaviour in the answering of this survey, the cost element was excluded. Within the four supply-chain principles (responsiveness, reliability, resilience and relationships) at least three industry-related aspects will be identified, related to one of the elements of customer value (quality, service and timing).

This results in the following table, to be filled with industry-related aspects:

	Quality	Service	Timing
Responsiveness	•	•	•
Reliability	•	•	•
Resilience	•	•	•
Relationships	•	•	•

Table 4-6: Aspects in customer value in supply chains

In Appendix A the characteristics of the chemicals industry have been discussed. Based on these characteristics Table 4-6 will be filled with industry-related aspects.

4.7.5 Step 3: Collect data about performances and importance (survey)

The next step is to find out how important these aspects are to customers and how the current performances on the aspects are. Two ways to do so where considered:

- Based on the knowledge of the sales force.
- Based on the experience of the customers.

The first option is the least time consuming and can be quite accurate when the sales force is well equipped with information about the preferences and experiences of their customers. The second option is a lot more time consuming, as it needs the customers to be involved but when executed well it gives better results and the prospect of new insights for the sales force. In this research the second option will be executed by means of an online survey.

Based on the industry-related aspects, an online survey will question a selection of customers to:

- Grade to performances of the company on the aspects
- Pair-wise compare the importance of the aspects

The survey starts with a short introduction to explain to the customer what is expected. Then for each theme; an introduction to the theme, an explanation of the aspects within this theme, a field for the pair-wise comparison of the importance of the aspects, a field for grading the performances on the aspects. Then a field for the pair-wise comparison of the importance of the themes and a field for grading the performances on the themes. Finally there is a feedback field where clients can give feedback regarding the topics discussed in the survey.

Putting the survey online is recommended as it is less time consuming; results can easily be exported for analysis, it is easy to reach a broad group of customers. There are a couple of remarks when using online surveys:

- The themes and aspects have to be explained clearly to prevent that customers are expressing their experiences on another topic than questioned.
- The method to compare the themes and aspects is a little complicated, it is important to explain this very clearly to the customers.
- Filling in the survey is time consuming, it is important to show that it is in the interest of the customer to participate and show how the results are used.

4.7.6 Step 4: Quantify importance of aspects (AHP)

The pair-wise comparison in the survey can be used to extract the importance that customers give to each of the aspects. This will be done with AHP, a structured technique for organizing and analysing complex decisions (Saaty 1994). In this process, the decision maker carries out simple pair-wise comparison judgments which are then used to develop overall priorities for ranking the alternatives (Saaty 1994). In this case the customer can be seen as the decision maker, deciding upon which supplier to choose by developing priorities for the identified aspects through pair-wise comparison. In a full AHP analysis the decision-maker will use these priorities in the end to select the best alternative, as shown in Figure 4-8.

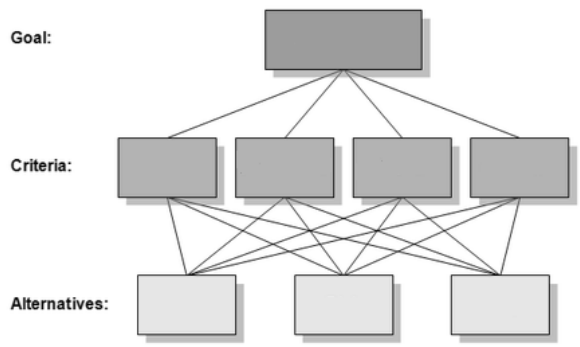


Figure 4-8: AHP decision tree hierarchy

For example the selection of the most appropriate supplier. Or from the company’s view to make a selection of a set of alternative supply configurations to most satisfy their clients. This last step will not be included in this research. The method is only used to determine the weight of the criteria, in fact the importance of the aspects.

4.7.7 Step 5: Select aspects that need most attention (importance-performance analysis)

The objective of the customer value analysis is to identify which aspects of the company´s processes need most attention. Through the survey and AHP it will be found how customers value the importance of the identified industry-based aspects and the company's performances on these aspects. An attractive feature of importance-performance analysis is that the results may be graphically displayed on an easily interpretable two-dimensional grid (Martilla 1997). Based on the position in this grid a quick interpretation can be drawn is shown in Table 4-7.

Importance	Performance	Interpretation
Low	Low	Low priority
Low	High	Possible overkill
High	Low	Concentrate here
High	High	Keep up the good work

Table 4-7: Interpretation of importance-performance analysis.

The aspects that need most attention are typically of high importance, but low performance.

5 CUSTOMER VALUE ANALYSIS

5.1 Introduction

5.1.1 Assessing the customer gap

In Chapter 4 it was discussed how the company's value proposition and the values of the company's customers should be aligned. The gap identifies deviations between the 'customers of choice' (the customers one would choose regarding the current value proposition) and the actual customers. In this chapter the Customer Value Analysis will assess this gap.

5.1.2 Methodology

The methods and steps taken can be summarized as:

- Step 1: Identify themes (literature review)
- Step 2: Identify industry-related aspects (literature review)
- Step 3: Collect data about performances and importance (survey)
- Step 4: Quantify importance of aspects (AHP)
- Step 5: Select aspects that need most attention (importance-performance analysis)

These methods and steps are discussed in detail in Chapter 4, this chapter will continue with the execution phase and the results will be presented.

5.2 Themes and industry-related aspects

5.2.1 Introduction

As defined in step 1 and 2, themes and industry-related aspects should be identified. This section will discuss how these themes and aspects were found and the identified aspects will be presented.

5.2.2 Industry related aspects

Based on the identified characteristics of the industry, interviews and conversations, for each theme a set of at least three aspects were identified. These three aspects relate to the subjects quality, service and timing. In the following paragraphs the four themes will be discussed briefly, these descriptions will form the industry related aspects.

5.2.2.1 *Responsiveness*

Responsiveness concerns the ability to respond to customers' requirements in ever-shorter time-frames. There requirements can be customized solutions, flexibility in quantity and logistic arrangements and shorter lead-times. A concern commonly raised by the company's customers is the ability of the company to support the customers' growth.

5.2.2.2 *Reliability*

One of the main reasons why any company carries safety stock is because of uncertainty. This can be uncertainty about the ability of the supplier to deliver a constant quality, keep the products available and meet delivery promises. The high emphasis on quality makes that good product documentation is required in the polyols industry.

5.2.2.3 *Resilience*

Today's marketplace is characterized by higher levels of turbulence and volatility. As a result, supply chains are vulnerable to disruption and, in consequence, the risk to business continuity is increased. These disruptions can either result in 'off-spec' products, products that do not comply with the specifications as required by the customer or in the worst case to a 'force-majeure', a longer period of time in which the company is not able to supply its customers.

5.2.2.4 *Relationships*

Increasingly companies are discovering the advantages that can be gained by seeking mutually beneficial, long-term relationships with suppliers. This relationship stimulates collaborative planning and scheduling and process alignment. The chemicals industry is characterized by a functional silo and secrecy mentality, this frustrates the ease of doing business.

This led to set of industry related aspects as defined in Table 5-1.

Theme	Subject	Aspect
Responsiveness	Quality	Customized solutions
	Service	Flexibility
	Timing	Support of growth
		Lead Times
Reliability	Quality	Constant quality
	Service	Product documentation
	Timing	Keeping delivery promise
		Product availability
Resilience	Quality	Dealing with 'off-spec' products
	Service	Dealing with 'force-majeure'-situations
	Timing	Recovery time from 'force-majeure'-situations
Relationships	Quality	Process alignment
	Service	Ease of doing business
	Timing	Collaborative planning and scheduling

Table 5-1: Industry related aspects

An explanation of these aspects is given in the survey that will be discussed next.

5.3 Survey

5.3.1 Introduction

As identified in step 3, data should be collected about how important aspects are to customers and how the current performances on these aspects are. This was done by means of an online survey.

5.3.2 Example

In this survey customers are asked to grade the performances of the company on the identified aspects, this would typically look like this:

	1	2	3	4	5	6	7	8	9	10	N/A
Customized solutions	○	○	○	○	○	○	○	○	○	○	○
Flexibility	○	○	○	○	○	○	○	○	○	○	○
Support of growth	○	○	○	○	○	○	○	○	○	○	○
Lead times	○	○	○	○	○	○	○	○	○	○	○

Use 1 for very disappointing and 10 for perfect, N/A if not applicable to your company.

And pair-wise compare the importance of the aspects, this would typically look like this:

	much more important	more important	equally important	less important	much less important
Flexibility ... than Customized solutions	○	○	○	○	○
Support of growth ... than Customized solutions	○	○	○	○	○
Lead Times ... than Customized solutions	○	○	○	○	○
Support of growth ... than Flexibility	○	○	○	○	○
Lead times ... than Flexibility	○	○	○	○	○
Lead times ... than Support of growth	○	○	○	○	○

5.3.3 Response

A selection of customers was invited to participate in the survey. Though the selection aimed on a good representation of the company's customers organizational issues led to a biased response. The products are grouped in Flexibles, Rigids and CASE. Applications for the Flexibles are among others mattresses and car seats. The Rigids are typically found in insulation panels. CASE is the abbreviation for its application in coatings, adhesives, sealants and elastomer. All three groups roughly represent 1/3 of the total profits. The Rigids are marketed through a partnership and were not considered in this analysis. Due to the availability of account managers and their willingness to cooperate there were two responses from Flexibles customers, five from CASE customers and one from a customer that buys from both groups. The company has ambitions to increase their market share regarding CASE, which emphasises the importance of these customers.

5.3.4 Deployment

Account managers contacted the selected customers and invited them to participate in the survey. The customer filled in the survey that could be reached by a link that was send by e-mail. The account manager would discuss the topics with the customer via telephone, in order to answer questions and also to note the responses from the customer that were out of scope for this survey. In general these conversations with customers were perceived as contributively to the relationship and understanding of the customers' preferences.

5.4 Results

5.4.1 Introduction

As defined in step 4, the importance of the aspects has to be quantified. Step 5 describes how a selection of aspects that need most attention can be made.

5.4.2 Importance of aspects

In the survey customers were asked to pair-wise compare the importance of the identified aspects. Through AHP, these comparisons were quantified as presented in Table 5-2. Figure 5-1 shows the performance and un-weighted importance of all aspects.

Theme	Aspect	Performance	Importance	Weighted importance
Responsiveness	Customized solutions	6.8	0.04	0.02
	Flexibility	7.4	0.25	0.09
	Support of growth	7.4	0.28	0.10
	Lead Times	7.3	0.43	0.15
	Theme	7.4	0.36	
Reliability	Constant quality	9.4	0.44	0.15
	Product documentation	7.9	0.14	0.05
	Keeping delivery promise	8.1	0.24	0.08
	Product availability	7.5	0.17	0.06
	Theme	8.1	0.34	
Resilience	Dealing with 'off-spec' products	8.3	0.40	0.06
	Dealing with 'force-majeure'-situations	7.5	0.34	0.06
	Recovery time from 'force-majeure'-situations	7.3	0.26	0.04
	Theme	7.3	0.16	
Relationships	Process alignment	7.9	0.15	0.02
	Ease of doing business	7.6	0.39	0.05
	Collaborative planning and scheduling	7.9	0.46	0.06
	Theme	8.1	0.13	

Table 5-2: Importance of aspects

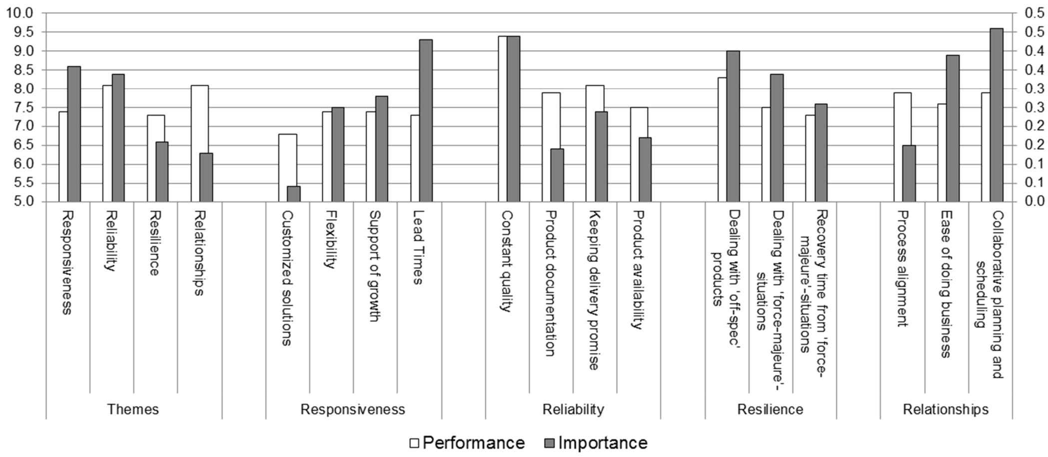


Figure 5-1: Performance and un-weighted importance of aspects

5.4.3 Interpretation

Overall the customers grade the performances of the company rather high, varying from a 6.8 for 'customized solutions' to a 9.4 for 'constant quality'. The importance of aspects within the themes (adding up to 100%) vary from 4% for 'customized solutions' up to 43% for 'lead times'.

In the following paragraphs the results within the themes will be discussed in more detail.

5.4.3.1 *Responsiveness*

Within the responsiveness theme, it becomes clear that the company is serving a commodity market where customers are not interested in customized solutions. Further it is striking that lead times are considered highly important while in reality customers are asked to nominate their demand several weeks on beforehand, shown through the moderate grade customers give for the performance on lead times.

5.4.3.2 *Reliability*

The quality sensitivity, before discussed as a characteristic of the industry, can be recognized in the high importance customers assign to constant quality. The company is doing very well on this aspect as performances are graded a 9.4 on average. The past investments of the company on reliability can be recognized in the relative high performances related to the importance.

