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MATCHING CUSTOMER DEMAND, OFFERING PORTFOLIO AND OPERATIONS SYSTEM IN TECHNOLOGY-INTENSIVE INDUSTRIES

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Dissertation for the degree of Doctor of Science in Technology to be presented with due permission for public examination and debate in hall TU1 at Helsinki University of Technology, Industrial Engineering and Management (Espoo, Finland) on December 7, 2005 at 12 o'clock.

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ABSTRACT

Speed, flexibility, product diversity and customisation have emerged as important sources of competitive advantage for companies, especially in technology-intensive industries. This thesis explores how to simultaneously fulfil divergent customer demands and achieve high operational efficiency through co-management of customer needs, offering portfolio, and operations. The research builds on and contributes to the areas of operations strategy, demand chain management, focused supply chains, and product design for supply chain.

The research is carried out as a series of collaborative case/action research interventions in three organisations in electronics industry. The collected data includes about 100 interviews carried out in six European countries, data from operational ERP systems of the three case companies and observations from 14 plant visits. The material is used for identifying relationships between customer needs, offerings portfolios, operations systems and operational efficiency. Secondly, tactics for mitigating the negative effect of product variety are evaluated. Based on cross-case analysis, a model is constructed that formalises the trade-off between serving each customer with a tailored offering and achieving maximum operational efficiency.

Research results suggest customer demand as the starting point for operations system design. When customers are buying a product for making it a part of a larger whole, unique offerings delivered via project-oriented operations are needed. When customers are buying the product for its own sake, generic offerings and efficient, process-oriented operations are appropriate. For a company targeting both types of demand, it may be beneficial to design several separate operations concepts. Secondly, the research evaluates pre-defined configurations, product configurability, form postponement and generic resources as tactics for managing the trade-off between a broad offering portfolio and high operational efficiency. For theory, the research provides a model for causal relationships between customer demand, offering portfolio, operations system and performance. Testing of the model testing is suggested as an issue for further research. For management, the thesis provides a structured way of thinking about the complex issues involved in design of offering portfolios and operations systems.

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Espoo, November 2005

Patrik Appelqvist

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1 INTRODUCTION

1.1 Background to the research

The Finnish high-tech industry sector showed a remarkable growth in the 1990s. Exports of high-tech equipment increased from 5% to 20% of total exports[1]. Most of this growth was from electronics industry, where value added increased from 2.63 Mrd € in 1995 to the maximum of 8.39 Mrd € in 2001 (Figure 1). Also in other EU countries, high-tech industry has been growing considerably, although the change has been slower. However, in the 2000s, volumes of Finnish high-tech industry have decreased while the growth in gross national product comes from the service sector. This development can also be distinguished globally (Tekes, 2004b).

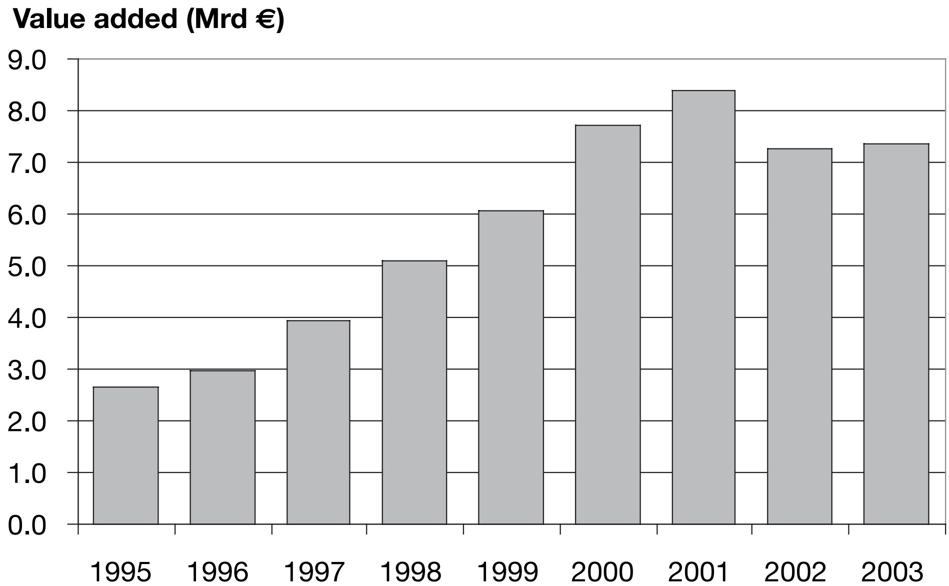

Figure 1: Growth of Finnish electronics industry sector (Tekes, 2004b)

[1] "High-tech equipment" is defined according to the product classification of OECD, 1995.

In addition to the increase in volumes, product ranges and variety have increased. The distinguished Harvard professors Robert Hayes, Gary Pisano, David Upton and Stephen Wheelwright identify how the source of competitive advantage has changed globally during the last 20 years (Hayes *et al.,* 2005). In the end of 1980s, global production capacity had finally cached up with global demand for most products, making pure mass production strategies insufficient as a source of competitive advantage. The answer was massive efforts on improving quality, including initiatives such as Total Quality Management (TQM) and Six sigma. A recent survey shows that within a sample of 30 Finnish companies in electronics and metal industry, quality is still seen as the competitive priority number one (Ketokivi and Heikkilä, 2003). However, in many areas, quality is today necessary but not a sufficient way to distinguish from competitors. Since the mid 1990s, the trend has been one of increasing need for speed, flexibility, increased product diversity and customisation (Hayes *et al.,* 2005).

In general, the diversity that consumers can choose from today is higher compared with the situation 10 years ago. In mid 1990s, Nokia started to release mobile phones targeted for different consumer segments such as a ‘business’ and ‘fashion’, which helped the company in achieving a leading market position (Häikiö, 2001). In the 2000s, the company has continued this development by expanding to such areas as media, games and business infrastructure (Talouselämä, 40/2003). Automobile companies used to standardise their cars to the extent that it is difficult to tell one brand from another (Karjalainen, 2002) but recently the selections have expanded to include large SUVs as well as small Smart cars and Hybrids. Even in food industry, product ranges are broadening. Chicken slices, for example, are today sold in a selection of 18 different marinades, compared to one marinade 10 years ago[2].

On the other hand, the “core competence” imperative of the 1990s has had the consequence that on a business level, companies are rather focused today. Despite a large number of products, Nokia is highly focused around the theme “life goes mobile”. Dell is providing a high diversity of computer hardware, but is not expanding into service business such as help-desks (Eriksson, 2004). Intel focuses on developing and manufacturing microprocessors in-house, but is only facilitating the development of all the other components that are needed for a computer to run faster (Gawer and Cusumano, 2002). All these companies are well known for their excellent operations systems that are suited for manufacturing and delivering their range of products. A Finnish example is Agco’s tractor factory in Suolahti that has been very successful in offering high product variety combined with assemble-to-order operations. On the other hand, Valmet Automotive also has an extremely flexible assembly plant in Uusikaupunki. This plant has had dif-

[2] Total number of different marinades found at websites if major Finnish food companies (www.atria.fi, www.hk-ruokatalo.fi; www.saarioinen.fi and www.plussa.fi, visited 15.12.2004).

ficulties in finding customers, as mainstream automobile industry is moving towards product standardisation and cost focus. In summary, successful companies tend to have a well-defined offering portfolio with a corresponding operations system. In addition, both the offering portfolio and the operations system should respond to customer needs.

According to an expert panel interviewed in a recent project, the development of new integrated product-service concepts is one of the most important challenges today (Tekes, 2004a). To be successful in a competitive business environment, companies need to co-manage their products, processes and supply chain (Fine, 2000). This is of particular importance in high-clockspeed industries, where product lifecycles are short and there is little time to correct mismatches before the lifecycle is over. The choice about product range and variety is one of the most critical decisions a company has to make in designing its operations system. Product variety and operations systems have traditionally been studied separately. Lehtonen (1999: 26) observes that “product range issues seem to be outside the scope of both manufacturing and supply chain functional strategies” and Ramdas (2003) concludes that supply chain issues, especially downstream distribution, are usually excluded from analyses of product variety.

This thesis is about matching customer needs, offering portfolio, and operations, particularly for companies that operate in technology-intensive industries. “We still know very little about how decisions in product design, process design, and supply chain design should be coordinated to maximize operational and supply chain performance” (Salvador *et al.*, 2002). This research attempts to address the gap.

1.2 Research problem and research questions

Due to the high interdependence between products, processes and supply chain, it is estimated that up to 70-80% of product lifecycle costs are determined in the product design phase (Whitney, 1988; Chapman, 1992; Dowlatshahi, 1996; Hatch and Badinelli, 1997; Dowlatshahi, 1999). This has resulted in stream of research about how to design supply-chain friendly products (Mather, 1992; Dowlatshahi, 1996; Feitzinger and Lee, 1997; Dowlatshahi, 1999; Hoek, 2001; Kaski and Heikkilä, 2002). A considerable body of knowledge also exists on the topic of how to select the best demand/supply chain for a given type of products (Fisher, 1997; Lamming *et al.*, 2000; Harland *et al.*, 2001; Li and O’Brien, 2001; Selldin and Olhager, 2005; Collin, 2003; Towill and Christopher, 2003). However, rather than optimising for each product separately, it can be beneficial for companies to consider several product families within one company (Salvador *et al.*, 2002). This is especially true in high-clockspeed environments, where it is not possible to renew manufacturing equipment and delivery concepts at the same speed as products shift.