5.4.3.3 *Resilience*

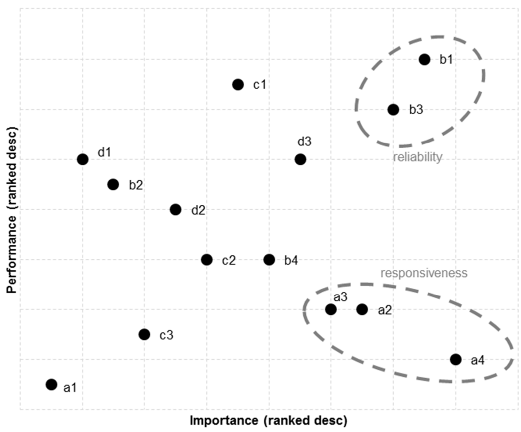
The importance the customers assign to dealing with 'off-spec' products can be explained as emphasising the quality sensitivity, also on this aspect the company is doing well with an average mark of 8.3. Next important is the dealing with a 'force-majeure' situation, which was assigned more importance than the recovery time from a 'force-majeure'. This indicates that customers more value a smooth execution of the procedures, among which providing usable information for the customers about the 'force-majeure' and its impact than the time that is needed to resolve the disruption.

5.4.3.4 *Relationships*

Overall the marks given for the performances are rather high, ranging from a 7.6 to a 7.9 on average. Both 'collaborative planning and scheduling' and 'ease of doing' business score high on importance. Low importance is given to process alignment. Which indicates that customers are interested in closer cooperation more on the soft elements as planning and administration than on hard elements as logistics and quality management. That customers are not interested in the hard elements can be explained through the objective of the company to serve customers that have the competencies to handle the products themselves, without extensive support.

5.4.3.5 *Overall evaluation*

In the previous paragraphs the aspects within one theme were compared. Customers were also asked to the importance of the themes as a whole. This makes it possible to compare the aspects of different themes. It was shown that responsiveness and reliability are indicated as most important (36% for responsiveness and 34% for reliability). Low importance was given to resilience (16%) and relationships (13%). Now the importance given to the themes is known, the weighted importance (as already presented in Table 5-2) can be calculated, enabling to compare the aspects of different themes.



a1	Customized solutions
a2	Flexibility
a3	Support of growth
a4	Lead Times
b1	Constant quality
b2	Product documentation
b3	Keeping delivery promise
b4	Product availability
c1	Dealing with 'off-spec' products
c2	Dealing with 'force-majeure' situations
c3	Recovery time from 'force-majeure'
d1	Process alignment
d2	Ease of doing business
d3	Collaborative planning in scheduling

Figure 5-2: Importance-Performance Diagram

In the Importance-Performance Diagram shown in Figure 5-2 the aspects are ranked and sorted descending (lowest importance in the left, lowest performance in the bottom). The aspects can easily be interpreted on a two-dimensional grid as shown in Table 5-3 (Martilla 1997).

Importance	Performance	Position	Interpretation
Low	Low	Left Bottom	Low priority
Low	High	Left Top	Possible overkill
High	Low	Right Bottom	Concentrate here
High	High	Right Top	Keep up the good work

Table 5-3: Interpretation of importance-performance analysis.

Regarding this table, the customized solutions is considered low priority, which can be explained through the commodity market. There are no aspects that clearly are in the area of possible overkill. The past investments of the company in the reliability of its supply are emphasised through the aspects 'constant quality' and 'keeping delivery promise' in the 'keep up the good work' corner. The aspects that are in the 'concentrate here' corner are all related to the responsiveness theme: 'support of growth' and 'flexibility' are important, but have low performances. The worst is 'lead times' that is indicated as most important of all aspects, while the performances is among the lowest.

5.4.3.6 *Product segments*

The products are grouped in Flexibles, Rigids and CASE, related to the application at the customer. The CASE customers are in general smaller than the Flexibles customers and are more exposed to the increasing volatility in demand experienced in consumer markets. Though the number of responses from the Flexibles customers doesn't justify solid conclusions on the differences between these customers groups, the results do give some insights that are interesting. Customers were asked to indicate the importance they attribute to responsiveness and reliability. In the company the idea that reliability is most important is widespread. The survey though indicated that customers found responsiveness a little more important than reliability. Figure 5-3 shows how CASE and Flexibles respondents indicated the importance of reliability and responsiveness.

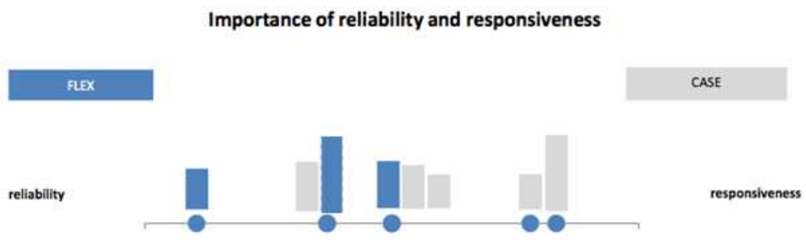


Figure 5-3: Importance of reliability and responsiveness

The figure shows that Flexibles customers find reliability more important while CASE customers more value responsiveness. This combined with the emphasis on economies of scale can explain the focus on the Flexible customers and past investments in reliability. The company has ambitions to increase their market share in CASE. This makes the results of this survey alarming regarding the performances on responsiveness.

5.5 Conclusion

5.5.1 Method

Customers were asked to indicate the performances and the importance of a set of identified aspects. These aspects were grouped in responsiveness, reliability, resilience and relationships and touched upon the quality, service and timing of the company's supply.

5.5.2 Validation

The results confirmed a couple of characteristics of the industry and thereby validated the applicability of this method. First of all the customers were not interested in customized solutions. This corresponds with the characterization of the industry as a commodity market. Also customers indicated that the company's performances on 'customized solutions' are not high. This is in line with the strategy of the company, serving only those customers that have the capabilities to handle the products themselves. Next to that customers indicated that they value a constant quality as highly important. This is in line with the high emphasis on quality as indicated as a characteristic of the market.

5.5.3 Interpretation of results

An importance-performance diagram was presented. This diagram distinguishes between aspects that are low priority (low importance and low performance), possible overkill (low importance and high performance), ‘concentrate here’ (high importance and low performance) and ‘keep up the good work’ (high importance and high performance). The ‘customized solutions’ was indicated as low importance, no aspects show a possible overkill. Most important finding is the positions of the aspects related to reliability and responsiveness. Two aspects related to reliability (constant quality and keeping delivery promises) are pointed out as ‘keep up the good work’. Three aspects related to responsiveness (lead-times, flexibility and support of growth) are pointed out as ‘concentrate here’. Efforts in the past in improving the reliability resulted in a good performance on these aspects, only the product availability could be invested more in (moderate importance and moderate performance). New efforts should concentrate on improving the responsiveness through shorter lead-times, more flexibility and more support of growth.

5.5.4 Importance of results

Most striking were the results on ‘lead-times’. This aspect was indicated as most important, while the performance was indicated as second lowest. Currently customers are asked to nominate their demand long (up to several weeks) before actual delivery. Though just a small sample was taken the results also confirmed that the CASE customers find responsiveness more important than the Flexibles customers. It is expected that this is caused by the exposure to the volatility of the demand in consumer markets, but no evidence was presented to confirm this. The emphasis on economies of scale can explain the focus on the larger Flexibles customers and past investments in reliability. The company has ambitions to increase their market share in CASE. This makes the results of this survey alarming regarding the performances on responsiveness and stresses the importance of investments in these aspects. The company should concentrate on improving the responsiveness in the first place through shorter lead-times, secondly through more flexibility and more support of growth.

6 SIMULATION ANALYSIS

6.1 Introduction

6.1.1 Objective

The strategic audit presented in Chapter 4 was followed up to the point where the competitive strategy and operations strategy meet each other in the value proposition, see Figure 4-6 on page 36. The Industry Trends Analysis identified the industry gaps, the Customer Value Analysis the customer gaps. In this chapter these gaps that together form the competitive strategy gap will be operationalized into the operations strategy gap. The objective of this chapter is to result in a new operations strategy that fits better. This will be accomplished by researching the competencies and underlying 'resources and processes' by means of a simulation model.

6.1.2 Simulation

Simulation can be defined as the process of designing a model of a real system and conducting experiments with this model for the purpose either of understanding the behavior of the system or of evaluating various strategies (within the limits imposed by a criterion or set of criteria) for the operation of the system (Shannon 1975). The supply chains in the chemicals industry were discussed to be one of the most complex. Simulation enables the analyst to reconstruct this complex system and analyse it through experimentation. There is a series of arguments that justify the effort of making a model. First of all it is not possible to experiment with the real system as this would be time-consuming, highly expensive, can be rather dangerous and hazardous for the continuity of operations. Next to that, it is an ill-structured problem, the information available is not detailed nor comprehensive enough to calculate one optimal solution. Also it is undoable to mathematically compute the impact of alternative configurations. In this respect, this model will be different than the models used in the company where the objective is to compute an optimum regarding a set of criteria and objective function. Considering these arguments simulation is a logical choice to get insight in the system and possible alternatives.

6.1.3 Structure

This chapter will discuss the full modelling cycle, starting with the conceptualisation. In this section the system boundaries and problem description will result in a conceptualisation of the system. Further a conceptualisation of the system will be made. This conceptual model will be specified into a simulation model in the specification section. Next the model will be verified by performing a series of tests, this will be discussed in the verification section. As a last test, the validation section will validate the results of the model with historical data. Finally experimentation section will discuss the experiments, followed by an evaluation of the alternatives.

6.2 Conceptualisation

6.2.1 Introduction

6.2.2 Problem description

In this section, the problem that will be modelled will be described through the strategic audit as presented in Chapter 4.

6.2.2.1 *The strategic audit*

In Chapter 4, the strategic audit was presented. This audit is based on both competitive strategy and operations strategy. It takes stock of the developments in the industry and the values of customers as an assessment of the fit of the company's value proposition with its competitive environment. Next it also takes stock of the company's operations to assess its degree of fit with the company's value proposition. The audit is a gap analysis to assess the degree of alignment and to develop improvement actions. Figure 6-1 shows the gaps that can be identified through the strategic audit.

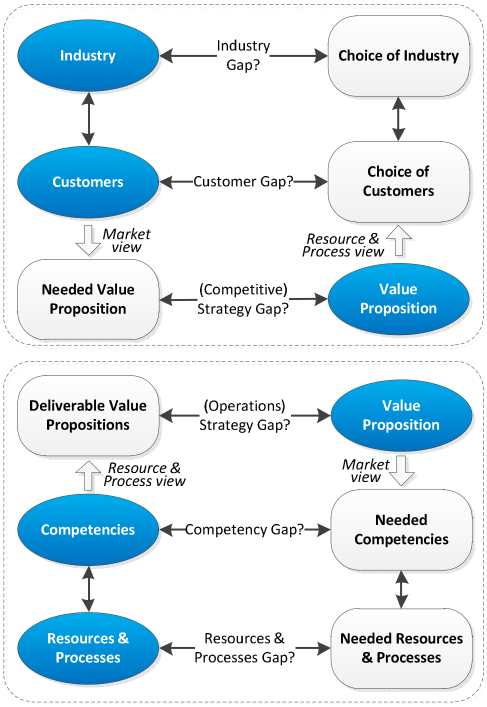


Figure 6-1: Strategic Audit

In this report, the 'market view' was applied, starting at the market and resulting in improvements in the resources and processes. The industry gap and customer gap have been assessed through the

Industry Trends Analysis in Appendix B and the Customer Value Analysis in Chapter 5. This will result in the competitive strategy gap, identifying the gap between the company's value proposition and the needed value proposition. The competitive strategy gap will be presented in the following paragraph. Next the operations strategy domain will be entered. As a first step, the competitive strategy gap will be translated to the operations strategy gap. This step identifies the relation between the outcomes of the competitive strategy gap and the company's operations. Next the competency gap will clarify this by identifying the key performance indicators that should be focussed on regarding the previous analyses. As a final step, the 'resources & processes' gap will be assessed through a simulation model. With this model, it can be researched what should be changed in the operations in order to mitigate the identified gaps. In the following paragraphs, the gaps as defined in the strategic audit will be discussed.

6.2.2.2 *Competitive strategy gap*

The Industry Trends Analysis indicated that in the long run the flexibility of the production will be challenged to absorb the increasing volatility in demand. This volatility in demand starts at the consumer markets, where companies are challenged to be very responsive to this demand. In order to become responsive, part of the solution lies in shifting this responsiveness to their suppliers. In fact demanding more flexibility in supply. Up to this moment, the company hasn't experienced these changes due to its emphasis on demand management and large bargaining power. This though might change in the future as mergers are taking place and large consumer serving parties are taking over the procurement of their suppliers, hence by-passing the low bargaining power of the smaller suppliers and dealing directly with the raw material suppliers. This supply chain integration will increase the pressure on the raw material producers to become more responsive.

The Customer Value Analysis also stresses the need to focus on responsiveness. The results of the survey showed that Flexible and CASE customers have different needs. The CASE customers value responsiveness aspects like lead-times, flexibility and support of growth among the highest, while they indicate the performances among the lowest. The company in the past focussed on reliability, which seems to be more valued by the Flexible customers, performances on these aspects are among the highest. The company's ambition to grow in the CASE market stresses the need to become more responsive, while safeguarding the current high performance on reliability.

6.2.2.3 *Operations strategy gap*

In the competitive strategy gap it was argued that the company should invest in its responsiveness. The operations strategy gap identifies the relation between this outcome and the operations of the company. As discussed in Appendix A, the chemicals industry is characterized by an inflexible production capacity and an emphasis on plant utilization. In order to be able to sustain the 24 hours operations, proper planning is essential. The down side is that customers have to indicate their demand long on beforehand, hence long lead times between the first indication of demand and actual production. Though this backlog of orders is comfortable for a company that emphasises optimal production, it compromises the responsiveness, hence the ability of the customers to anticipate on demand volatility in the downstream markets. The challenge for the company will be to become less dependent on forecasts and increase the agility of operations while sustaining the current level of reliability. In the competency gap this will be further specified through defining key performance indicators that the company should improve.

6.2.2.4 *Competency gap*

Increasing the agility of operations while sustaining the current level of reliability means quickly serving the customers' demand. This can easily be achieved through high inventory levels, making the products directly available in the quantity required. But the high costs involved in keeping these inventories would make a more sophisticated solution preferable. The objective of the system should be to limit the lead-times, achieve a high order fulfilment rate and keep appropriate inventory levels.

With the lead times, the number of days between the receiving of the order and the supply (excluding transport) is considered. The moment of receiving an order needs further explanation. Currently the demand management processes of the company requires customers to nominate their orders several weeks on beforehand and after negotiation the actual order is placed a couple of days on beforehand. The first contact a customer establishes about an order will be considered the moment of ordering, hence internalizing the negotiation activities.

The current performances on reliability are highly valued by the customers. That is why these practices should be sustained. The customer survey indicated that constant quality is highly important for customers, though the product quality will not be included in the model this should not be compromised. Reliability in this model will be defined through product availability and keeping delivery promises. This will be measured through the order fulfilment rate. Which can be defined as the percentage of orders that is delivered in time.

Inventory is commonly considered waste; it is valuable production time spend on a product that is not needed at that time. Especially for the batch processes where this production time could have been spend on products that are needed at that moment in time. Next to that it hides the real causes of problems that would be experienced with no or low inventories. If inventory is reduced then management must deal with the forecast inaccuracy, unreliable production processes and unreliable suppliers. The downside of low inventories is the consequential system volatility.

6.2.2.5 *Resources & Processes gap*

The competencies that the company should improve and safeguard are: short lead-times, high order-fulfilment and appropriate inventory-levels. In order to achieve this, the concept of JIT (just-in-time) will be tested on the assets of the company. The prime goal of JIT is the achievement of zero inventory, not just within the confines of a single organization, but ultimately throughout the entire supply chain (Hutchins 1999). Other studies have proven the success of JIT application in other industries. For instance the study at IBM where the supply chain was modelled as a multi-echelon network (An 2005) in order to test a JIT strategy which showed reduction in inventory costs of 69% while securing the serviceability to customers. Also it was concluded that supply chain performances are affected by the processes that introduce delays, variability and constraints into the system. A good JIT strategy reduces the delays and variability.

How the system will be modelled will be discussed in the following sections.

6.2.3 Modelling objective

The objective of this model is to contribute to answering the main research question. This contribution will be given through answering sub questions 4 and 5. Regarding sub question 4, it was already identified that the operations should become more responsive in order to quickly react on the changing demand of the customers. Objective of the modelling efforts will be to identify how this can be achieved through the company's resources and processes and to identify the effects of these changes.

6.2.4 Definition

A system is defined as a group of components that work together for a specified purpose (Sage 2000). For the purpose of a simulation model, this definition can be more specific. The system to be modelled is that part of reality that is perceived relevant given the problem and during a given period of observation can be seen as one entity, separate from the rest of the world (the environment) and can be seen as a collection of objects with attributes, processes and relations (Verbraeck 2006). In order to define the system in line with these definitions, this section will discuss the following aspects:

- System boundaries and environment
- System purpose and instruments
- System objects and relations
- System processes

6.2.5 System boundaries and environment

6.2.5.1 *Environment*

Though the supply chain management thinking supports supply chain integration to an extend where ideally the entire supply chain is considered as one entity, reality is different. Firms tend to only deal with detail complexity, they are obstructed from seeing how relations of different kinds reach beyond their own firms and change over time (Holmberg 2000). The framework presented in Chapter 4 aims to align the operations strategy of a firm with the environment of the firm. This environment is considered from the supply chain point of view. Coordinating activities in a supply chain, is difficult due to the complexity induced by the large number of related and interdependent activities in the supply chain (Holmberg 2000). Next to that coordination is frustrated by the focus on value maximization on the level of each individual firm, instead of the whole supply chain. The research question also focusses on the individual firm. The environment considered in the competitive strategy in this research aims to set the scene for the operational strategy of the company.

6.2.5.2 *System boundaries*

This is why the company will be the starting point of setting the system boundaries for the simulation model. The focus is on the downstream activities as it is there where the problem is perceived, that is why the interactions with the customers will draw the borders of the system. Figure 6-2 shows an IDEF-0 diagram of the system and indicates the inputs and outputs.

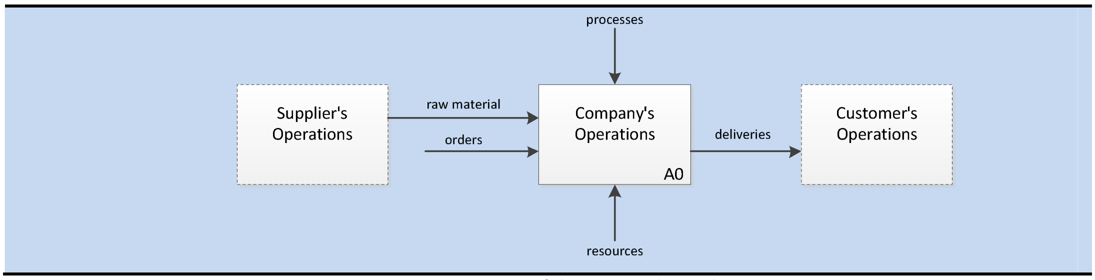


Figure 6-2: IDEF-0 Diagram of the system boundaries

The orders and raw material will be considered as input, the deliveries will be considered as the output of the system. As products are commonly picked up by a third-party logistics function of the customer, this is considered within the customer's operations, hence out of scope of this model. This draws the boundaries of the system that is able to transform these inputs into outputs by means of resources and processes.

6.2.6 System purpose and instruments

6.2.6.1 *System purpose*

Performance measure plays an important role in managing a business as it provides the information necessary for decision making and actions (Holmberg 2000). Lacking connection between a company's strategy and its measuring activities commonly make measurements activities focused on internal functions instead of overall company performance and customer needs (Holmberg 2000). The company's performance is related to its profitability, the customer needs should be reflected by the value proposition. In line with the previous analyses this model will focus on two aspects in particular: lead-times and order fulfilment.

6.2.6.2 *System instruments*

In order to experiment with the model two types of input were identified: environmental and instrumental. The environmental input parameters cannot be influenced by the company, the instrumental can be influenced. In the experiments the following instrumental inputs are used: the production regime (Make to Stock or Just in Time), acceptance of bulk orders and the stock targets. Further the ability to cope with major disruptions will be tested, which is considered an environmental input as the company cannot prevent a disruption directly.

6.2.7 System objects and relations

6.2.7.1 *Unified Modelling Language (UML)*

There are multiple ways of describing a system. One of them is object oriented, where the objects and their attributes are identified and the relations between these objects are described. Unified Modelling Language (UML) is a standardized modelling language in the field of object-oriented software engineering, which can be used to describe a system through its objects, relations between these objects and their attributes. Figure 6-3 shows a UML representation of the system. In Appendix A the production of polyols was described, in the next paragraph this description will be translated to a systematic description in the Unified Modelling Language.

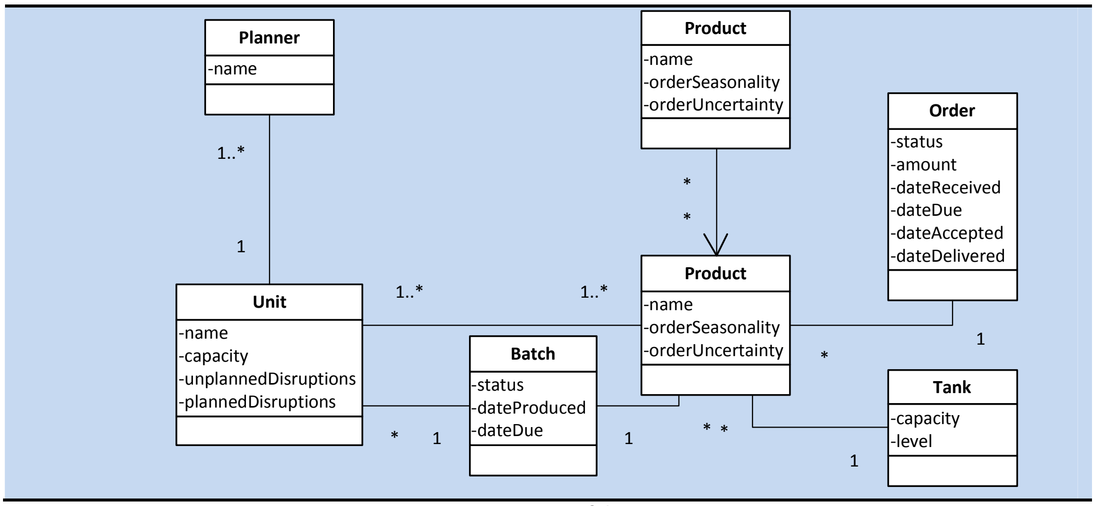


Figure 6-3: UML Diagram of the system

6.2.7.2 *Explanation of UML diagram*

In this UML diagram classes are defined as a type of object. The system contains a number of production units, in this figure this class is defined as Unit. For each object that is a Unit, the name and capacity are known. Also a distribution for the probability of an planned or unplanned disruption to occur and its duration is given in the attributes of this class. The lines between the classes represent the relations. For instance the relation between the Planner and the Unit. A Planner makes the planning for one or more (1..*) Units. The other way around, there is only one Planner responsible for each Unit. The planning is based on the order seasonality and order uncertainty as defined in the Product class. A Unit can produce one or more Products and Products can be produced on one or more Units. Through the planning activities, the batches will be defined. For each Batch it is known what its status is, the date it is produced and the due date. Each Batch is related to one Product and one or more Units. In the production raw materials and intermediates are inputs for the process. The recipes in the production of polyols can be rather complex. For each Product the recipe is defined through the relations with other products. As shown in the diagram a Product can have one or more input products and a Product can be used as an input to a number of other products. Finished product is stored in a Tank, for which the attributes capacity and level are defined. Each Order has a set of attributes: the status, amount, date received, due date, date accepted and date delivered. As a simplification each order is assumed to only contain one type of Product.

6.2.8 System processes

6.2.8.1 *IDEF-0 method*

Next to the object oriented way of describing a system another way to go is process oriented. This is formalised in the IDEF-0 method, where activities and their relations are presented. Figure 6-4 shows an IDEF-0 diagram that presents the most important activities the company's operations entail regarding supplying its customers.

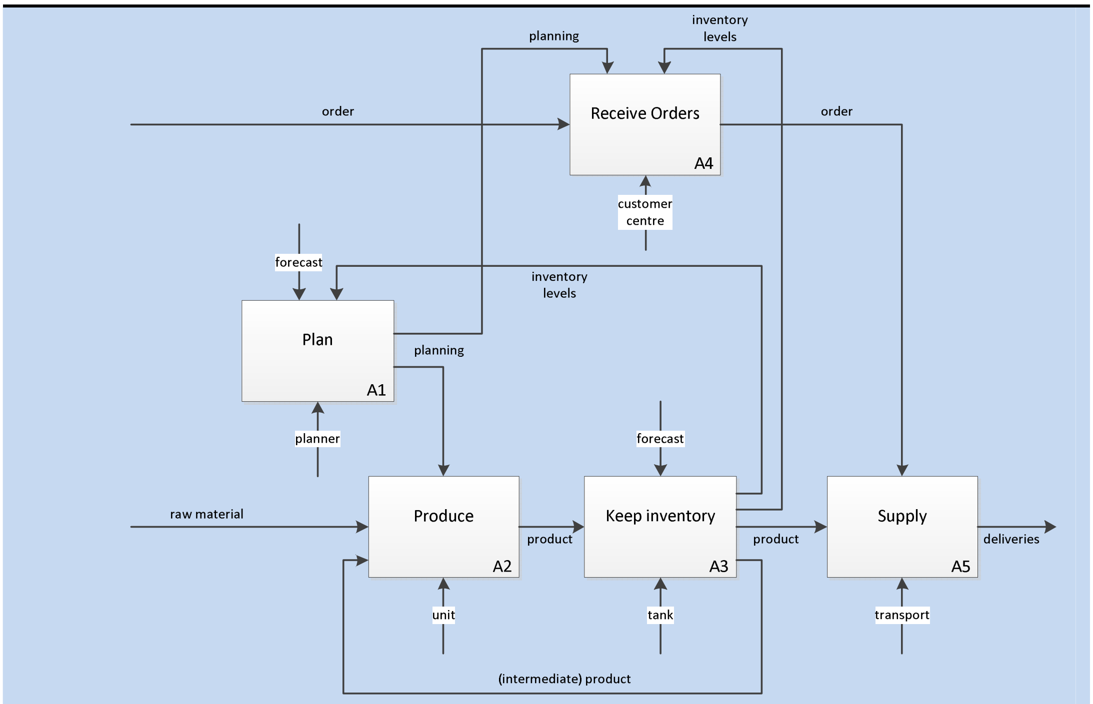


Figure 6-4: IDEF-0 Diagram of system

The production is characterized by its inflexible capacity. This makes proper planning critical and in this diagram the starting point (A1 – Plan), this planning is facilitated by the S&OP process. Based on the forecast the planner will make a production planning. This production planning will control the actual production (A2 – Produce). Here units will transform raw material into products, that thereafter will be kept as inventory in tanks (A3 – Keep inventory). Part of the inventory is created against the uncertainty of forecasts. Another part is kept as intermediate, to facilitate the production of other products. Orders will be received by the customer centre (A4 – Receive orders). Dependent on the planning and the inventory levels, the order will either be accepted or rejected. Once accepted, the actual supply will take place (A5 – Supply), resulting in a delivery.

There is a high emphasis on forecasting and planning. The product is committed to the orders quite late in the process (at the supply block). The balance between supply and demand is achieved through forecasting ahead of demand and creating inventory against that forecast.

The sales and operations planning (S&OP) process facilitates the matching of the sales and production plans with the financial objectives of the company. Sales & Operations Planning can be considered as a lubricant between partners in the supply chain, enabling the total chain to function harmoniously and with minimum disruption (Wallace 2004). First a sales forecasting will be made based on historical sales and analysis of trends. Secondly the forecasts are validated and a demand planning is made which is in line with the customer service policies. Thirdly the available capacity will be reviewed and a supply planning is made. In the fourth step, the supply and demand plans are matched with financial considerations. In the fifth and last step the plans are finalized and implemented. During the data collection for the model, a couple of shortcomings of the S&OP as implemented in the company were found. A more detailed explanation of the S&OP process and the identified shortcomings are discussed in Appendix E.

6.3 Specification

6.3.1 Introduction

In this section the conceptual model will be translated to a simulation model. This section will discuss the choice of modelling paradigm and simulation software.