The research problem of this thesis is stated as follows:

> *Can a company produce and deliver a high variety of products while maintaining high operational efficiency?*

In chapter 2, I will, based on literature, argue that the relevant entities to consider are customer needs, offering portfolio, and operations system. Diverse customer needs require a broad offering portfolio that in turn poses challenges when designing an efficient operations system. This assumption about a trade-off is based on a pre-understanding that operational flexibility is always associated with some cost (Gerwin, 1993; Upton, 1995; Narasimhan and Das, 1999; Safizadeh *et al.*, 2000).

The research problem will be solved via two perspectives: a market perspective that has the value proposition of a product as its starting point and an engineering perspective that has the product architecture as its starting point. The research problem is thus divided into two research questions:

1) *What are relationships between offering portfolio, operations system design and operational performance? (market perspective)*

2) *How can a company manage trade-offs between a broad offering portfolio and high operational efficiency? (engineering perspective)*

Question 1 is concerned with clarifying how relevant dimensions of product variety, operations system design and operational performance relate with each other. A descriptive approach is used here, with the aim to find generally applicable relationships. Question 2 takes a managerial viewpoint by providing prescriptive advice about how to overcome trade-offs between a broad offering portfolio and high operational efficiency. These pieces of advice are necessarily more context-specific than the general relationships that are explored in the first question.

1.3 Methodology

The long-term goal of scientific research is to create theories that are relevant, generalisable and parsimonious (Weick, 1979: 35-42). However, each study usually contributes with just one piece to the emerging theory (DiMaggio, 1995). The theory-building process in the area of product design for logistics and product-focused supply chains has currently proceeded to a stage somewhere between mapping of key constructs and relationship building (section 3.2). The chosen research strategy in this thesis is therefore in-depth field studies and Handfield and Melnyk (1998) recommend.

The research is carried out as a series of collaborative case/action research interventions (Kotnour, 2001) in three organisations. They all design, assemble and deliver discrete-part products that are technically advanced. Industry clockspeed and production volumes vary between cases. The three organisations are facing a common challenge of matching product design, manufacturing process and supply chain design. The research design follows the European tradition of working closely with companies in order to ensure that research results have practical utility (Maloni and Benton, 1997; Hill *et al.*, 1999; Kotnour, 2001; Bertrand and Fransoo, 2002; Småros *et al.*, 2003).

The collected data includes about 100 interviews carried out in six European countries, data from operational ERP systems of the three case companies and observations from 14 plant visits. Dissemination of data has been a process of reporting and discussing findings together with management of case the companies, with fellow researchers in the Global Oparations Competence (GLOCO)[3] research group and with industry representatives in Gloco steering group. Results from each case have been published as conference papers (Appelqvist and Heikkilä, 2003; Appelqvist and Gubi, 2004; Appelqvist and Vehtari, 2004). Results from one of the cases are also published as a journal article (Appelqvist and Gubi, 2005).

Further information about used methodology and justification for methodological choices are presented in chapter 3.

[3] The Global Operations Competence (GLOCO) project is aimed at analyzing, evaluating and developing operational competencies of globally operating manufacturing companies. The project was carried out in years 2001-2005 at BIT Research Centre of Helsinki University of Technology, TKK. The author was employed by the project since its start (www.glocoproject.net).

1.4 Outline of the thesis

The thesis follows a six-chapter layout. The chapters contribute to answering the research questions in the following way (Figure 2):

Chapter 1 *Introduction* presents research problem and research questions, justifies why they are important and outlines how they will be addressed.

Chapter 2 *Research issues* provides partial answers to the research questions based on previous research. As a theoretical contribution, a conceptual framework addressing research question 1 is presented. Secondly, candidates for answers to research question 2 are identified and mapped into the conceptual framework.

Chapter 3 *Methodology* addresses how to gain additional answers to the research questions via empirical data collection. The chapter presents and justifies strategies and research settings for gaining knowledge, research design for carrying out the study, and research techniques for measuring, manipulating, controlling and otherwise contending with variables. The chapter also includes a discussion about validity.

Chapter 4 *Case studies* contains three stand-alone case studies. The research problem is studied in three different environments. For research question 1, the chapter provides three *as is* descriptions of customer needs, offering portfolios and operations systems. For research question 2, the chapter evaluates ways of managing the trade-off between a broad offering portfolio and high operational efficiency.

Chapter 5 *Conclusions* uses data from the previous chapter for answering the research questions through cross-case analysis. Final constructs and relationships among them are identified. Next, efficacy and use criteria for different tactics for mitigating the negative effects of high product variety are evaluated

Chapter 6 *Discussion* compares research findings (chapters 4 and 5) with existing literature (chapter 2). Theoretical and practical implications are evaluated. Finally, limitations and issues for further research are discussed.

Research question	1. Introduction	2. Research issues	3. Methodology	4. Case studies	5. Conclusions	6. Discussion
1. What are relationships between offering portfolio, operations system design and operational performance?	Justification for theory and practice	Identification of ’a priori’ constructs Conceptual framework	Identifiying good research settings and methods	Description of customer needs, offering portfolio and operational performance of each company	Cross-case analysis: Final constructs and causal relationships	Contributions to theory and practical implications
2. How can a company manage trade-offs between a broad offering portfolio and high operational efficiency?	Justification for theory and practice	Identification of potential ways of managing the trade-off	Identifiying good research settings and methods	Evaluation of a performance improvement opportunity	Within-case analysis: Observed effect and use criteria for each way of managing the trade-off	Contributions to theory and practical implications

Figure 2: Outline of the thesis and role of each chapter in answering the research questions.

2 RESEARCH ISSUES

The ability to match products, processes and supply chain has been called “the ultimate core competence of the corporation” (Fine, 2000). However, despite growing recognition about the issue, many pieces of information are still missing about how to coordinate decisions in order to maximize operational and supply chain performance (Salvador *et al.*, 2002). This chapter will review recent research results in the area and extract research questions that will be answered in the empirical part of the thesis. Secondly, ‘a priori’ constructs are defined in order to help in answering the research questions. The chapter starts from the broad area of strategic management of operations, and then narrows down the scope towards the specific research questions on which data will be collected (Figure 3).

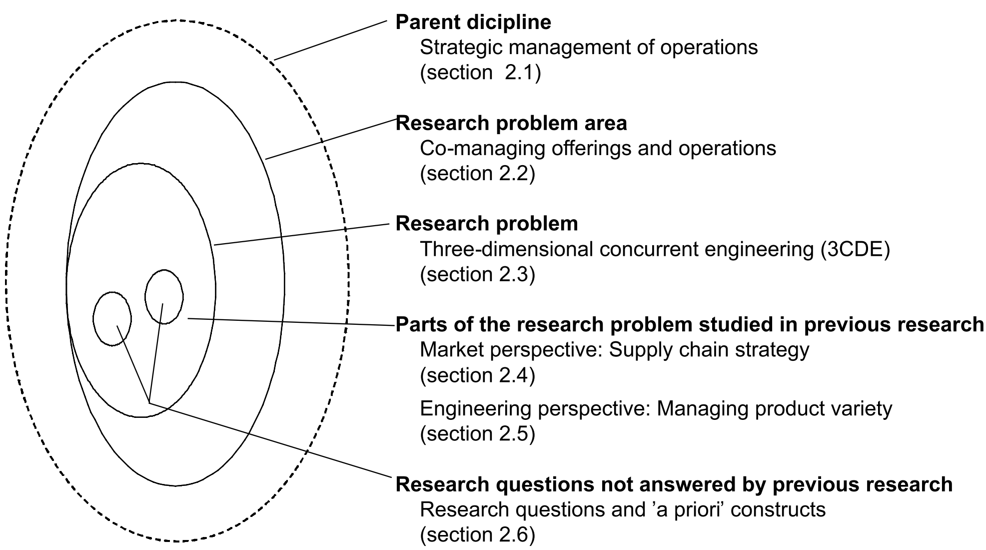

Figure 3: Hierarchy of research issues (applied from Perry, 2002).

The chapter starts with a 35-year historical overview. Operations management that once was considered a single-organisation cost-minimisation task is now recognised as a potential source of competitive advantage within a network or organisations (section 2.1). Managing operations to support a business strategy includes co-designing offering portfolios and operations systems according to boundary conditions that are set by industry characteristics (section 2.2). The research problem of the thesis will be approached via two perspectives (section 2.3). The *market perspective* emphasises how the value proposition of a product affects desired operational performance (section 2.4). The *engineering perspective*, in turn, provides a range of tactics for dealing with high product variety without compromising on operational efficiency (section 2.5). The last section provides a synthesis of previous research, defines research questions and defines 'a priori' constructs (section 2.6).