6.3.2 Modelling paradigm

The major paradigms in simulation modelling are system dynamics (SD), discrete simulation (DS) and the relatively new agent based model (ABM) (Boschchev 2004). SD deals with continuous processes whereas DS and agent ABM in discrete time steps. SD represents the real-world processes in terms of stock, flows between these stocks and information that determines the values of the flows (Forrester 1958). The continuous production in the refinery, EO and SMPO units upstream of the polyols production could perfectly be translated in such an model. But in the polyols production, many discrete events that support the use of DS can be recognized. DS represents real-world processes in terms of entities, resources and flow charts describing the entity flows and resource sharing (Boschchev 2004). The batch-wise production and batch-wise transport modes are examples of this. The discrete events and the numerous choices make planning a complicated task. When looking at the system from a supply chain point of view, ABM presents a good fit. In ABM real-world processes are represented through autonomous agents that interact with one another through links. The behaviour is defined at an individual level and results in system behaviour to emerge. Regarding the supply chain view, each company or department could be represented through an agent. In this research the objective is to support the individual company with insights in improving the supply to its customers, the focus in this chapter therefor will be on developing a model that represents just one company. As the production of the polyols and the choices that can be made in its batch-wise production are the focus of this research, DS will be the most important paradigm for the model.

6.3.3 Modelling approach

Now the choice for the discrete event simulation paradigm is made, the translation of the conceptual model into a simulation model will be further specified. As discussed in Appendix A, the chemicals industry has one of the most complex supply networks. This complexity grows with the complexity of the bill of materials and the numerous of grades that can be produced at several units. Complexity is commonly addressed in the ABM paradigm. Here the behaviour of autonomous agents and the interactions between them emerges to complex system behaviour. This inspired to view the system as a set of passive agents (not having autonomy) and focus on the interactions between these agents. These agents and interrelations were already addressed in the UML diagram (Figure 6-3) as classes and relations in the conceptualisation. In this way, by programming the interactions between the agents, a company's supply can easily be modelled, without the need to hard-code the underlying infrastructure. As the links between the agents now play an important role, the conceptualisation in the UML diagram will be extended in Figure 6-5. In this new UML diagram, some links are represented by associative classes to describe their attributes.

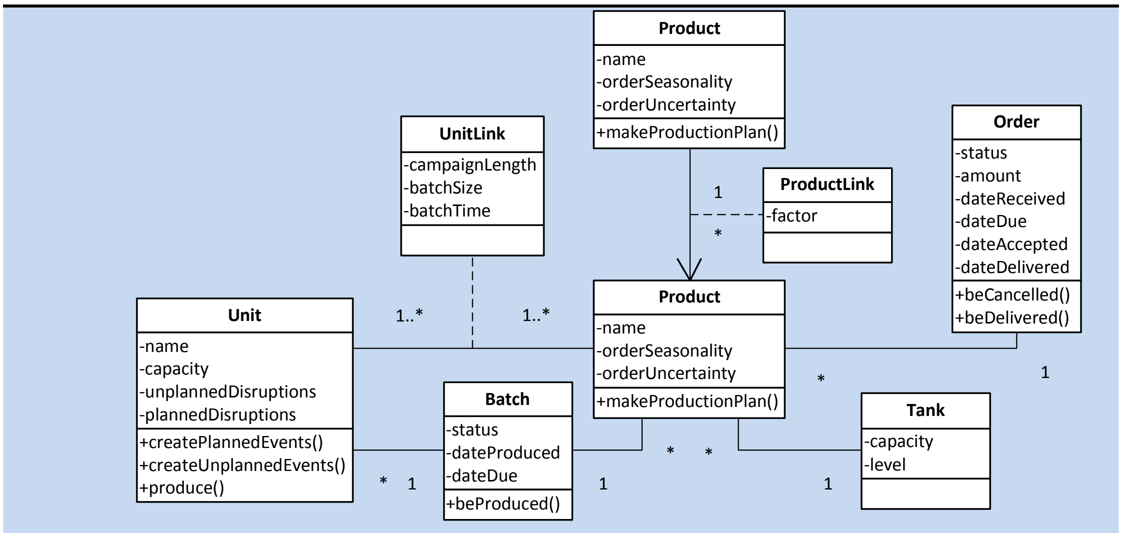


Figure 6-5: UML Diagram of the system including associative classes

In this new UML diagram, two associative classes are described; the UnitLink and the ProductLink. The UnitLink describes the attributes of the relation between the Unit and Product classes. For each Unit / Product combination a minimum campaign length to prevent cross-contamination, the production batch size and production time of a batch are given. The ProductLink describes the attributes of the relation between the products. In fact the recipes are stored in these relations through which it is described with what factor each product serves as an input for the production process of the other product. The other links will also be used in specifying the model, but as they do not contain other information than the classes it links, these are not shown in the figure. These links will be called from the perspective of the Product class: UnitLink, BatchLink, ProductLink, OrderLink and TankLink.

6.3.4 Simulation Software

The model has been built in NetLogo (Wilensky 1999). The modelling approach that focusses on the interaction between the defined classes combined with the objective of the company to be able to research other product lines in the future with the same model provided the main arguments to make use of the NetLogo simulation package. The package provides a high level language to program the procedures and define the classes (breeds[4]), attributes and relations (links). In order to make the model re-usable for other product lines, a procedure was written to import the data of agents, attributes and links from an Excel spread sheet. This also helped in the verification of the data, as it could easily be presented through the spread sheet. The package comes with a graphical representation of the agents and links, this helped in verifying and validating the procedures as it made it possible to see how different agents are related and made it possible to follow one agent in particular. Next to that the graphical interface comes with a series of easy to setup graphs that supported the validation phase, where experts were asked to review the system behaviour.

6.3.5 Specification of instances and links

In the modelling approach, the classes and relations were already defined, in this paragraph the particular instances of these classes and particular links of these relations will be defined. A full overview of the instances and links can be found in the Excel spread sheet *Simulation_Input.xls*.

[4] In NetLogo agents are also referred to as turtles, different types of agents are referred to as breeds. In relation to UML, breeds can be seen as classes and agents as instances.

Table 6-1 shows an overview of the number of instances that are defined of each class and the sources that are available through which the attributes can be defined.

Class	Instances	Attributes	Source
Product	39+	Product	Sales '10
Product Links	50	Factor	Product Bill of Materials
Units	10	(Un)planned Disruptions	Incident log '05 – '11
Unit Links	33	Min. Campaign Length	Production Documentation
		Batch size	Production Documentation
		Batch production time	Production Documentation
Tanks	44	Capacity	TankStock Report
Order	-	Annual Sales	Sales '10
		Bulk Characteristics	Sales '10
		Order Seasonality	Seasonality Analysis
		Order variation and uncertainty	Sales '09-'11

Table 6-1: Data sources for the attributes of all classes

In section 6.4 the identified sources will be used to perform further data and make a selection of the instances that should be included and define their attributes.

6.3.6 Specification of processes

In the conceptualisation phase, the following processes where identified on the highest aggregation level (See Figure 6-4): Plan, Produce, Keep inventory, Receive Orders, Supply. In Appendix D the production processes are specified and flow diagrams are presented.

6.4 Data collection and analysis

6.4.1 Introduction

In the previous section Table 6-1 showed data sources that are available to select the instances and define their attributes. The following paragraphs give a detailed overview of the further data analysis that will be performed in this section.

6.4.2 Data Collection

6.4.2.1 *Products: Product banding*

There are 39 end-products in the polyols product line. As the intermediates should also be included in order to simulate the production processes to the full detail, we would end up with an extensive amount of products. In order to decrease the number of products and thereby the amount of work to analyse all output data, a product banding analysis will be performed. This analysis will be based on the sales data of 2009 and 2010.

6.4.2.2 *Orders*

Bulk characteristics

Some of the products are sold both in bulk and in trucks, it will be analysed what percentage of the orders is sold in bulk and how the quantities of these orders can be characterized. This analysis will be based on the sales data of 2009 and 2010.

Order Seasonality

The company in the past already studied the seasonality of the demand. This study was based on historical sales data from between 2005 and 2009. No further analysis is needed.

Order variation and uncertainty

In order to determine the predictable variation in demand, historical sales data will be analysed. By comparing the actual sales with the sales one would expect based only on the seasonality, the order variation (predictable) and uncertainty (unpredictable) can be determined. The seasonality and the sales data of 2010 will be used for this.

6.4.2.3 *Market mechanism*

The market mechanism as discussed in the conceptualisation is built on three parameters: (1) negotiation delay, (2) price-elasticity of supply and (3) price-elasticity of demand. The Stock Operations Analysis (Appendix A) presents the values that were used for these parameters.

6.4.2.4 *Product Links: Bill of Material*

In order to determine the bill of materials of each product, product links will be defined. In these directed links it will be stored how much of one product is used to produce another. The recipes of the products contain all data needed to define these links, so besides collecting this data, no further analysis is required.

6.4.2.5 *Units: Disruptions*

Due to the 24 hours operations, disruptions in the operations can have large impacts and are an important determinant of the company's ability to meet delivery promises. One of the key performance indicators of the manufacturing department is the uptime of units. That is why incidents are logged with quite detailed information about the cause, the downtime and production losses. The data from 2005 to 2011 will be analysed in order the find the frequency and duration of planned and unplanned incidents.

6.4.2.6 *Unit Links: Batch properties*

The Unit Links define the relation between the products and the units. In the first place it describes which products can be produced on which units. Next to that it describes the properties of the batch-wise production process. The minimum campaign length to prevent cross-contamination, the batch size and the time the production of one batch takes should be known to simulate the production. All this is described in the production documentation, used by the manufacturing department. No further data analysis is needed.

6.4.2.7 *Tanks: Capacity*

For the tanks, the most important property is its capacity. For this, the capacity that can be used in normal operations is used. This is the total capacity minus the un-pump-able capacity and the capacity that is not used due to the risk of a spill-over. These capacities are given in the TankStock Report, that is generated on a daily basis. No further analysis is needed.

6.4.3 Further analysis

This chapter identified a number of analyses to be performed. Table 6-2 summarizes the need for further analysis.

Class / Process	Attributes	Source	Analysis
Product	Product	Sales '10	Product Banding
Product Links	Factor	Product Bill of Materials	
Units	(Un)planned Disruptions	Incident log '05 – '11	Disruptions Analysis
Unit Links	Min. Campaign Length	Production Documentation	
	Batch size	Production Documentation	
	Batch production time	Production Documentation	
Tanks	Capacity	TankStock Report	
Order	Annual Sales	Sales '10	
	Bulk Characteristics	Sales '10	Bulk Characteristics
	Order Seasonality	Seasonality Analysis	
	Order variation	Sales '09-'11	Order variation and uncertainty
	Order uncertainty	Sales '09-'11	Order variation and uncertainty
	Market Mechanism	Data from other markets	Comparison, assumption building
Planning	S&OP process	S&OP literature	Sales and Operations Process

Table 6-2: Further analysis

6.5 Simulation setup, Verification and Validation

6.5.1 Introduction

The previous sections resulted in a simulation model. In this section the model will be made ready to be used in experimentation. In this section the simulation setup will discuss the starting conditions, run-length and the number of replications.

6.5.2 Starting conditions, run-length and replications

The system is a never-ending system. That means that there is no natural ending of the system. This is different from for example a bakery, where in the morning, the production will stop and will end in the same state as it started that morning. This same system state will be the starting point of a new day. Due to the 24 hours operations this is not the case in the production of polyols. Next to that, the inventories make that the system has a 'memory' that exceeds the boundary of one day, month or a year.

The seasonality of the demand makes that a year is the minimum period in which the whole cycle of demand is simulated. That is why the run length will be one year, thereby giving information about the performances of the system in all months.

Because the system is never-ending the initial state of the system should be determined. The most important conditions are the inventory levels. As the planners aim on an inventory level of roughly 50%, this will be the starting condition for the system. Next to that, the backlog of orders influences the inventories. That is why after simulating one year, an extra month will be simulated. This prevents the inventories to decrease because of lacking demand after December.

The non-deterministic elements in the model, such as the demand and disruptions make that the outcomes of the model depend on the seed (long list of 'random' numbers). Repeating the same experiment with another seed can lead to different results. That is why in simulation studies a simulation run will be replicated several times to get more accurate results. For this model for each experiment 15 replications will be made, afterwards it will be checked if the results are accurate enough.

6.5.3 Verification and validation

In order to check whether the model is coded correctly and represents the right system behaviour, it has been verified and validated. In the verification the coding of the input, the logic and the output has been checked. In the validation the behaviour of the model was tested and a sensitivity analysis has been performed. Appendix F gives a detailed overview of the tests and the results.

Regarding the verification it was concluded that the coding of input, logic and output are correct.

Regarding the validation it was concluded that the variability of the base polyols inventory differs from the historical data. It was concluded that the underlying system of MTS production is rather unstable. Next to the market mechanism that is represented in the model, in reality there are more mechanisms in place that manually keep the variability of base polyols inventory low. Due to lack of information about these mechanisms, it is not possible to simulate them. As the objective of this simulation is to compare MTS production with JIT production, representation of the underlying system is considered more important than mimicking the historical data, hence the model is accepted for experimentation. Further it was concluded that with the available information, the market mechanism could not be validated, further improvement of the model would need more detailed analysis of this mechanism and its parameters. Next to that it was identified that bulk orders have a big impact on the variability of inventory levels, further experiments could show the impact of the bulk orders on the order fulfilment.

The conclusion is that though points for improvement were identified the model is ready to be used for experiments. Suggestions for further improvement of the model will be made in the discussion section of this chapter.

6.6 Experiments

6.6.1 Introduction

In the previous sections, a simulation model was made, the input data collected and analysed, the model was set-up and the model was verified and validated. Now the model is ready to be used for experimentation. In this section, the experiments will be defined and the results will be discussed.

The experiments will focus on the processes, rather than the resources. As discussed in Chapter 4, the resources are considered out of scope for this research. The objective of these experiments is to change the operations strategy in such manner that the perceived value of customers is increased through shorter lead-times, higher order fulfilment and inventory levels that support the reliability of supply. The experiments should give insight in the applicability and impact of JIT production with the current assets of the company.

6.6.1.1 *Experiment 1 will simulate the current situation and serves as a reference*

In order to be able to relate the insights about JIT production to the current situation Experiment 1 will show the base case, which is discussed in detail during the validation (Appendix F). The simulation model will be run in MTS mode and KPI's will be computed.

6.6.1.2 *Experiment 2 will show whether JIT can be applied and what the impact is on the stability of operations*

Next, JIT production will be applied in Experiment 2. This experiment will show whether JIT can be applied on the complex and interdependent production processes of the company. Next to that it will give insight in the impact on the KPI's. In this experiment in fact the production will be adapted quickly to the demand and should lead to less variability in the inventory levels, which should lead to a higher order fulfilment.

6.6.1.3 *Experiment 3 will show the impact of bulk orders on the stability of operations*

With the current emphasis on asset utilisation, for some products maximum production is facilitated by bulk orders to fill the gap between the high supply and regular demand. It can be expected that these bulk orders make the system unstable. That is why in Experiment 3 the impact of these bulk orders will be investigated for JIT production. It is expected that substituting bulk orders will lead to less variability in the inventory levels, which leads to higher order fulfilment.

6.6.1.4 *Experiment 4 will show the impact of lower inventories*

In the current situation inventories are commonly used to mitigate the difference between supply and demand. With better alignment of supply and demand, these inventories are dedicated to the reliability of supply only. It can be expected that lower inventories are needed to comply with the need for reliability. As inventories are costly, Experiment 4 will investigate the impact of lower inventory levels for both MTS and JIT production.

6.6.1.5 *Experiment 5 will show the predictability of the impact of disruptions*

In the current situation it is hard to predict the impact of a disruption and no predefined reactions to changing circumstances are defined. With more stable inventories, it can be expected that the impact of a disruption can be predicted more precisely and can be mitigated with calculated responses. This is why in Experiment 5 the predictability of the impact of disruptions of varying duration will be tested for the MTS, JIT and JIT with no bulk mode.

6.6.2 Experiment 1: MTS serves as a reference

6.6.2.1 *Input parameters*

This experiment serves as a reference for the other experiments hence the input parameters are equal to the current situation. The only difference is that force-majeure situations are excluded, these will be discussed in more detail in Experiment 5. The input parameters are shown in Table 6-3.

Parameter	Value	Comments
Planning	MTS	The make-to-stock production regime is applied
Target stock level	PO: 60% Base Polyol: 50%	The target stock levels are set in such fashion that the average inventories are similar to those in the historical data set, discussed in the Stock Operations Analysis (Appendix C).
Disruption size	0 days	In this experiment only the regular planned and unplanned downtimes were included. Force majeure situations are excluded.
Bulk orders	TRUE	This run includes bulk orders, based on historical data.

Table 6-3: Input parameters for Experiment 1

6.6.2.2 *Summary of output*

Table 6-4 summarizes the output of this experiment. For each KPI the 'Average Value' is presented. The 'Variability of Value' shows the standard deviation of a variable during one run. For instance the variability of the PO inventory level is given as the standard deviation expressed in a percentage of the average value. All experiments were replicated 20 times in order to find out what the variability of the output is. The 'Standard Deviation Replications' shows this standard deviation expressed as a percentage of the average value. For instance the standard deviation of the average PO inventory level shows that the average PO inventory level is quite similar for all runs.

KPI	(Average) Value	Variability of Value (in one run)	Standard Deviation Replications
Quantity not supplied	μ = 1.2%		σ = 58%
Inventory PO	μ = 59%	σ = 11%	σ = 3%
Inventory Base Polyol	μ = 55%	σ = 28%	σ = 14%
Planning lead time	30 days		
Occupancy of assets	μ = 80%		

Table 6-4: Summary of output Experiment 1

The average inventory level of PO is 59%, with a standard deviation of 11%. Figure 6-6 gives an impression of the PO inventory levels in one of the runs.

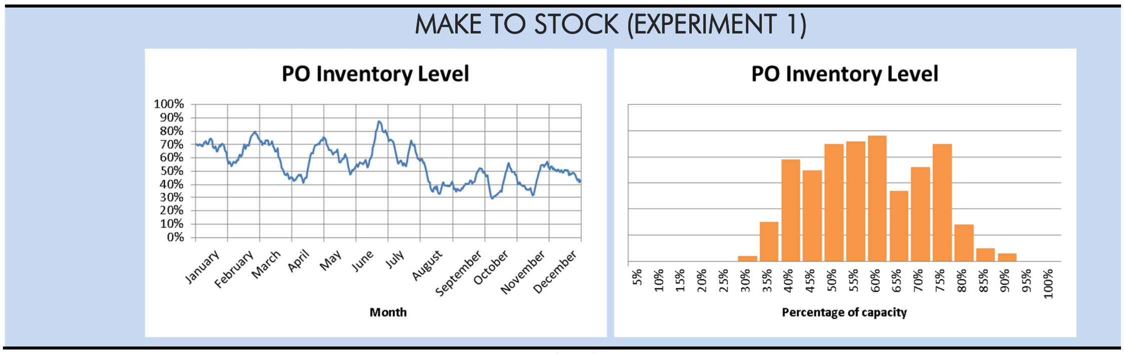


Figure 6-6: Inventory levels PO in Experiment 1

6.6.2.3 *Conclusion*

The MTS will serve as a reference for the JIT experiments. The relatively high inventory levels that are maintained, which are based on the Stock Operations Analysis, already result in a high order fulfilment, but obviously with a cost.

6.6.3 Experiment 2: Applying JIT

6.6.3.1 *Input parameters*

In this experiment, JIT production is applied. All other settings are the same as in Experiment 1. In the JIT mode, production will only take place when the product will be supplied within 5 days. Regardless of the inventory levels, production of the precursor products is also executed when the product will be supplied within 5 days. This KANBAN type of system leads to synchronized production in all stages. Table 6-5 gives an overview of the input parameters for this experiment.

Parameter	Value	Comments
Planning	JIT	The just-in-time production regime is applied
Target stock level	PO: 60% Base Polyol: 50%	The target stock levels are set in such fashion that the average inventories are similar to those in the historical data set, discussed in the Stock Operations Analysis.
Disruption size	0 days	In this experiment only the regular planned and unplanned downtimes were included. Force majeure situations are excluded.
Bulk orders	TRUE	This run includes bulk orders, based on historical data.

Table 6-5: Input parameters for Experiment 2

6.6.3.2 *Summary of output*

First of all this Experiment showed that JIT can successfully be applied to the complex network of assets of the company. The output of this experiment is shown in Table 6-6. There is a higher order fulfilment as the 'quantity not supplied' is decreased from 1.2% to 0.5%.

Experiment 1 showed, that though there is a high emphasis on asset utilisation, assets are occupied for 80% of the time. The rest of the time, assets are in maintenance or not running due to consequential downtime. In this experiment, the occupancy of assets also is 80%, which indicates that production is not compromised by applying JIT production. The higher order fulfilment without compromised production indicates a better alignment of supply and demand, this should result in more stable inventory levels.

The variability of PO inventory is decreased from a standard deviation of 11% to 7%. For the base polyol the standard deviation decreased from 27% to 17%. Next paragraphs will discuss the variability of inventory in more detail.

KPI	(Average) Value	Variability of Value	Standard Deviation Replications
Quantity not supplied	μ = 0.5%		σ = 73%
Inventory PO	μ = 57%	σ = 7%	σ = 6 %
Inventory Base Polyol	μ = 45%	σ = 17%	σ = 9 %
Planning lead time	5 days		
Occupancy	μ = 80%		

Table 6-6: Summary of output Experiment 2

6.6.3.3 *Inventory variability of PO*

The variability of PO inventory is decreased from a standard deviation of 11% to 7%. This results in much more stable inventories, Figure 6-7 gives an impression of the variability of PO inventory levels in Experiment 2 compared to those in Experiment 1.

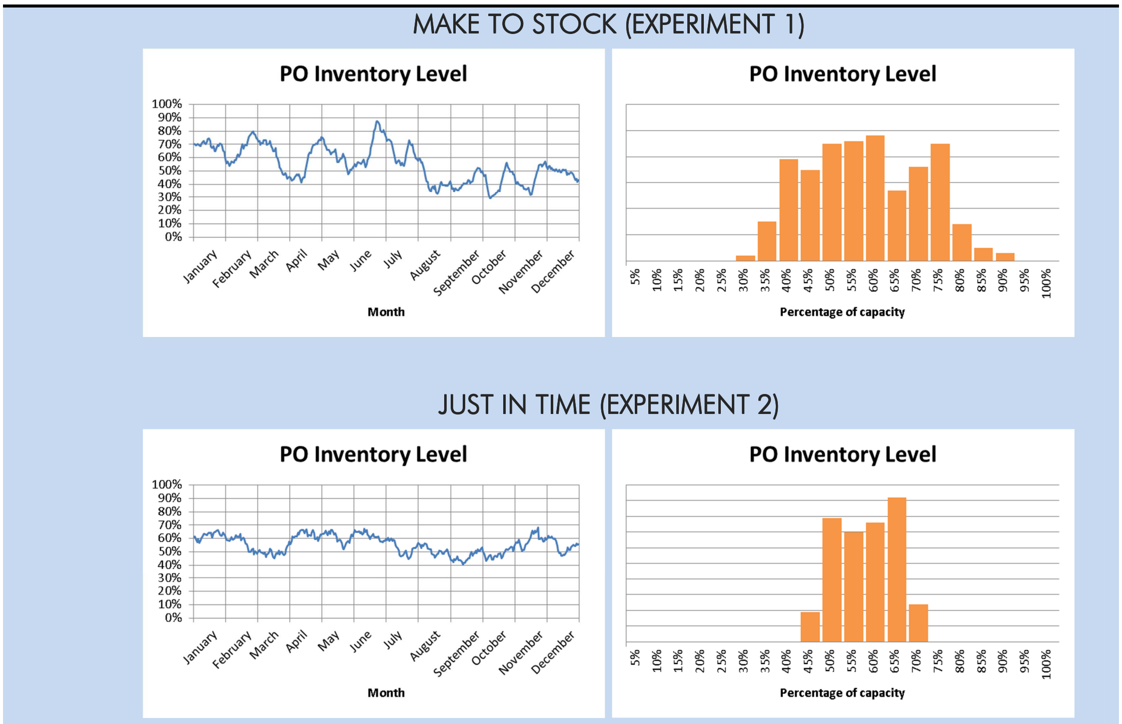


Figure 6-7: Inventory levels PO in Experiment 2

6.6.3.4 *Inventory variability of Base Polyol*

The variability of the inventory level of the base polyol is still at a relative high level of 17%. This is mainly due to the bulk orders, this will be further investigated in Experiment 3.

6.6.3.5 *Inventory levels of end products*

Most products are made in large campaigns. The way JIT production is implemented in this experiment doesn't change this. The only difference is that when an order is placed for one of these orders, the need for its precursor products is directly communicated. In this way, the precursor products will be produced, regardless whether it is needed immediately for the production or not.

Imagine three products that are low in stock and need the same precursor product, in this setting the stock of this precursor product is compensating for these low stocks and ensures the availability of the product at the moment of production. This is done for all stages of production, preventing volatile inventory levels through synchronisation of demand and production in all stages.

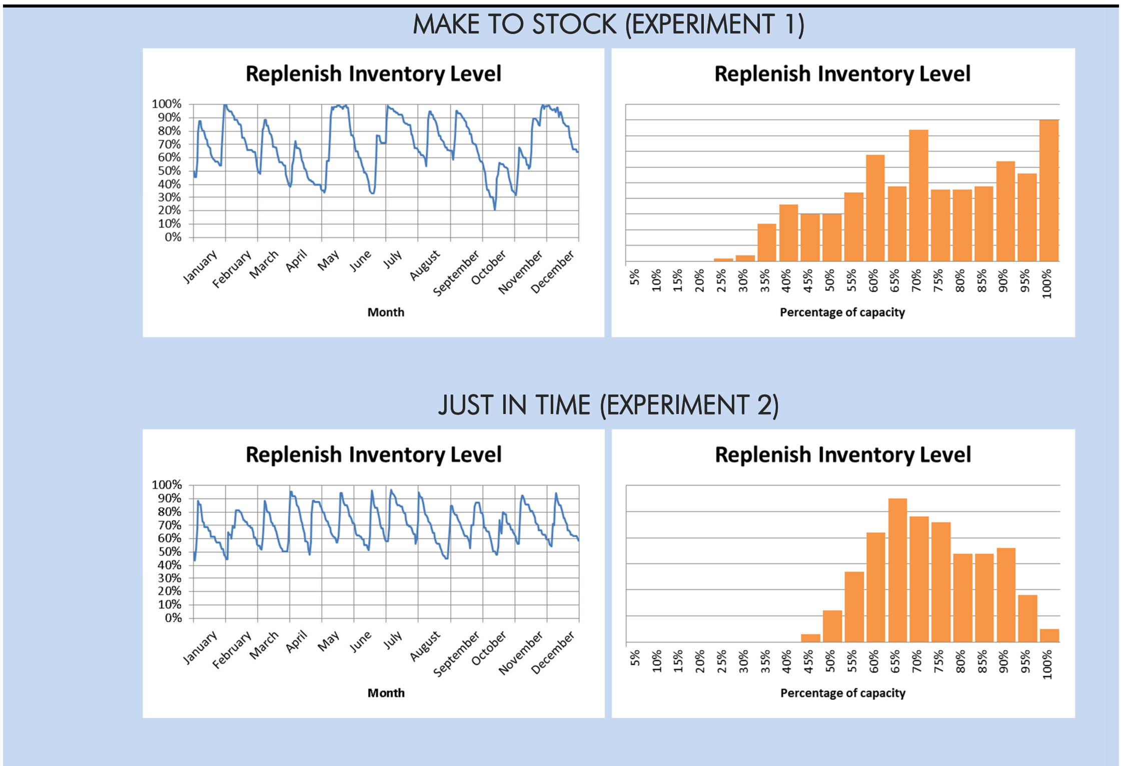


Figure 6-8: Inventory levels of end products (replenish) in Experiment 2

6.6.3.6 *Conclusion*

First of all it can be concluded that JIT production can be applied to the complex production processes of the company as the system performs well and no major problems are identified. As expected JIT production leads to a better alignment of supply and demand, hence more stable inventories. To a large extend the variability in demand can be responded to with the adaptive production. Exceptions are the bulk orders that makes that the inventory level of base polyol has a high variability. The impact of bulk orders will be investigated in more detail in the next experiment.