2.1 Strategic management of operations

In a free-enterprise society, the prospect of profit is the prime motivating force of the businessman (Alt and Bradford, 1952: 1). Profits are earned when goods and services are sold at a price that exceeds the cost of producing and delivering them. Different companies tend earn their profits in different ways; these differences are the object of analysis in strategy research (Halldórsson, 2004). A *strategy* is a pattern or plan that integrates an organisation's major goals, policies, and action sequences into a cohesive whole (Minzberg and Quinn, 1991). The strategy addresses how a company intends to engage its environment: where it will be active, how it will win in the marketplace and what will be its economic logic for obtaining returns (Hambrick and Fredrickson, 2001).

An *industry* is a group of firms that produce products that are close substitutes to each other (Porter, 1980: 5). Strategy research has traditionally been concerned with how companies select industries, how they compete within these industries and ultimately, how some of them succeed in creating sustainable competitive advantage. Operations are one potential source of competitive advantage. In the 1960s, researchers from Harvard Business School discovered that even within the same industry, companies tend to organise their operations in ways that are different from each other (Skinner, 1969). For example, at that time, low cost and high quality were seen as contradictory targets. Hence, the operations of a successful company competing on low cost would look different from the operations of a successful company competing on high quality. Operations should not be seen a cost factor only but as an important contributor in creating and carrying out corporate strategy (Hayes and Wheelwright, 1984).

In the 1990s, there was a shift in attention from single companies competing with each other towards groups of companies competing, collaborating or complementing each other (Hoover *et al.*, 2001: 22-32). Supply chain management that emerged in the 1980s considers flows of material and information within companies and over company borders (Christopher, 1998). The core statement is that a saving in total supply chain cost will ultimately benefit all parties in the chain (Houlihan, 1987). Later on, it was recognised that also on the supply chain level, there may exist targets other than cost minimisation (Fuller *et al.*, 1993; Fisher, 1997; Stock *et al.*, 1998). Different ways of organising the supply chain are appropriate depending on products, environmental conditions, and strategic targets of companies. Companies can gain competitive advantage by matching their products, their manufacturing processes and their supply network with each other (Fine, 1998). Furthermore, the "best match" depends on industry clockspeed, that is, the dynamism of the environment (Fine, 1998).

2.2 Co-managing offerings and operations

Research in the late 1990s and 2000s has brought much insight about how to make the most of operations for creating and sustaining competitive advantage. Operations are affected by industry characteristics; in different industries, rules are different (section 2.2.1). Secondly, within each industry, companies can have different competitive priorities. Operations should be in line with these priorities (section 2.2.2). Thirdly, innovations in the customer interface, *i.e.* value offerings, can bring benefits for the customer as well as the company (section 2.2.3).

2.2.1 Industry characteristics

According to a rational perspective, organisations exist for fulfilling specific goals (Scott, 1998). The ultimate goal of companies is to maximise the wealth of their investors. This can be done by maximising income, minimising cost, minimising capital deployed or any combination of these. Supply chain strategy literature contains arguments that different strategies are appropriate in different industries. In particular, companies in highly dynamic environments should emphasise maximisation of sales rather that minimisation of cost.

The classical news-vendor problem is to find a product's order quantity that maximises the expected profit under probabilistic demand (Khouja, 1999). The basic observation is that when future demand is uncertain, a company should keep inventory that covers more than expected demand (Scarf, 1958). The news-vendor model is particularly useful in industries where demand is highly uncertain, *e.g.* fashion and sporting (Gallego and Moon, 1993) or where margins are high, *e.g.* airline booking (Weatherford and Pfeifer, 1994). The general trend of decreasing product lifecycle lengths brought about by technology advances makes the news-vendor model even more relevant today (Khouja, 1999). Marshal Fisher from

Wharton Business School popularised the news-vendor model in a supply chain setting through an article in Harvard Business Review (Fisher, 1997).

The argument of Fisher (1997) goes as follows: In industries where demand is uncertain and life-cycles are short, margins tend to be high (margin = price – variable cost). In such situations, maximising availability is more important than avoiding excess inventory, which makes agile practices such as excess capacity, buffer stocks, lead-time reduction and modular product designs appropriate. In industries where demand is more predictable, cost minimisation is a better way to increase profits. Lean practices such as high utilisation rates, high inventory turns and cost-minimising product designs contribute to reducing cost.

Since 1997, the Fisher model has been extended by adding product uniqueness and product complexity (Lamming *et al.*, 2000), value added (Li and O'Brien, 2001), focal firm supply network influence (Harland *et al.*, 2001), and supply uncertainty (Lee, 2002). The underlying argument that the news-vendor model should be applied in supply chain management (Fisher *et al.*, 2001) has not been questioned. Rather, other authors tend to bring up additional issues for a manager to consider. Secondly, it seems that the practices that Fisher (1997) recommends for different situations should be seen more as illustrations than strict rules. Many of the practices that Fisher (1997) recommends for delivering innovative products can also be useful for delivering products that are not innovative (Lehtonen, 1999; Li and O'Brien, 2001; Selldin and Olhager, 2005). Thirdly, although Fisher talks about supply chains in general, the findings strictly apply to consumer goods retail. In a complete supply chain, upstream parties do not necessarily have to apply the same agile practices as downstream parties (Naylor *et al.*, 1999; Childerhouse and Towill, 2000).

In summary, industry characteristics set the rules to be followed in a business. It is important for managers to realise these rules that apply to all companies in an industry.

2.2.2 Competitive priorities

Industry level characteristics are useful for explaining differences between industries and for managers within single industries to understand their situation better. However, once a company has decided in which industries to compete, industry characteristics serve as boundary settings, not as decision variables. Still, not all companies in an industry have to compete in the same way. Strategy is about performing different activities compared to competitors, or performing the same activities in a different way (Porter, 1996). For example, in mature industries companies typically compete on cost. However, also in a mature industry, a company can gain market share by providing products or services that are better than those that competitors provide (Hill, 1988). If economies of scale are available, increased volumes can, in turn, lead to lower cost structures (Hill, 1988).

The strategic choice perspective tells that it is better to have a strategy than not having one (Stock *et al.*, 1998). Survey research has showed that companies following a generic strategy (Porter, 1980) in logistics tend to outperform companies that follow no coherent strategy (Lynch *et al.*, 2000). In the same study, no differences in success were found when comparing companies following a cost leadership strategy with companies following a differentiation strategy. Different strategies, if properly implemented, lead to different ways of organising the supply chain (Stock *et al.*, 1998; Harland *et al.*, 1999; Lamming *et al.*, 2000).

Competitive priorities provide the link between strategy and design of operations system. Competitive priorities are concerned with the importance companies attach to different dimensions of performance such as quality, cost and flexibility (Safizadeh *et al.*, 2000). Competitive priorities can be based on assessment of customer preferences, as Hill (1994) recommends. For example, if customers base their purchase decision on availability, a company should design a reliable operations system rather than a cost-minimising one. However, customer requirements do not necessarily translate directly into operational requirements; the fact that customers are price sensitive does not necessarily mean that a company should buy cheap machines to its factories (Spring and Boaden, 1997). Preliminary results from the 3rd round of the High Performance Manufacturing study indicate that there is a link from business strategy to competitive priorities in operations, but the relationship is rather complex (Ketokivi, 2004).

2.2.3 Value offerings

Successful companies are those that succeed in fulfilling customer needs with their offerings. The starting point in *demand chain management* is to define target customers and try to understand their needs as well as possible. Once the needs are known, one should work backwards through the supply chain to find ways to fulfil the identified needs (Korhonen *et al.*, 1998; Vollmann *et al.*, 2000). In project business, single customer relationship characteristics require different levels of customer service and can affect the choice of operational mode (Heikkilä, 2002). Different supply chains might be needed for delivering the same product to different customers, if their service needs are very different. In consumer business, it would not be practical to start from single customers, but segments of customers with similar needs can be a good starting point (Christopher, 1998).

In addition to listening carefully to customers, companies can also affect customer requirements by building *value offerings* that change the customers' way of doing business (Holmström *et al.*, 1999; Holmström *et al.*, 2000; Hoover *et al.*, 2001). Vendor managed inventory (VMI) is an example of such a value offering. Traditionally, retailers manage their own inventory and issue replenishment orders to suppliers. In vendor-managed inventory (VMI), the supplier takes care of inventory management. This arrangement saves work for the retailer and gives the supplier more time to replenish (Hoover *et al.*, 2001). It is essential to understand a customer's purchasing process in order to be able to find potential new value offerings (Collin, 2003). Doing so can benefit both the customer and the supplier considerably.

2.3 Three-dimensional concurrent engineering (3DCE)

2.3.1 From concurrent engineering to 3DCE

To make a physical product, a company needs a production process. In the 1980s, many companies discovered that it was possible to gain efficiency by co-designing products and production processes rather than designing them separately or sequentially (Harmon and Peterson, 1990). Automobile assembly is a good example as each new model requires a new assembly line. Toyota co-designs new car models and their assembly lines, which shortens time-to-market and makes it possible to design cars that are easy to assemble (Ward *et al.*, 1995). The practice is known as *concurrent engineering* (*CE*) and includes multi-functional product development teams, early involvement by operations and concurrent workflows (Koufteros *et al.*, 2001).

Distinctive competences are defined as enduring firm-specific abilities that lead to above-average economic performance (Makadok and Walker, 2000). In the 1990s, the paradigm was that companies should focus on their distinctive competences and outsource non-core activities. This resulted in an outsourcing boom. Consequently, it is no more enough to match products with internal production processes, as much of the value-adding activity is performed somewhere else in the supply chain. The product structure, *i.e.* the bill-of-materials (BOM), influences directly the supply chain that is needed for manufacturing and delivering a product. For example, complex products with many parts tend to require complex supply networks with many actors (Choi and Hong, 2002). Charles Fine, operations management professor at MIT, introduced the concept *three-dimensional concurrent engineering (3DCE)* that emphasizes the supply chain as a third entity to coordinate (Figure 4). The book of Fine (1998) is mainly descriptive, but also includes a few pieces of prescriptive advice. Managers should remember to consider co-dependencies between products and the operations system. The emphasis on developing each should be "balanced". When deciding about products, the operations systems should be included in the analysis, and vice versa. However, products and operations systems do not necessarily have to be designed at the same time.

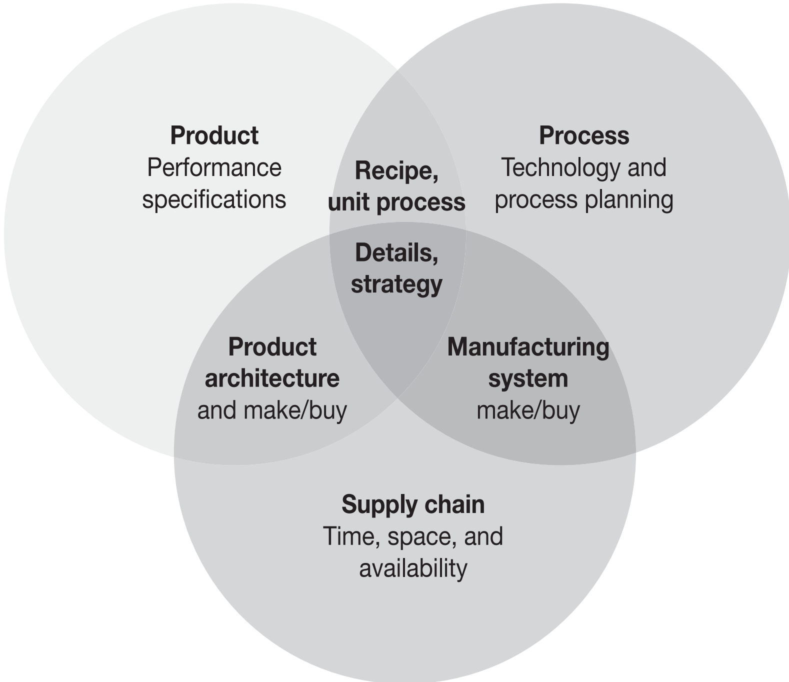

Figure 4: *Components of three-dimensional concurrent engineering (Fine, 1998). This version of the well-known picture was found at SAP's website www.sap.info.*

2.3.2 Two perspectives on 3DCE

The research problem of this thesis is:

> *Can a company produce and deliver a high variety of products while maintaining high operational efficiency?*

Ebbe Gubi (2004), in his doctoral thesis for Aalborg University, suggests that in the context of supply chain design, it makes sense to study products from two perspectives: a market perspective and an engineering perspective (Figure 5). The *market perspective* has the value proposition of a product as its starting point while the *engineering perspective* has the product architecture as its starting point. These two perspectives both seem useful for solving the research problem of this thesis.

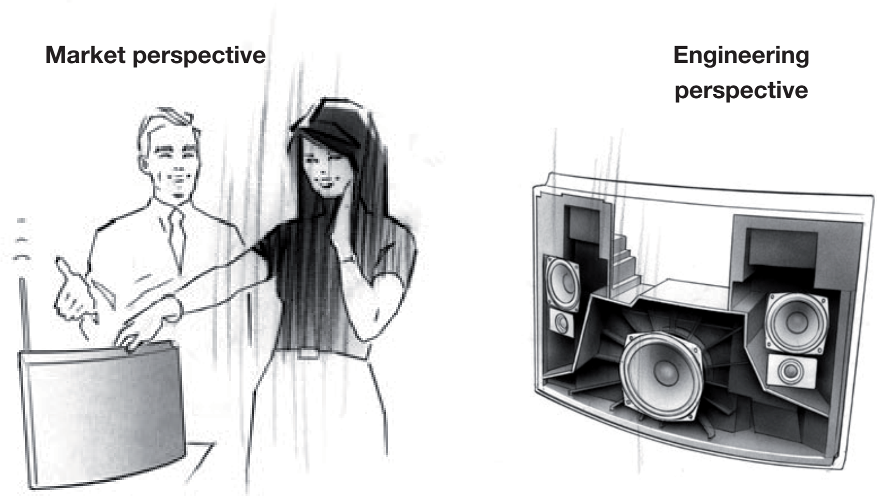

Figure 5: Two product perspectives (Gubi, 2004: 44)

The market perspective and the engineering perspective both have their own implications for operations system design. As such, fast deliveries, high availability and low cost are all desirable ends of operations systems design. However, according to a market perspective, some ends are more important than other ends are, depending on the value proposition of a product. For example, if fast deliveries are an important part of the value proposition of a product, only a limited proportion of the production process can be order-driven (Childerhouse *et al.*, 2002; Olhager, 2003). From an engineering perspective, the decision-making takes a different route. The product architecture tells which parts a product consists of and how it should be assembled. This technical information is the basis for deciding where and how to source parts, where and when to assemble and so forth. Any attempt at redesign the operations system is severely limited by the basic design of the product (Lee and Sasser, 1995). In summary, the market attributes of a product determine desired operational performance while engineering attributes set technical constraints (Figure 6)

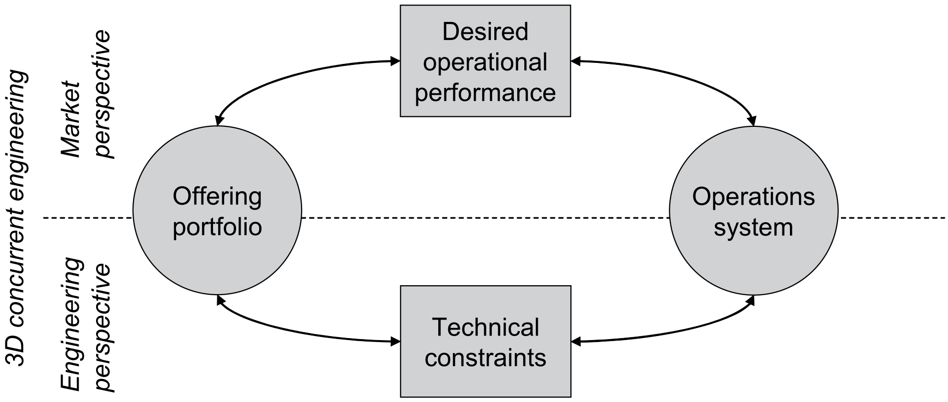

Figure 6: Two perspectives on three-dimensional concurrent engineering.

In the next two sections, previous research on three-dimensional concurrent engineering will be reviewed from a market perspective (section 2.4) and an engineering perspective (section 2.5). An observation will be that although both streams of literature provide answers to the question about how to design the best operations system for delivering a product with given attributes, the streams hardly overlap at all.

2.4 Market perspective: Impact of offering on supply chain

Fast deliveries, low inventories, and high flexibility are examples of high operational performance. All of them are desirable end as such, but under some circumstances, they are conflicting. In designing a supply chain, one needs to prioritise between several desirable ends. The seminal contribution on the topic was written by Marshall Fisher (1997). He divides supply chains into two classes – efficient and responsive – based on one attribute: product innovativeness (Fisher, 1997). Since 1997, the idea about supply chain design as a strategic choice rather than a total-cost minimisation task has been developed further. The common theme is that a company should choose between being cost efficient/lean (low inventories, cheap transportation, and small investments) or responsive/agile (fast deliveries, high availability, scalability and mix flexibility). However, product innovativeness is not the only attribute of an offering that has impact on the supply chain. Further research has identified several offering-related issues that are of strategic importance.

So, which attributes of an offering are of strategic importance when designing the supply chain? To answer the question, a systematic literature survey was undertaken. Survey articles were selected as follows:

1) Articles citing (Fisher, 1997) were searched in online databases ABI/Inform, Elsevier Science and MCB Emerald Library.[4]

2) Those articles that explicitly add one or several offering- or market-related attributes to consider in supply chain design were included. The articles are (Mendelsson and Pillai, 1999; Lamming *et al.*, 2000; Harland *et al.*, 2001; Childerhouse *et al.*, 2002; Heikkilä, 2002; Lee, 2002). The doctoral thesis of Jari Collin (2003) was also included.

Table 1 shows the results of the literature survey. Each surveyed article is represented by a column and the attributes that the article brings up are listed in the cells of the column. For example, the third column tells that Lamming *et al.* (2000) classify supply chains based on three attributes: product innovativeness, product uniqueness and product complexity. Attributes that are very similar to each other, are grouped on the same row. For example, in the fourth column, Harland *et al.* (2001) bring up "number of competitors" and "ease of switching". Both are measures of product uniqueness. The table is sparse, indicating that none of the studies includes more than a few attributes. Finally, the last column summarises identified attributes of an offering that are of strategic importance when designing the supply chain: rate of change, uncertainty, variety, volume, uniqueness, price erosion, order fulfillment lead-time, margin, complexity, and collaboration. Their suggested implications are explained below.