6.6.4 Experiment 3: Substituting bulk orders

6.6.4.1 *Input parameters*

Applying JIT production clearly identifies irregularities in both production and demand. In Experiment 2, the variability of Base Polyol was identified to be still relatively high (17%). This experiment will investigate the impact of bulk orders on the variability of inventories and order fulfilment. In this experiment, bulk orders are substituted with orders of regular size. The total demand is kept equal to the base case.

Parameter	Value	Comments

Planning	JIT	The just-in-time production regime is applied
Target stock level	PO: 50% Base Polyol: 50%	The target stock levels are set in such fashion that the average inventories are similar to those in the historical data set, discussed in the Stock Operations Analysis.
Disruption size	0 days	In this experiment only the regular planned and unplanned downtimes were included. Force majeure situations are excluded.
Bulk orders	FALSE	In this run, bulk orders are substituted by regular orders (total quantity demanded remains the same).

Table 6-7: Input parameters for Experiment 3

6.6.4.2 *Summary of output*

In Table 6-8 the output of this experiment is summarized. The absolute standard deviation is smaller than in the other experiments. The variability of both PO and base polyol are very low (5% and 2%), this will be discussed in more detail.

KPI	(Average) Value	Variability of Value	Standard Deviation Replications
Quantity not supplied	μ = 0.1%		σ = 173%[5]
Inventory PO	μ = 52%	σ = 5%	σ = 3 %
Inventory Base Polyol	μ = 49%	σ = 2%	σ = 0 %
Planning lead time	5 days		
Occupancy	μ = 80%		

Table 6-8: Summary of output Experiment 3

Though bulk orders are less rigid in the real system than in this model, this experiment makes the impact of bulk orders very clear. Figure 6-9 shows the base polyol inventory levels of a run in Experiment 2, where the steep falls are caused by the bulk orders. Figure 6-10 shows these for Experiment 3.

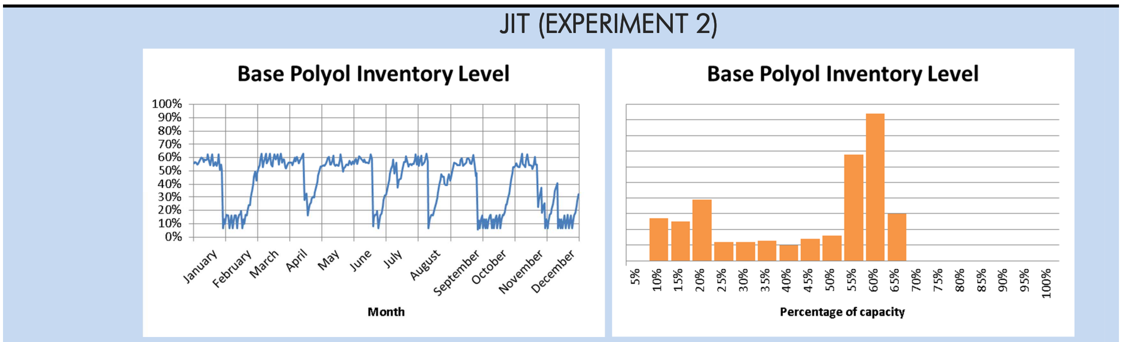


Figure 6-9: Base Polyol inventory levels in Experiment 2

[5] The standard deviation of 'quantity not delivered' is quite high. The standard deviation is given as a percentage of the average value, which is just 0.1%, hence a high standard deviation.

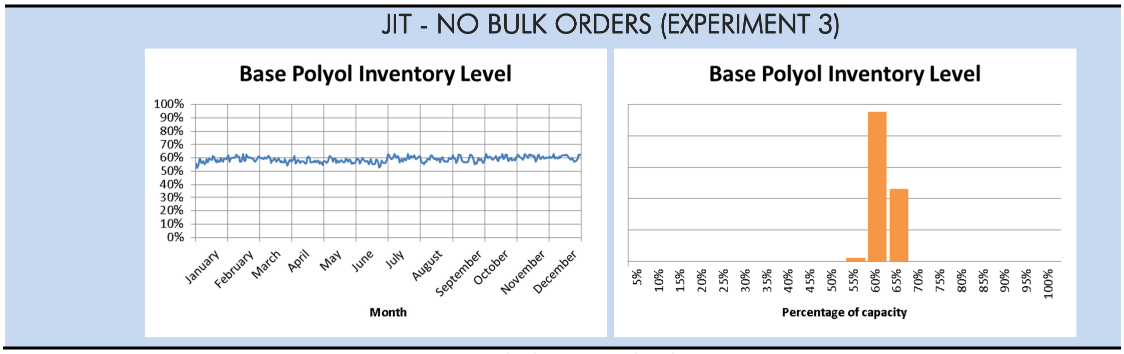


Figure 6-10: Base Polyol inventory levels in Experiment 3

The variability of the inventory level is clearly a lot lower in the case where bulk orders are substituted with regular orders. Figure 6-11 shows the variability of inventory levels of both base polyol and PO in all three settings; MTS, JIT and JIT without bulk. The variability of the PO inventory level is decreased to only 5%. The variability of the Base Polyol inventory is decreased even further from 17% (in Experiment 2) to just 2% in this experiment.

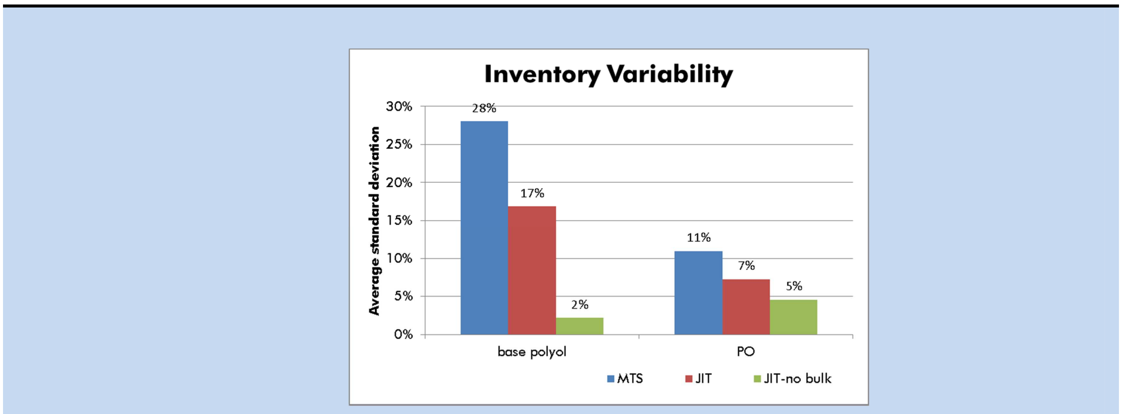


Figure 6-11: Inventory Variability for MTS, JIT and JIT without bulk orders

The consequence of lower variability in the inventory levels is a higher order fulfilment. In this experiment the quantity not delivered is decreased to 0.1%, as shown in Figure 6-12.

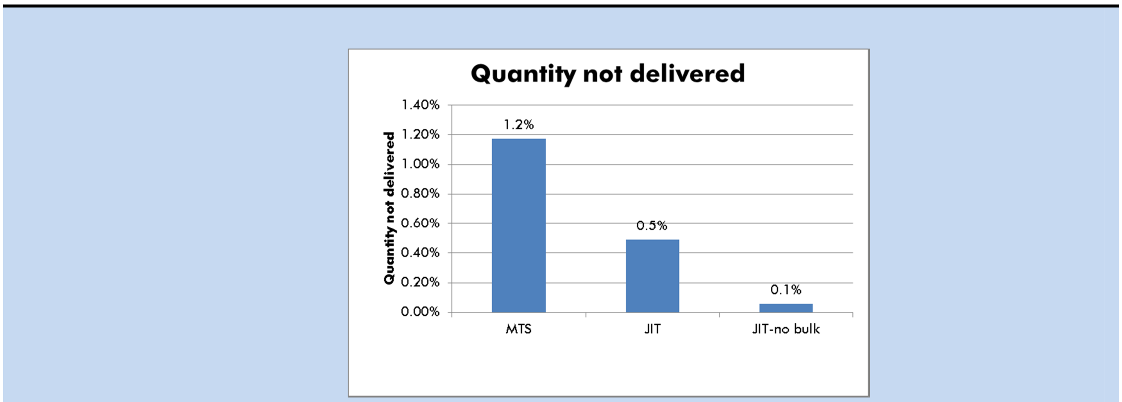


Figure 6-12: Quantity not delivered for MTS, JIT and JIT without bulk orders

6.6.4.3 *Conclusions*

It can be concluded that substituting bulk orders lead to much more stable inventories (for base polyol from σ=17% to σ=2%) and thereby increases the order fulfilment (quantity not delivered decreased from 0.5% to 0.1%).

6.6.5 Experiment 4: Impact of lower inventories

6.6.5.1 *Input parameters*

Experimentation with multiple target stock levels

Parameter	Value	Comments
Planning	MTS, JIT	Both the make-to-stock and just-in-time production regime are experimented with
Target stock level	Variable: 60% … 10%	In this experiment multiple target stock levels are tested.
Disruption size	0 days	In this experiment only the regular planned and unplanned downtimes were included. Force majeure situations are excluded.
Bulk orders	TRUE, FALSE	For the JIT-no-bulk runs the bulk orders are substituted with regular orders.

Table 6-9: Input parameters for Experiment 4

6.6.5.2 *Summary of output*

Table 6-10 shows for varying target stock levels and production regimes the; average inventory level of PO (PO) and the quantity not supplied (C). These figures are graphically represented in Figure 6-13.

Target Stock Level	MTS		JIT		JIT no bulk	
	PO	C	PO	C	PO	C
0.6	**58%**	**1.2%**				
0.5	43%	1.5%	45%	0.5%	52%	0.1%
0.4	36%	2.1%	35%	1.0%	41%	0.0%
0.3	29%	2.8%	**25%**	**1.3%**	31%	0.1%
0.2	23%	4.2%	17%	2.5%	**21%**	**0.3%**
0.1	19%	6.4%	12%	6.2%	13%	1.5%

Table 6-10: Summary of output Experiment 4

Figure 6-13 shows that for all target stock levels JIT production results in a higher order fulfilment (hence lower 'quantity not supplied') than MTS production. Also JIT without bulk orders always leads to higher order fulfilment than JIT production with bulk orders.

Also it can be identified that the same level of order fulfilment can be reached with an average stock level of 58% for MTS, 25% for JIT and less than 20% for JIT with no bulk.

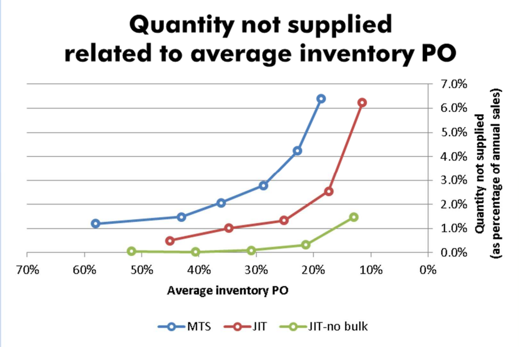


Figure 6-13: Quantity not delivered for MTS, JIT and JIT without bulk orders with varying target stock levels

6.6.5.3 *Conclusion*

It can be concluded that with JIT the average stock levels can be lowered from 58% to about 25% and when bulk orders are substituted even till less than 20% without compromising the level of order fulfilment. In other words, the inventory levels can be much lower with JIT production when not taking force majeure situations into account.

6.6.6 Experiment 5: Impact of disruptions

6.6.6.1 *Input parameters*

In this experiment the MTS, JIT and JIT with no bulk setting will be tested with disruptions of varying duration.

Parameter	Value	Comments
Planning	MTS, JIT	Both the make-to-stock and just-in-time production regime are applied
Target stock level	PO: 60% Base Polyol: 50%	The target stock levels are set in such fashion that the average inventories are similar to those in the historical data set, discussed in the Stock Operations Analysis.
Disruption size	0, 5, 10, 20 40 days	In this experiment force majeure situations of varying duration are simulated.
Bulk orders	TRUE, FALSE	For the JIT-no-bulk runs the bulk orders are substituted with regular orders.

Table 6-11: Input parameters for Experiment 5

Due to the complex production network it is hard to determine the exact impact of a disruption. That is why the total 'quantity not deliver' will be taken as a proxy for the impact of the simulated disruption. Table 6-12 shows the average 'quantity not delivered' (Avg.) and the variability (Var.) of this impact. The variability can be seen as the predictability of the impact of a disruption. This variability is presented as an percentage of the average impact in MTS mode. The average quantity not delivered can be found in Figure 6-14. Figure 6-15 shows the variability.

Duration of disruption	MTS		JIT		JIT no bulk	
	Avg.	Var.	Avg.	Var.	Avg.	Var.
5 days	0.8%	41%	0.5%	25%	0.0%	3%
10 days	1.0%	38%	0.5%	30%	0.5%	12%
20 days	2.1%	32%	1.0%	17%	1.5%	13%

40 days	6.0%	18%	2.4%	16%	6.0%	11%

Table 6-12: Impact of disruptions of varying duration for MTS, JIT and JIT with no bulk

Figure 6-14 shows that the quantity not supplied is about the same for MTS, JIT and JIT with no bulk, the differences can be explained through the small difference in average inventory level. There is a difference with small disruptions, where on average JIT results in a higher order fulfilment (hence less quantity not supplied). Up to 10 days the impact is lower with JIT than with MTS. When the disruptions get bigger, the pattern is the same for all modes.

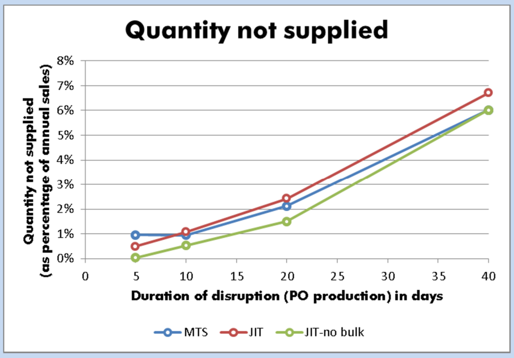


Figure 6-14: Quantity not supplied for MTS, JIT and JIT without bulk orders with varying disruption duration

What is interesting is the predictability of this impact. Figure 6-15 shows the variability of the impact of disruptions of varying duration for MTS, JIT and JIT with no bulk.