[4] The leading citation index *ISI web of science* was also used but yielded only a few hits, as only few operations management journals are included in the database. These hits overlap with the hits in other databases.

Table 1: Offering- and market-related attributes affecting supply chain design.

Title (short)	*The right supply chain for your product*	*Measuring clockspeed*	*Initial classification of supply networks*	*Taxonomy of supply networks*	*Designing demand chains*	*SC Strategies and product uncertainties*	*From supply chain to demand chain*	*Selecting supply chain*	***Identified attribute***
Reference	Fisher, 1997	Mendelson and Pillai, 1999	Lamming *et al.*, 2000	Harland *et al.*, 2001	Childerhouse *et al.*, 2002	Lee, 2002	Heikkilä, 2002	Collin, 2003	
Attributes	• Product life cycle	• Product life-cycle length • Revenue from new products	• Product innovativeness	• Frequency of new product launch	• Product life-cycle length	• Maturity of technology		• Technology lifecycle stage	**Rate of change**
	• Forecast accuracy • Lost sales • Obsolescence				• Demand variability	• Demand uncertainty • Supply uncertainty	• Planning accuracy	• Plan error	**Uncertainty**
	• Product variety			• Process variety	• Number of product variants	• Product variety			**Variety**
				• Process volume	• Sales volume		• Volume		**Volume**
			• Product uniqueness	• Number of competitors • Ease of switching					**Uniqueness**
		• Price erosion							**Price erosion**
	• Lead time (MTO)				• Delivery time		• Lead time		**Delivery speed**
	• Contribution margin								**Margin**
		• Product complexity	• Product complexity						**Complexity**
							• Buyer-supplier relationship	• Buyer-supplier relationship	**Collaboration**

Rate of change and *uncertainty* are mentioned in a majority of articles. Short product lifecycles are expected to be related with high uncertainty of demand and supply and require flexibility rather than cost focus in operations (Fisher, 1997; Lee, 2002; Collin, 2003). *Industry clockspeed* is a combined measure of rate of change and uncertainty (Fine, 1998; Mendelsson and Pillai, 1999). *Margins* provide an indirect measure of product innovativeness (Fisher, 1997).

Production volume is traditionally considered as the major construct that determines process choice (Hayes and Wheelwright, 1979; Hill, 1994). High volumes can justify "lean-type production and make-to-forecast strategies" (Childerhouse *et al.*, 2002) while low-volume products would typically be made to order. Harland *et al.* (2001) state that "process volume" has an impact on "operations process dynamics" but are rather vague about the nature of this relationship.

Product variety: In the last decades, product variety has emerged as a source of competitive differentiation as companies are responding to requests for increasingly customised products and services (Hayes *et al.*, 2005). High product variety clearly requires flexible operations (Fisher, 1997; Harland *et al.*, 2001; Childerhouse *et al.*, 2002; Lee, 2002; Ramdas, 2003) but the exact relationship is hard to pinpoint, possibly due to the loose definitions of product variety that are found in operations management literature.

Product complexity: A complex product consists of many technology-intensive and interrelated components (Lamming *et al.*, 2000). It requires a large upstream supply network with many suppliers (Lamming *et al.*, 2000; Choi and Hong, 2002). Buyers often rely on single sourcing, suppliers have great bargaining power and information management becomes challenging (Lamming *et al.*, 2000). It is more challenging and time-consuming to develop a complex product than developing a simple one (Mendelsson and Pillai, 1999).

Product uniqueness: Product differentiation is the traditional way to avoid cost-based competition (Porter, 1980). Supply chains for unique products could be expected to be different due to lack of cost competition (Lamming *et al.*, 2000; Harland *et al.*, 2001), but according to Lamming *et al.* (2000), there has been little research on the topic. However, few companies can enjoy the luxury of having products that are so unique that customers really don't care about price (Schlie and Goldhar, 1995).

Order fulfillment lead-time is sometimes mentioned as a design parameter for supply chains, especially when it comes to choice of operational mode. A requirement for short order fulfillment lead-time is a good reason for selecting ship-to-order rather than make-to-order (Childerhouse *et al.*, 2002; Olhager, 2003).

Price erosion is a phenomenon that occurs especially in electronics industry. It is a direct effect of *rate of change* (Mendelsson and Pillai, 1999).

Buyer-supplier relationships and collaboration can be considered as belonging to the core of supply chain management (Arlbjørn and Halldórsson, 2002; Chen and Paulraj, 2004). This is especially true within the Nordic school of logistics research that is influenced by the descriptive research on industrial networks carried out by Håkan Håkansson and the IMP group (*e.g.* Håkansson *et al.*, 1999; Gadde *et al.*, 2003; Håkansson and Ford, 2003). Also research at Helsinki University of Technology has showed that buyer-supplier relationships have clear performance implications (Heikkilä, 2002; Collin, 2003). The main message is that good relationships and information sharing enable smooth operations for both parties.

In this thesis, buyer-supplier relationships are not studied. This is motivated by a need to keep research scope focused. Excluding buyer-supplier relationships enables putting more effort into studying other constructs that affect supply chain design

In summary, previous research within the market perspective has identified a large number of offering- and market-related attributes that can be used for explaining differences between operations systems. However, the attributes tend to express *type of products* rather than actual product design decisions. Secondly, causal relationships between product-related constructs and operations systems are not clearly defined. That is, they bring up many issues to consider but do not give prescriptive advice about how to the company should act.

2.5 Engineering perspective: Managing product variety

For a company that targets one homogenous market with one product line, designing the operations system should be a straightforward task. The main issue is to ensure that operations capabilities are in line with market needs (Hill, 1994). However, markets are not homogeneous. Product variety has emerged as a source of competitive differentiation as companies are responding to requests for increasingly customised products and services (Hayes *et al.*, 2005). Coping with high variety within one operations system without compromising on efficiency is challenging.

Product variety is the diversity of products that an operations system provides to the marketplace (Ulrich, 1995). When studying product variety, it is important to distinguish between *external variety* and *internal variety* (Pil and Holweg, 2004). External product variety is the range of choice offered to customers. It can be estimated by multiplying all possible features offered (Fisher and Ittner, 1999).

Internal variety refers to the range of different variants that are handled in each production step (Pil and Holweg, 2004). Finally, *technical variety* refers to diverse design methodologies and manufacturing processes that are necessary to achieving variety (Fujimoto *et al.*, 2003). In short, the following types of product variety are defined:

External variety:	Number of permutations of options in the final product
Internal variety:	Range of different variants that are handled in each production step
Technical variety:	Diverse design methodologies and manufacturing processes necessary to achieving variety

Product variety requires a degree of operative flexibility that, in turn, is always associated with some cost (Gerwin, 1993; Upton, 1995; Narasimhan and Das, 1999; Safizadeh *et al.*, 2000). For mitigating the negative effects of product variety on operational efficiency, a range of tactics are available. Based on literature, six such tactics are identified: limiting external variety, customisation, design for supply chain, form postponement, focused manufacturing and flexible manufacturing. Each of these tactics will be presented in a subsection. They all provide partial answers to the research problem about how to deliver high product variety while maintaining high operational efficiency. The tactics will be evaluated in the empirical part of the thesis.

2.5.1 Limiting external variety

The reason for creating high external variety is to provide customers with products that closely match their specific needs or taste. Most research on product variety assumes the situation when product variety is created in anticipation of customer demand (Ramdas, 2003), as typically is the case when products are sold in retail. Increasing number of variants is expected to increase total sales. However, introducing new variants usually increases internal variety and "cost of complexity", reduces sales per variant, makes forecasting more difficult and increases inventories (Cooper and Griffiths, 1994; Randall and Ulrich, 2001; Pil and Holweg, 2004).

A company should carefully consider the amount of external product variety that it offers (Lampel and Mintzberg, 1996; Agrawal *et al.*, 2001). In some cases, the markets might define the product variety that a company must provide if it is to compete in the market (Kaski and Heikkilä, 2002). Otherwise, a company can reduce external variety by offering fewer variable features or fewer options for each feature. Another possibility is option bundling, that is, allowing only certain permutations of options (Pil and Holweg, 2004).

2.5.2 Customisation

Customisation provides an alternative to creating a large number of variants in advance. Customisation refers to the extent to which products are manufactured according to wishes of individual customers. It is a relative concept, ranging from full standardisation (*i.e.* no customisation) to customer specific design, fabrication, assembly and delivery (Lampel and Mintzberg, 1996). According to a recent review article, the question of what degree of customisation a firm should adopt and what factors influence this decision has been left largely unanswered, as studies "invariably assume a particular degree of customisation and then optimises given that constraint" (Ramdas, 2003).

The degree of customisation largely determines manufacturing costs: usually a high degree of customization leads to high cost (Safizadeh *et al.*, 2000). However, once a company has defined its product range along with an appropriate production process, customization that falls within the range offered does not cost any extra (Bozarth and Edwards, 1997; Safizadeh *et al.*, 2000). Manufacturing throughput time for customised products is typically longer than for standard products (Sievänen, 2004).

Product variety and customisation are closely related to each other, because a high degree of customisation usually ends up in high external and internal product variety. Conceptually, they are different. Product variety tells how many different variants there are while customisation tells to what extent these variants are created based on customer specifications.

2.5.3 Design for supply chain

Design for supply chain provides a set of principles for creating product architectures that enable high external variety without disturbing operations with too much internal variety. Design for supply chain principles are useful when product variations cannot be limited without taking the risk of serious disadvantage in competition (Kaski, 2002: 9). By considering supply chain issues in the design phase of new products, it is possible to affect operational performance positively (Simchi-Levi *et al.*, 2000; Kaski and Heikkilä, 2002). In fact, although only a few percent of product lifecycle cost are spent in product design, up to 70-80% of lifecycle costs are determined in this stage (Whitney, 1988; Chapman, 1992; Dowlatshahi, 1996; Hatch and Badinelli, 1997; Dowlatshahi, 1999).

From the perspective of supply chain efficiency, modular product architectures are best. Ideally, there will be a one-to-one mapping between modules and functions. Each module drives the performance of only one function, and each function is affected by only one module (Ulrich, 1995). A modular architecture with maximal independence between modules enables creating functional variants by exchanging a minimum number of modules (Kaski, 2002).

Modularity is a special case of *configurability*. Configurable products can be created by combining pre-defined parts rather than custom-designed parts. Unlike modularity, configurability does not require a one-to-one mapping between parts and functions. Limiting the offering portfolio to configurable products reduces the need for order-bound engineering, decreases order fulfillment lead-time and makes it easier for sales personnel to sell products without involving engineering personnel (Salvador and Forza, 2004).

Design for supply chain analyses often include some sort of trade-off. For example, the principles often result in higher material and direct manufacturing costs. One should analyse if these extra direct costs will be outweighed by *e.g.* lower inventory cost (Lee and Sasser, 1995).

2.5.4 Form postponement

Product variety should ideally be introduced as late as possible in the supply chain (Mather, 1992; Feitzinger and Lee, 1997). By arranging production in this way, the negative impact of internal variety will affect only the last steps in the supply chain. Well-designed products enable form postponement. According to the dictionary, postponement means "causing an event to take place later". In the case of form postponement, the event is differentiation of a physical product (Forza *et al.*, 2004). Actual definitions of form postponement vary within operations management literature (Forza *et al.*, 2004). According to some authors, postponement means performing at least one differentiating step later than it used to be performed. To others, postponement means performing at least one differentiating step after receiving a customer order, rather than in anticipation of orders.

Pagh and Cooper (1998) combine form postponement and logistical postponement into a framework[5]. Products are made to stock or assembled to order. Inventories are either kept at a central location or decentralised at the different markets. In combination, there are four options ranging from assemble to order at a central location – full postponement – to stocking finished goods at many decentralised locations – full speculation (Figure 7).

[5] Pagh and Cooper (1998) use the alternative term *manufacturing postponement* rather than *form postponement*.

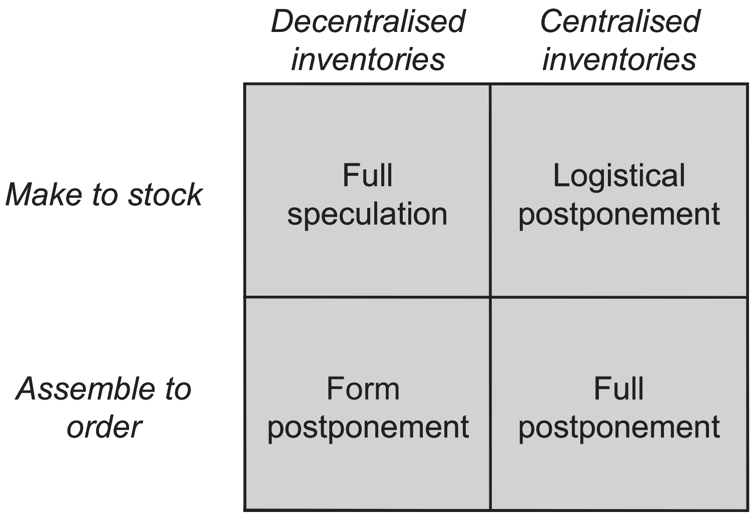

Figure 7: Postponement framework (Pagh and Cooper, 1998).

The benefits of postponement are reduced need for inventory, increased responsiveness by shortening the final customising cycle time and reduced complexity in operations (van Hoek, 2001). However, form postponement requires a modular product architecture (Silviera *et al.*, 2001) that can be more demanding and time-consuming to create compared with an integrated product architecture (Ulrich, 1995). In some cases, postponement requires retail outlets to invest in new equipment (Hoover *et al.*, 2001: 55).

Postponement has for long been seen as a promising approach to provide high product variety at moderate cost (Christopher, 1998; van Hoek, 2001; Forza *et al.*, 2004). The European authority in logistics, professor Martin Christopher from Cranfield School of Management, predicts postponement to be one of the main trends in the "leading-edge logistics of the 2000s" (Christopher, 1998: 269-271). However, van Hoek (2001) concludes that surprisingly little research has been conducted on postponement. He calls for more research that takes a complete supply chain perspective rather than a functional perspective, considers the challenges of global supply chains, and uses methodical triangulation to get deeper insights.

2.5.5 Focused manufacturing

Product-focused manufacturing provides a final possibility to reduce internal and technical product variety in operations. Focused manufacturing can be used as a means toward the end of providing a broad product portfolio while maintaining efficiency in operations.

The original idea of focused manufacturing, as stated by the pioneer of manufacturing strategy Wickham Skinner (1974), is that "a factory that focuses on a narrow product mix for a particular market niche will outperform the conventional plant, which attempts a broader mission". The statement was based on the experience that factories are managed wrong as mangers attempt to fulfil too many tasks or, more commonly, only to minimize costs (Skinner, 1974; Skinner, 1996b). When examined more in detail, manufacturing focus as defined by Skinner (1974) includes three dimensions (Bozarth, 1993):

a) The plant faces a consistent and limited set of market demands.
b) Plant operations are consistent and aligned around a limited set of targets.
c) There is a fit between plant targets and market demands.

There are empirical evidence that fit on all three dimensions a) to c) is associated with high manufacturing performance (Bozarth and Edwards, 1997).

For a diverse product portfolio, focusing includes allocating products to focus units according to one or many focus criteria. The focus units can be focused factories, plants-within-plants or focused work-cells. Sheu and Laughlin (1996) summarise focus criteria found in literature:

1) product line
2) volume
3) life cycle stage
4) product variety
5) process requirements
6) competitive priorities
7) operational mode (this last one by Bozarth and Chapman, 1996)

The criteria are partly interrelated. For example, the classical product-process matrix predicts that mature products (3) tend to have high volume (2), low variety (4) and compete on low cost (6) (Hayes and Wheelwright, 1984). Consequently, manufacturing task heterogeneity is reduced if products at different locations along the diagonal of the product-process matrix are manufactured in different focus units. The process requirement criterion states that one focus unit should not include too many different process technologies and machines (Sheu and Laughlin, 1996). Finally, the operational mode (engineer-to-order, assemble-to-order *etc.*) has such considerable impact that one should avoid implementing more than one operational mode in one focus unit (Bozarth and Chapman, 1996).

The logic behind assigning different parts of the product portfolio to different focus units is that within each focus unit, internal and technical product variety will be lower. This is expected to contribute to higher operational efficiency.

A drawback is that dividing products that have common processes into different focus units will lead to some degree of equipment duplication. There is no methodology available for assigning products to focal units such that task similarity is maximised and, at the same time, resource duplication is minimised (Sheu and Laughlin, 1996). Consequently, other things being equal, more capacity is needed for fulfilling demand using product-focused capacity compared with using generic capacity.

2.5.6 Flexible manufacturing

The principal alternative to operating focused manufacturing units is to produce all products using generic capacity. The arguments for flexible rather than focused manufacturing are to reduce cost by spreading fixed costs over a larger number of products and reduce risk by not depending on a few products or customers (Bozarth and Edwards, 1997). In uncertain environments, the risk argument stands out. If product demands are difficult to predict, market-driven manufacturing focusing will be very difficult to implement (Bhattacharya *et al.*, 1996). Generic resources are expected to provide greater flexibility in an uncertain environment (Bhattacharya *et al.*, 1996; Mukherjee *et al.*, 2000). Finally, generic equipment gives better mix flexibility than dedicated equipment (Koste and Malhotra, 1999).

Mukherjee *et al.* (2000) report that they have not found a single article that systematically investigates the relationship between focus and volume flexibility. They call for more research on this topic in an environment of high demand uncertainty. Thanks to advances in production technology, it is not self-evident that "repetition and simplicity" (Skinner, 1974) gives the best operational performance of a unit today. Focusing removes much complexity and some overhead from manufacturing, but it restricts the variety of products produced and the rate of change in product design (Schlie and Goldhar, 1995). New techniques, equipment and procedures have made some of the trade-offs from the past obsolete (Dermott *et al.*, 1997). Firms simply no longer face the same manufacturing constraints as they did in the 1970s. Today managers can choose to occupy a combination of strategic positions simultaneously through their choice of manufacturing practices (Dermott *et al.*, 1997).