The graph shows that for MTS production, with increasing duration, the variability decreases. In other words, the predictability of the impact of a disruption increases when the disruption is longer. For short disruptions, the impact can be negligible if the inventory level is high, but can be disastrous when the inventory level is low.

With JIT production, low disruptions will more often result in no impact, and there for their impact is more predictable. Equal to MTS, the variability will decrease when the duration of the impact increases.

With JIT production with no bulk orders, it is even clearer that the impact of small disruptions is less variable and the impact of disruptions is up to 40 days more predictable than with MTS production.

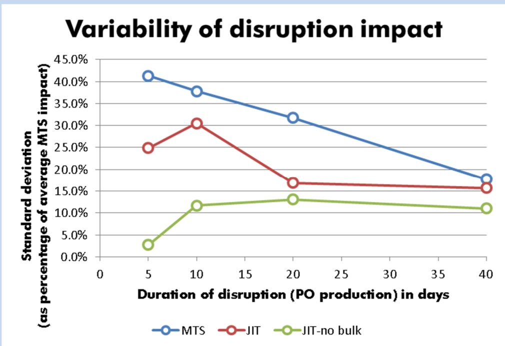


Figure 6-15: Variability of disruption impact for MTS, JIT and JIT without bulk orders with varying disruption duration

6.6.6.2 *Conclusions*

It can be concluded that the impact of large disruptions on the average is the same for MTS, JIT and JIT with no bulk. For disruptions under 10 days JIT results in a higher order fulfilment as inventory levels are more certain. Another advantage of JIT is the predictability of the impact of a disruption. It was shown that the variability of the impact of a disruption is much lower for JIT production than for MTS. For a disruption of 10 days this results in σ=38% for MTS, σ=30% for JIT and σ=12% for JIT with no bulk. This advantage is bigger for small disruptions, when the duration of disruption increases, the predictability of JIT approaches the relative lower predictability of the MTS mode.

6.7 Discussion

6.7.1 Introduction

In the previous section five experiments have been performed and the outcomes have been presented. In this section the results will related to the assumptions and simplifications of the model. Moreover suggestions how the simulation model can support further steps towards implementation of JIT will be discussed.

6.7.2 Reflection

6.7.2.1 *The model showed that JIT production can be applied to the production process*

The chemical industry has one of the most complex production chains due to a bill of materials that decomposes a few raw materials into many finished products. In order to capture this complex bill of materials, an object oriented representation of the system was used. The relations between the objects describe the bill of materials and the properties of batch production[6].

In order to be able to simulate the system, a couple of simplifications had to be made. The internal logistics were simplified and considered not to be a bottleneck for operations. In the model the focus is on production and storage, not on the logistics between production facilities, tanks and loading docks. In reality the internal logistics sometimes frustrate the system as not all pipelines are dedicated to one process, tanks are not always available due to lab testing and loading docks have a limited capacity.

When JIT will be implemented, these bottlenecks either should be eliminated or mitigated through safety stock.

6.7.2.2 *The model showed that JIT production results in more stable inventory levels*

The chemicals industry is characterized by low margins, leading to an emphasis on asset utilization. In order to facilitate the production, demand management is used to adapt demand to the production rate. During the validation of the MTS model it has become clear that stabilizing the system only through the market mechanism[7] is not possible. This resulted too often in either full or empty tanks. It is the time delay between the price setting and the response of the market that makes the system volatile. The advantage of adapting the supply to the demand, as applied by JIT production, is that the time delay can be reduced to a minimum. This results in a system where inventory levels are more stable than with MTS production.

In order to be able to apply JIT production, a couple of simplifications have been made. The system represents an ideal situation regarding information sharing and decision making. Information about the demand is totally accurate with a horizon of 5 days and inventory levels are always available and accurate. In reality there can be rush orders, and orders can be changed even in the last 5 days before supply. Also accurate inventory levels are not known to all parties as currently inventory levels are faxed to the supply coordinators on a daily basis and incidentally shared with the sales department. Next to this, in the model decisions about production are always followed instantly. In

[6] As a relation between the product and the production unit.
[7] With this mechanism the price of products is set through supply and demand, when there is more supply than demand prices will fall, when there is more demand than supply prices will rice.

reality the continuous production units cannot be stopped, but will be slowed down gradually. This leads to a small delay, which will make that the inventory levels vary more in reality than in the model.

6.7.2.3 *The model showed that JIT provides better performances*

Driven by the emphasis on asset utilisation, occupancy of assets is considered an important KPI for manufacturing divisions. In this model next to the occupancy also order fulfilment, inventory variability and planning lead-time have been considered important KPI's for the system. Lower inventory variability leads to a higher order fulfilment as stock-outs occur less often. And with the implementation of JIT production the planning horizon was set to 5 days.

In order to be able to simulate this, historical data about the managed demand was used. In the model, this demand is fixed. The occupancy of assets is a result of this managed demand, which makes the occupancy predetermined. What can be concluded from this model is that the current occupancy can also be reached with JIT production. Further experimentation could provide insight where the occupancy reached the point that the system gets volatile. Another important underlying assumption is that the demand still will be managed. This managed demand is more suitable for the system than the raw demand. Further experimentation could give insight on the impact of a more volatile demand. Managing the demand is costly and often puts profit margins under pressure, decreasing the need for demand management would increase profit margins and flexibility as perceived by customers.

The model showed that newly introduced KPI's can be improved by introducing JIT production and doesn't compensate the current most important KPI: occupancy. The order-fulfilment[8] was increased from 98.8% for MTS production to 99.5% for JIT and even 99.9% for JIT with no bulk orders.

6.7.2.4 *The model showed that JIT results in a more predictable production process*

The bill of materials composes a few materials into many finished products. This makes it hard to predict the impact of a disruption. Also it is hard to take appropriate measures to prevent consequential downtime or compromised customer order fulfilment. This predictability decreases when inventory levels are volatile. With high inventory levels, a disruption can be not felt at all, while the impact with low inventory levels can be disastrous.

In all experiments major disruptions were excluded in order to determine how JIT can stabilize the system in normal operations. In reality "normal operations" do not exist. Every unit suffers from a significant disruption several times a year, causing consequential downtime or compromised customer order fulfilment.

The model showed that the impact of an isolated disruption is better predictable with JIT production than with MTS. For a disruption of 10 days it resulted in a standard deviation of 38% for MTS, 30% for JIT and 12% for JIT with no bulk.

---

[8] Order fulfillment is expressed as the invert of 'quantity not supplied', which is 1.2% for MTS, 0.5% for JIT and 0.1% for JIT with no bulk.

6.7.3 Suggestions

6.7.3.1 *The model could be made more accurate when the market-mechanism is modelled in detail*

Currently the underlying assumptions about the market-mechanism is at a macro level. The price-elasticity of supply and demand was based on a rough comparison with other industries, no actual data analysis was performed. Moreover it was assumed that the price setting is directly related to the inventory level, which in reality is much more complicated. In reality the price is also related to the price and availability of the precursor products, market demand, prices of the alternative products the company can produce and the availability of assets and many other considerations.

In order to be able to do this, the price-elasticity's should be calculated, the underlying determinants for the price should be identified and quantified, and the reaction and delay of demand should be quantified. Next the logic and data should be included in the model.

6.7.3.2 *The model can support a business case by including financial aspects*

The model has shown the potential of JIT production. Implementing JIT production will be costly and time consuming. For the company to support this decision a robust business case should be developed. The model can support this business case when financial aspects are included. Also the model can support trade-offs to be made about the degree of implementation, for instance about how adaptive production should be to the demand.

Currently no financial measures are included due to the lack of information about product prices. In order to support a business case these financial aspects and its logic should be included in the model.

6.7.3.3 *The model can be used to identify bottlenecks in the internal logistics*

The model has shown that JIT production can be applied to the assets of the company. Underlying assumption is that the internal logistics do not frustrate the operations. In reality the internal logistics do matter and can form bottlenecks. JIT production with low inventories makes these bottlenecks visible and makes that the model can be used to identify those bottlenecks which frustrate operations most.

Currently the internal logistics are very simplified, in order to identify bottlenecks in the internal logistics this should be included in more detail. The object oriented approach makes that objects like pipelines and loading docks can be included. Switching these objects on and off will identify the impact these limitations have on the operations and makes the identification of bottlenecks possible.

6.7.3.4 *The model can support the development of calculated responses to events*

The model has shown that JIT production makes the impact of a disruption more predictable than with MTS production. For the company it is very valuable to be able to understand the consequences of a disruption.

This understanding enables the development of appropriate and calculated measures. These measures can be applied proactively in the case of planned maintenance and reactively in the case of unplanned disturbances. Combined with including the financial aspects this enables the company to make a proper calculated trade-off about the measures to take in a specific situation and develop standardized responses to common events.

7 CONCLUSIONS AND RECOMMENDATIONS

7.1 Introduction

7.1.1 Introduction

This thesis presented a strategic audit that comprises the operational strategy and competitive strategy of a company, as shown in Figure 2-2. The market view was applied which starts in the market and ends with recommendations for the operations of the company. First the fitness of the competitive strategy with the industry and customers was researched through respectively the Industry Trends Analysis and the Customer Value Analysis. This resulted in recommendations for the operations strategy of the company. The identified competency gap was discussed and improvements were presented to mitigate this gap. Finally the recommended improvements where tested in a simulation model as discussed in the Simulation Analysis.

7.1.2 Structure

In order to answer the main research question, five sub questions where presented to structure the work. Detailed answers to these five sub questions can be found in Appendix G. In this chapter the main question will be answered and conclusions will be drawn. Finally recommendations will be presented.

7.2 Conclusions

The main question as presented in Chapter 2 is:

How can manufacturing companies delivering to intermediate markets improve the customer-perceived value of supply in a cost-effective way?

7.2.1 Conclusion 1

Increased demand for responsiveness

Supply chain management increasingly is recognized as a means by which competitive advantage is gained. That is why the supply chain perspective is the driving force for many changes in many industries. Increasing volatility in the demand on consumer markets makes that requirements of the industries downstream include the responsiveness to this volatile demand. As a consequence this also influences the customer-perceived value of the manufacturer's supply. The commoditization in the downstream markets increases the need for agile operations and make that customers focus more on service-aspects like lead-times. In the company this is especially the case for the CASE[9] customers. This is a segment in which the company wants to grow and where customers on average are smaller and deliver to industries where just-in-time practices are more common. This explains why Flexibles[10] customers value reliability more, while CASE customers value responsiveness more. In contrast with the high performances on reliability the customers graded the performances regarding responsiveness amongst the lowest. The ambition of the company to grow in the CASE segment makes this insight quite alarming.

7.2.2 Conclusion 2

The emphasis on asset utilisation compromises order fulfilment

The current production regime, based on make to stock (MTS) and a high emphasis on asset utilisation compromises the order fulfilment. The high unit occupancy leads to varying availability of products and a long planning horizon. The delay in information between the complex production chain and demand management makes that inventory levels vary a lot and consequentially order fulfilment is compromised. Simulation showed that this emphasis on unit occupancy disturbs the supply more than the minor downtimes[11] of the units.

7.2.3 Conclusion 3

The downstream demand should be leading in the planning rather than the upstream production

Currently the upstream production and the available production capacity for polyols are leading in the production planning. The consequence is compromised order fulfilment and consequential downtime of assets. The divergent bill of materials makes it possible to only produce those products for which a demand is present, in other words produce on a pull basis. This mind shift will make the upstream integrated production beneficial for reliability whereas currently the push mentality makes that this integration compromises the reliability.

7.2.4 Conclusion 4

Simulation can give insight in the complex production chain of specialty chemicals

The production processes and assets were successfully represented in a simulation model, which delivered valuable insights for the industry. The chemicals industry is characterized by a bill of materials that decomposes a few raw materials into many finished products. This makes that the chemicals industry has one of the most complex production chains. In this thesis an object oriented representation of the system was proposed. The relations between the objects describes the bill of materials, thereby enabling the simulation of the complex production chain.

[9] CASE is one of the three product segments and finds its application in Coatings, Adhesives, Sealants and Elastomer.
[10] Flexibles is one of the three product segments and finds its application among others in car-seats and isolation.
[11] The disruptions caused by force-majeure situations were excluded from this simulation.

7.2.5 Conclusion 5

The just-in-time (JIT) production regime leads to shorter lead-times and higher order fulfilment in the production of polyols

Through simulation it was shown that the JIT production regime can be applied to the assets of the company regarding the production of polyols. Experiments based on historical data of sales and disruptions showed that this regime is quite successful. Production lead-items were decreased to 5 days (excluding transport) and order fulfilment could be increased to 99.5% (compared to 98.8% with MTS). Though model gives a simplified representation of the real system, it shows the prospects of JIT. When bulk orders are substituted with normal orders, the order fulfilment can even be increased to 99.9%.

7.2.6 Conclusion 6

The just-in-time (JIT) production regime allows lower inventories

Data analysis showed that inventory level of PO on average is 60%. With the JIT production regime, the variation in inventory levels can be decreased. This enables lower inventories without significant impact on the order fulfilment. The simulation showed that the inventory of PO could be decreased to 25% of the tank capacity by applying the JIT production regime while sustaining the order fulfilment level.

Regarding the base polyol, data analysis showed an average inventory level of 52%. Simulation showed that bulk orders provided a barrier for decreasing the inventory levels. These bulk orders are the result of production surplus and have lower margins than regular orders. When substitution these bulk orders with regular orders, JIT proved to be successfully in decreasing the inventory levels for the base polyol. The simulation showed that the inventory of the base polyol could be decreased to 21% of the tank capacity by applying the JIT production regime with even a better order fulfilment (99.7%) than MTS (98.8% at an inventory level of 60%).