2.6 Research questions and 'a priori' constructs

In this final section of the literature study, the research problem area is summarised as a conceptual framework. The framework is used for identifying 'a priori' constructs. In case research, 'a priori' constructs help the researcher to focus attention and measure final constructs more accurately (Eisenhardt, 1989).

2.6.1 Market perspective

The first research question of this thesis is:

1. *What are the relationships between offering portfolio, operations system design and operational efficiency?*

This first research question calls for descriptive research about actual relationships that managers need to consider when deciding about products, manufacturing processes and supply chains. As section 2.4 indicated, previous research has identified many offering- and market-related attributes that are expected to have impact: ten attributes are mentioned in a small sample of eight articles (Table 1). However, most previous research has been concerned with supporting a manager in choosing between a responsive and cost efficient supply chain strategy. Sections 2.2 and 2.5 included examples of many other important choices.

The literature review in this chapter has explored various issues related to matching of products, manufacturing processes and supply chains. As a synthesis, a conceptual framework is presented (Figure 8).

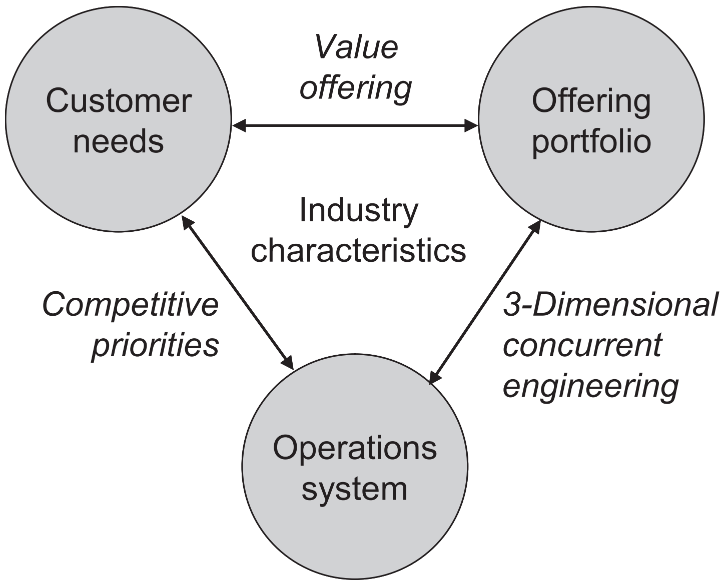

Figure 8: Conceptual framework presenting the research problem area.

The circles in the framework represent issues to design or decide. Selected *customer needs* are met by an *offering portfolio* containing products and services. An *operations system* is needed for manufacturing and delivering products and services in a way that fulfils customer needs. Compared with the original framework of Fine (1998) (Figure 4), the revised framework (Figure 8) brings up the following principal contributions:

1) In-house operations (process) and operations performed by network partner (supply chain) are considered as one *operations system*. This is in accordance with the current understanding that operations systems usually span over many facilities and companies (Skinner, 1996a; Heikkilä and Ketokivi, 2005).

2) Customer needs are explicitly included in the revised framework. Customer needs are expected to affect directly the operations system as well as the offering portfolio. Thus, the revised framework enlarges the original scope of 3DCE to include the customer.

Customer needs, offering portfolio and operations system are taken as 'a priori' constructs to guide data collection in the empirical part of this thesis. The 'a priori' constructs are defined as follows:

Offering portfolio: A product is the end object of a transformation process that includes physical objects, information or services (SCOR, 2003). Products are usually accompanied by service elements such as packaging, delivery, installation, technical support and field support (Bowen *et al.*, 1989). For the purpose of this thesis, a product is defined as a physical object while an offering is defined as a product with its accompanying service elements[6]. A product portfolio is all products that a company provides to its marketplace and an *offering portfolio* is all offerings that a company provides to its marketplace.

Customer needs include both need for specific products and requirements for how and when they should be delivered. A good customer service policy contains realistic and relevant targets for key metrics such as on-time delivery (Christopher, 1998). A basic requirement for business exchange to take place is that customer needs and offerings match with each other.

[6] For example, the offering "one-hour photo-processing" is different from the offering "three-day photo-processing" although the product remains the same. Actually, one-hour photo shops are able to charge a considerable premium for their offering, compared with the offering of traditional photo shops.

An **operations system** provides the platform for fulfilling customer needs with offerings. Designing the operations systems is to decide how to do things. According to the classical list of Hayes and Wheelwright (1984: 31) decision areas include capacity, facility locations, technology, vertical integration, personnel, quality policies, production planning and control and organisation. According to current understanding, operations systems usually span over many facilities and companies; limiting the scope of analysis to a single facility is seldom motivated (Heikkilä and Ketokivi, 2005)

Creating a list of "issues that are important" is a good first step in building a new theory (DiMaggio, 1995). However, a complete theory should also include causal relationships between those issues (Sutton and Staw, 1995). Those causal relationships will be studied in the empirical part of this thesis.

2.6.2 Engineering perspective

The second research question of this thesis is based on a pre-understanding that product ranges are broadening and product variety are increasing in offering portfolios of companies today (section 1.1; Hayes *et al.*, 2005). Other things being equal, broadening the product range and increasing product variety is expected to have negative impact on operational efficiency. This challenge serves as a starting point for the second research question:

2. *How can a company manage trade-offs between a broad offering portfolio and high operational efficiency?*

This second research question calls for prescriptive research about how to act, given the relationships uncovered by the first research question. The literature study in section 2.5 has provided partial answers to the second research question. As a synthesis, the tactics for mitigating the negative effects of broad product range and high product variety on operational efficiency are mapped into the new conceptual framework (Figure 9).

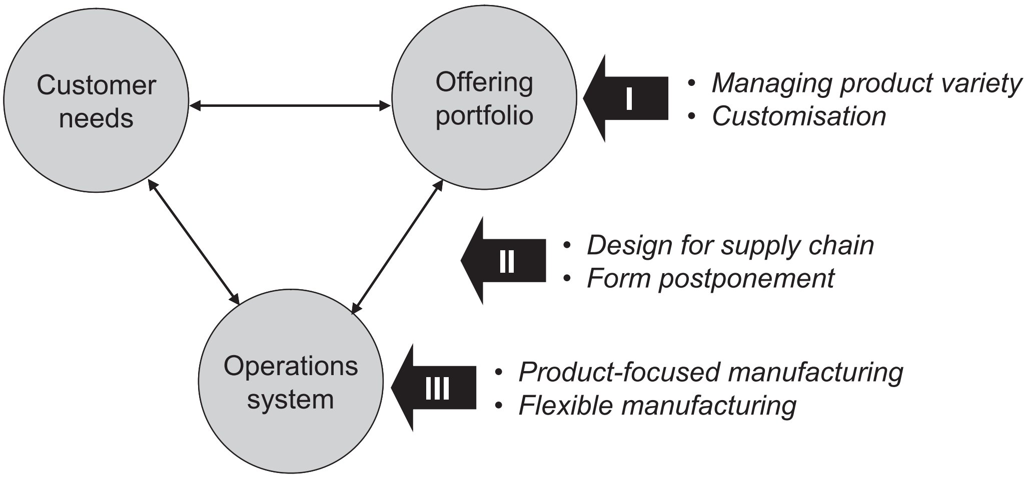

Figure 9: *Tactics for mitigating the negative effects of product variety on operational efficiency.*

Mapping tactics into the conceptual framework highlights three alternative "points of impact". The points are:

I) Offering:
Operational efficiency can be improved by limiting the product variety that is offered to customers. For example, Henry Ford became famous for limiting the selection of colours to black. Today, car buyers can choose from many colours, but they are still not allowed to choose number of wheels. A related possibility is to manage degree of customisation.

II) Offering/operations interface:
Another possibility to improve operational efficiency is to create product architectures and delivery processes that provide customers with high external variety without disturbing operations with too much internal variety. Design for supply chain, including form postponement, is such a tactic. The classical example is the re-design of Hewlett-Packard's printers (Feitzinger and Lee, 1997). After re-design, the offering remained the same but inventory costs decreased due to operations that were more efficient.

III) Operations:
Finally, one can create an operations system that is able of handling high variety. Assigning products to focus units *i.e.* focused manufacturing, or investing in facilities that can handle any product, *i.e.* flexible manufacturing are such approaches. To return to the car-colour example: today consumers are offered many colours because changing colour is not a problem using flexible painting equipment.

The three "points of impact" and the six tactics for mitigating the negative effects of high product variety on operational efficiency all provide good candidates for answers to the second research question. However, much of the literature cited in section 2.5 is conceptual, indicating that the tactics have not been thoroughly evaluated in practice. Recent literature contains several recent calls for further empirical testing of the tactics (Mukherjee *et al.*, 2000; van Hoek, 2001; Ramdas, 2003; Pil and Holweg, 2004; Salvador and Forza, 2004). In the empirical part of this thesis, a theory testing approach is taken for answering research question 2. The aim is to identify efficacy and use criteria for the tactics that have been identified in the literature study.