7.2.7 Conclusion 7

The just-in-time (JIT) production regime makes the impact of disruptions more predictable

For large disruptions the impact on average is the same for MTS, JIT and JIT with no bulk. For disruptions under 10 days JIT on average result in a higher order fulfilment as inventories can cope with the disruptions. It is especially for these disruptions that the impact of the disruption can be better predicted. The model showed that the variability of the impact of a disruption of 10 days results in $\sigma=38\%$ for MTS, $\sigma=30\%$ for JIT and $\sigma=12\%$ for JIT with no bulk. When the duration of disruption increases, the predictability of JIT approaches the relative lower predictability of the MTS mode. This feature of JIT makes it possible to develop calculated responses to common disruptions and makes it possible to make better trade-offs in case of a disruption.

7.3 Recommendations

7.3.1 Recommendation 1

Lead-times should be considered as a key performance indicator

Currently no structural evaluation of the lead-times is taking place. Two types of lead-times can be identified, the lead-times for production and the lead-times for transport. This research focussed on the lead-times for production, starting at the moment the customer indicates the need for a product and ending at the moment the product is supplied (excluding the transport).

7.3.2 Recommendation 2

The production and demand forecasts should be evaluated structurally

The current make to stock (MTS) production regime heavily depends on proper forecasting and planning. The monthly process of forecasting and planning is facilitated by the sales and operations planning (S&OP) process. There is no structural evaluation of the accuracy of the forecasts, while this can be considered a key performance indicator of the supply department. Regarding the production forecast, the data needed to evaluate is currently available. This is not the case for the demand forecast. Requests that don't result in an order are not logged, neither are request that cannot be fulfilled to the full extend.

7.3.3 Recommendation 3

Implementation of the JIT requires investments in information technology

The company uses SAP to keep track of all outstanding orders and to manage the transport from the production site to the customer. Also the manufacturing department is equipped with advanced information systems. In order to enable the JIT regime, the challenge for the company will be to integrate these systems. Currently the information system of the supply department, responsible for the forecasting and planning, is mainly based on (partly personal) spread sheets that are not shared. This will not give the essential information for operation on a JIT basis. Hence the advice to invest in the needed information technology to support JIT.

7.3.4 Recommendation 4

Investigate the financial benefits of the JIT regime to support a business case

This research doesn't include a financial trade-off between the MTS and JIT operations. Further research can give insight in the costs involved in maintaining the inventory capacity, the costs due to orders that cannot be fulfilled, consequential downtime, the costs involved with utilizing the assets more flexible and investing in a proper information system and the competitive advantage of short lead-times.

8 REFLECTION

8.1 Introduction

In this chapter I would like to share my personal reflection on the work I've performed. This project considered a system with a high degree of complexity. Managing this complexity in my view has been interesting and challenging. During this thesis project, I was in the privileged position to perform a desk research and experience the daily activities in a chemicals manufacturer. This study gave me insight in the way the company dealt with this complexity but also gave me the experience of performing in a complex environment. Bringing structure in your work has been automatism for me before I started this project. It is through this project that I experienced how it is to lose grip on things when structure is lacking and made me aware of the importance of structure in dealing with complex systems.

8.2 The downside of key performance indicators

The initial question from the company was to provide answers about how the customer-perceived value of supply could be improved. For me, the first key performance indicator (KPI) of the system was set: customer satisfaction. A logical first step was to find out what the characteristics and challenges of the industry are and how customers value the supply. This approach was supported by the audit that is provided in the Research Framework and resulted in an outside-in approach. I have been surprised by the reactions this generated in the company. The workshop I organised contained a series of characteristics of downstream industries. The insight I wanted to share was that the company's customers should be able to satisfy their own customers in order to be successful and that the choice of the right supplier is key in this. This resulted in a heated discussion in which in the first place the chosen characteristics were considered to be not relevant to the company's supply. It required a lot of persuasion to get the point stressed that the supply chain as a whole is important in improving the supply to customers. There are two sources for this limited view on the supply chain that require attention.

First of all the company uses the term 'supply chain management' only for the management of the part of the supply chain that is owned by the enterprise itself. In other words their supply chain ends at the point that an end-product is produced. This relates to the discussion in literature where either supply chain management is considered a function of the company's supply or the company's supply is considered as a function of the total supply chain. In my opinion both views are valid and result in very different conclusions. From a company perspective the more pragmatic view where supply chain management is a function of the company's supply is the most logic. But the fitness of a company in the total supply chain becomes increasingly important and in my view is commonly underestimated in mature markets. This made me curious about why the view of the company was mostly limited to only their own operations.

This becomes clear in the second point: the performances of different divisions of the company are expressed through KPIs. For instance the teams responsible for production units are mainly focussed on the KPI that indicates the production of the unit. Though this reduces the experienced complexity of the system, it supports local decision making which results in local optima. For instance when there are disruptions, for these teams there is no indication of priority. For them all disruptions are of the same priority, regardless of the impact on the supply. This limits the system view and frustrates the performances of the overall system. One of the supply optimizers told me his job was to optimize the production and that it was up to the sales department to get it sold, which for me clearly illustrated the push mentality that is also discussed in the literature about the chemicals industry. In my view this behaviour is supported by the local KPIs that do not propagate proper alignment between supply and demand and frustrate the overall system performance: reliability of supply.

This experience showed me the importance of cross-functional processes and teams, which I will discuss in more detail in the section about the importance of teamwork. Next to the observations within the company, I experienced the effects of KPIs for this project. Often I felt pushed into solutions, without a proper understanding of the underlying system. While to my opinion these system insights in the end are the most valuable contributions of my work. In my view structure in your work enables you to gain these insights while also fulfilling the KPIs set, I will discuss this in more detail in the next section.

8.3 The importance of a structured and systematic approach

Working with complex systems in a complex environment stresses the need for structure. My experience is that when you're working on a (personal) project that consumes most of your time and takes several months, at some point you'll start to identify yourself with the work. Leaving a structured way of working puts you in the comfortable position where you're able to hide the potential problems that might rise both for yourself and your stakeholders. A very volatile position when it considers scientific research, as in the end you'll have to face and overcome these hidden problems. Though most problems can be overcome quite easily, it compromises your ease of mind that is needed to gain new insights. In other words, it keeps you occupied and prevents you from taking a next big step. Structuring your work will bring these problems to the surface and forces you to deal with them. This gives you the ease of mind to focus on the part you're working on, and a good structure prevents you from losing sight on the overall project.

My personal experience is comparable to what I've experienced in the company. The company is working with a highly experienced staff which through the years gained the tacit knowledge that is needed to fulfil their position in a good way. With the current system approach, they are occupied a lot with fire fighting. The real causes of problems are easily hidden through volatile inventory levels, that hide the link between cause and effect. There is no such thing as 'normal operations', which prevents the building of a shared understanding why things go wrong and develop structural solutions or a systematic approach to solve problems when they occur.

The provided solution brings structure in the operations of the company. Just in time production provides a structured way of working that will force managers to deal with the problems adequately as consequences will be visible and can easily be linked to their causes. Next bringing the system (inventories) in a stable state will enable the employees to develop structural solutions and improvements rather than being occupied with fire fighting. Finally just in time production will create a focus on system wide performances, rather than local optima.

8.4 The importance of cross-functional teams and explicit decision making

Working with complex systems often includes a lot of stakeholders and increases the need for explicit decision making.

At the company I saw how important the S&OP meetings were to get everybody on the same page and made decisions explicit. These meetings gave parties insight in the difficulties the other parties were facing and stimulated a system view. Historically the focus in the company was on functions, the shift towards a process minded organisation could be felt in several developments. In my opinion cross-functional teams are very important for companies that deal with supply chains, as it stimulates a system view and prevents local thinking.

Setting up a research on my own also made me realise the importance of team work. For me the most valuable moments were those were I had the opportunity to spar with the supervisors both in the company and at the university and the discussions we had in the workshop and team meetings. Working with multiple stakeholders stressed the need to make decisions explicit, which at times was difficult, but absolutely necessary.

8.5 Similarities with quality control

As a final section of this reflection, I would like to show the similarities between quality control and just in time production. Quality control is very important in the chemicals industry and the approach is quite similar as just in time production.

In quality control the emphasis is not on achieving the highest quality possible, but more on providing a constant quality. Reaching a constant quality is achieved through eliminating variation in the total production process as much as possible. Not only at the final stage but through the entire chain of production. This constant quality makes that the performances of the product at the customer are highly reliable. This reliability is key, customers are not only looking for the company with the highest quality, but also with the most reliable quality.

Applying just in time production strives to accomplish the same for the supply. By eliminating the variations in the supply, the reliability of supply is increased. The difference with the current situation is that the focus now is on the production rather than on the supply. This focus on production frustrates the overall system performances by compensating the reliability of the supply.

Equally to achieving reliable quality a reliable supply needs the elimination of variation throughout the whole of production processes.

8.6 Conclusion

In this chapter the following aspects were discussed; (1) the downside of key performance indicators, as they stimulate local optima. (2) The importance of a structured and systematic approach in complex systems in order to get a shared understanding of the relation between cause and effect. And (3) the importance of cross-functional teams and explicit decision making in order to stimulate a system view. Finally (4) it was demonstrated how reliability of supply is achieved by eliminating variations throughout the whole of production processes.

The bottom line message is that achieving reliability of supply requires a system view rather than local optimisation.

LITERATURE

AMR (2004). AMR Benchmark Analytix: Bulk Chemical Industry. Boston.

An, C. (2005). Supply Chain Management on Demand - Strategies, Technologies, Applications. Heidelberg, Springer.

AT Kearney, I. (1997). "Supply Chain Management in the Chemical Industry." The 1996-1997 Supply Chain Study.

Boschchev, A. (2004). "From System Dynamics and Discrete Event to Practical Agent Based Modeling: Reasons, Techniques, Tools." The 22nd International Conference of the System Dynamics Society.

BTS, B. T. S. (2002). "Supply Chain Optimization: Design, Planning, Controlling." Website.

Christopher, M. (2011). Logistics and supply chain management : creating value-adding networks. Harlow, England ; New York, Financial Times Prentice Hall.

Consultants, S. C. (2002). "Sustaining Supply Chain Applications." SC Consultants White Papers.

Coxhead, P. (1998). "Oil industry white paper. Manugistics solution for the oil industry." Not published.

Davis, T. (1993). "Effective supply chain management." Sloan Management: 11.

Ellram, L. M. (1990). "The supplier selection decision in strategic partnerships." Journal of Purchasing and Materials Management 26(4): 6.

Ellram, L. M. (1994). "A managerial guideline for the development and implementation of purchasing partnerships." International Journal of Purchasing and Materials Management 27(3): 6.

Forrester, J. W. (1958). "Industrial Dynamics - A major Breakthrough for Decision Makers." Harvard Business Review 36(4): 29.

Friscia, T. e. a. (2004). The AMR Research Supply Chain Top 25. Report November 2004. Boston, AMR Research.

Harwick, T. (1997). "Optimal decision-making for the supply chain." APICS - the Performance Advantage 7(1): 2.

Holmberg, S. (2000). "A systems perspective on supply chain measurements." International Journal of Physical Distribution & Logistics Management 30(10): 21.

Holweg, M. e. a. (2005). The Second Century - Reconnecting Customer And Value Chain Through Build-To-Order, The MIT Press.

Hussain, R. e. a. (2006). "Supply Chain Management in the Petroleum Industry:

Challenges and Opportunities." International Journal of Global Logistics & Supply Chain Management 1(2): 7.

Hutchins, D. (1999). Jist in Time. Hamphsire, Gower Publishing Limited.

Interview (2011). General Manager Sales.

Interview (2011). Regional Integration Manager

Jenkins, G. (1998). "Managing inflexible supply chains." International Journal of Logistics Management 9(2): 1.

Johansson, H. J. e. a. (1993). Business Process Reengineering, John Wiley & Sons.

Kafoglis, C. C. (1999). "Maximise competitive advantage with a supply chain vision: Eliminating 'silos' of information is essential." Hydrocarbon Processing 78(2): 3.

Krenek, M. R. (1997). "Improve global competiveness with supply chain management." Hydrocarbon Processing 76(5): 3.

Lapide, L. (2004). "Sales and Operations Planning part I: The Process." The Journal of Business Forecasting.

Louw, J. J. (2006). Advanced Supply Chain Planning Processes and Decision Support Systems for Large-Scale Petrochemical Companies. Logistics, University of Stellenbosch.

Mani, J. (2003). "Who can stop the leaks?" Oil Review - Middle East(4): 2.

Martilla, J. A. e. a. (1997). "Importance-Performance Analysis." The Journal of Marketing 41(1): 2.

Mieghem, J. A. v. (2008). Operations strategy: principles and practice, Dynamic Ideas.

Miller, T. (2001). Hierarchical Operations and Supply Chain Planning. London, Springer.

Moore, F. T. (1959). "Economies of Scale: Some Statistical Evidence." The Quarterly Journal of Economics 73(2): 13.

Morroni, M. (1992). Production Process and Technical Change, Cambridge University Press

Porter, M. E. (1980). Competitive Strategy: Techniques for Analyzing Industries and Competitors. New York, Free Press.

Porter, M. E. (1985). Competitive Advantage: Creating and Sustaining Superior Performance. New York, The Free Press, Macmillan Publishing.

Saaty, T. L. (1994). "How to Make a Decision: The Analytical Hierarchy Process." Interfaces 24(6): 24.

Sage, P. (2000). Introduction to Systems Engineering. New York, John Wiley & Sons, Inc.

Schwartz, B. (2000). "The Crude Supply Chain." Transportation & Distribution 48(8): 5.

Shannon, R. E. (1975). Systems Simulation: the art and science, Prentice-Hall.

Sherbrooke, C. C. (2004). Optimal inventory modeling of systems - Multi Echelon Techniques. Boston, Kluwer Academic Publishers.

Stevens, G. C. (1989). "Integrating the Supply Chains." International Journal of Physical Distribution & Logistics Management 8(8): 5.

Verbraeck, A. (2006). Discrete modellen - Simulatie theorie (course material: SPM2320). Delft, Delft University of Technology.

Wallace, T. F. (2004). Sales & Operations Planning. Cincinnati Ohio, T.F. Wallace & Company.

Waller, D. L. (1999). Operations Management: A Supply Chain Approach. London, International Thomson Business Press.

Wilensky, U. (1999). "NetLogo."

Wynarczyk (2000). "The role of digital networks in supply chain develop." New Technology, Work and Employment 15(2): 14.