3 METHODOLOGY

The disciplines of operations and logistics have traditionally followed the scientific paradigm of positivism, where reality is considered as objective, tangible and fragmentable (Mentzer and Kahn, 1995). So does this thesis. This chapter justifies theory building through collaborative case/action research (Hill *et al.*, 1999; Kotnour, 2001) and describes how the research was conducted.

The chapter starts with defining what theory is and with introducing a vocabulary (section 3.1). Following McGrath (1982), I distinguish between strategies and research settings for gaining knowledge (section 3.2), research design for carrying out the study (section 3.3), and research techniques for measuring, manipulating, controlling and otherwise contending with variables (section 3.4). Finally, tactics for enhancing validity of the research are discussed (section 3.5).

3.1 What is theory?

The goal of research in the positivistic paradigm is to create generalisable theories. There are four building blocks of a theory for explaining a phenomenon (Whetten, 1989):

- *Constructs* (factors, variables, concepts) that should be considered as part of the explanation of the phenomena of interest.
- *Relationships* between the identified constructs. In a nomological network (*i.e.* box-arrow model), constructs are usually depicted as boxes while relationships are illustrated by arrows.
- *Logic* of the underlying model, that is, an explanation of why the constructs are relevant and why they are related as suggested.
- *Contextual* and *temporal* factors that set the boundaries for generalisability of the model.

Good theory can be tested empirically (Bacharach, 1989). It is parsimonious, that is, as simple as possible (DiMaggio, 1995; Schmenner and Swink, 1998). Finally, a good theory is able to tell something interesting and useful about reality (van der Ven, 1989). References, data, variables, diagrams and hypotheses are not theory by themselves (Sutton and Staw, 1995), but they are important building blocks of a theory (Weick, 1995).

The vocabulary for expressing theories is not unified, as one can conclude by reading *Academy of Management Review's* special issue on theory building from 1989. For example, one of the building blocks of a theory is called "construct" (Bacharach, 1989; Eisenhardt, 1989), "factor" (Whetten, 1989) or "concept" (Chimezie and Osigweh, 1989) depending on author.

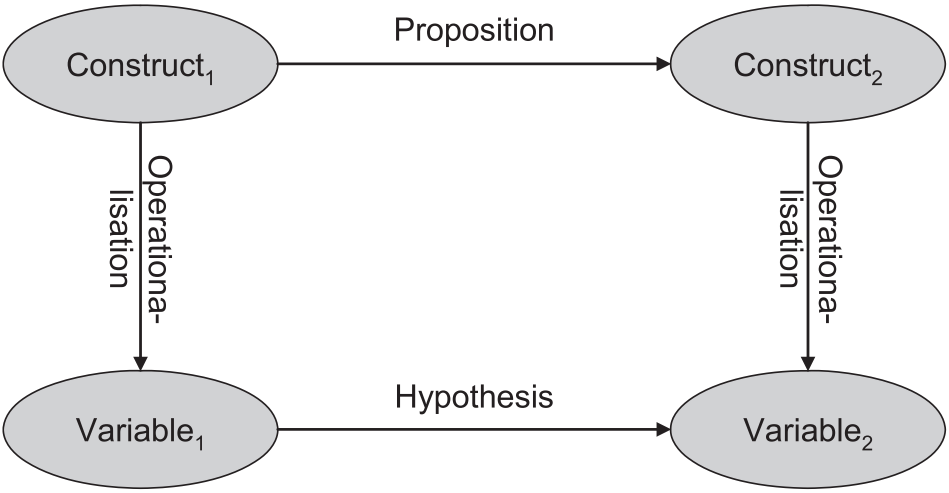

Figure 10: Components of a theory (Bacharach, 1989)

In this thesis, the vocabulary of Bacharach (1989) is used. *Constructs* are terms that, although not observational either directly or indirectly, may be applied or even defined based on observables. Thus, a construct is a broad mental configuration of a given phenomenon. A *variable* is an observable entity that is capable of assuming two or more values. The process of deriving variables from constructs is called *operationalisation*. Constructs are related to each other by *propositions* while variables are related to each other by *hypotheses*. Figure 10 shows the terminology graphically.

Some authors make a sharp distinction between theoretical entities, constructs, and entities that we can observe, variables (Bacharach, 1989; Chimezie and Osigweh, 1989; Giere, 1997). From this follows a distinction between propositions and hypotheses. A proposition is a statement about causal relationships between constructs, such as "Smoking causes cancer". A hypothesis is a prediction about data, such as "The number of cigarettes smoked per day will correlate positively with occurrence of cancer". Hypotheses are dependent of how things are measured while propositions are more general in nature (Bacharach, 1989). For example, a new way of measuring amount of smoking would require a new hypothesis, but would not affect the underlying causal relationship expressed by the proposition.

3.2 Research strategy

Complete theories seldom emerge out of single research efforts. Rather, each study can contribute with one piece to the emerging theory (DiMaggio, 1995). Selecting which piece to contribute with requires a trade-off between three scientific ideals: accuracy to describe a specific system (relevance), applicability to other systems (generalisability) and simplicity (parsimonity) of the resulting theory (Weick, 1979: 35-42). When the researcher wishes to maximise two of these ideals, the third ideal is simultaneously minimised. McGrath (1982) applies this idea to the selection of research strategy: field studies maximise realism by taking contexts into account, surveys maximise generalisability and laboratory experiments maximise control over research settings. At the same time, in field studies, it is hard to control research settings, surveys are of little value for describing specific systems and lab experiments may not be very realistic. In his classification, McGrath (1982) places computer simulations close to field studies because of their ability to describe specific systems with high accuracy. Compared to field studies, computer simulations have the benefit that specific systems can be studied under controlled circumstances (McGrath, 1982).

As it is not possible to fulfil all scientific ideals at one time, theory building proceeds such that the ideals are fulfilled sequentially. Good theories are grounded in empirical study of specific systems (Glaser and Strauss, 1967). From the complex reality, simple constructs and relationships are extracted and made explicit. Finally, validity and generalisabilty can be tested using experiments and large-sample surveys. Handfield and Melnyk (1998), divide the operations management theory-building process into five stages:

1) Discovery and description of a phenomenon
2) Mapping of key constructs
3) Relationship building
4) Theory validation
5) Theory extension and refinement

Different research strategies are appropriate in different stages of theory building: in the beginning of the process, a small number of unfocused, longitudinal case studies are useful. As more becomes known about the phenomenon, multisite, focused case studies give deeper insights. Finally, in the theory validation and theory extension/refinement stages, experiments and large-population surveys can prove or disprove the validity and generalisability of the theory that has been developed. In summary, the appropriate research strategy depends on the stage of theory development in a field (Handfield and Melnyk, 1998).

The stage of theory development in the fields of "product design for supply chain" and "product-focused supply chains" can be traced in literature. The quite obvious relationship between product diversity and manufacturing "headaches" is already discussed in the textbook of Bethel *et al.* (1945: 179-191. Citation marks are original.). Rutenberg and Shaftel (1971) suggest modularity and part commonality as a way to save cost when designing products for multiple markets. However, a more wide-spread interest emerged in the mid 1990s, when a number of articles emphasising the importance of considering supply chain issues in product design were published (Mather, 1992; Lee and Sasser, 1995; Dowlatshahi, 1996; Feitzinger and Lee, 1997; Fine, 1998). In the 2000s, the emphasis has been more on identifying issues that one should take into account when matching products and supply chains (Lamming *et al.*, 2000; Harland *et al.*, 2001; Li and O'Brien, 2001; Childerhouse *et al.*, 2002; Lee, 2002). Lately, some researchers have also provided hypotheses that can be tested empirically (Choi and Hong, 2002; Kaski and Heikkilä, 2002; Salvador *et al.*, 2002; Collin, 2003). In conclusion, the theory-building process in the area of product design for logistics and product-focused supply chains has currently proceeded to a stage somewhere between mapping of key constructs and relationship building. Stuart *et al.* (2002: 432) reach a similar conclusion regarding design for manufacturability. In particular, they point out, the links to performance are largely unexplored.

Eisenhardt (1989), suggests case research mainly for totally unexplored areas where no theory exists. Voss *et al.* (2002), however, emphasise that all research, including case research, must be built on existing theory and that case research can be used in all stages of theory building. For the mapping and relationship building stages of theory building, the following research strategies are appropriate (Handfield and Melnyk, 1998): few focused case studies, in-depth field studies, multi-site studies and best-in-class case studies. Following the advice of Handfield and Melnyk (1998), the chosen research strategy in this thesis is in-depth field studies in organisations that are facing a common challenge of producing and delivering a high variety of products while maintaining high operational efficiency.

3.3 Research design

In designing a case research study, one needs to address the level of involvement, number of cases and case sampling. These issues are discussed below.

3.3.1 Degree of involvement

In multiple-case studies as Eisenhardt (1989) describe them, data is collected in a large number of organisations but the interaction is limited to interviews, document analysis and unobtrusive observation. This research design is of particular value for distinguishing general patterns, resulting in high internal validity. Different types of validity, are discussed in section 3.5. At the other extreme, in action research the researcher is not an independent observer but a participant in the implementation of a system (Westbrook, 1995). This variant of case research is useful for theory building where the object of study is a change process (Westbrook, 1995). The collaboration model takes an intermediate position between the two extremes (Kotnour, 2001). In the collaboration model, an organisational performance improvement opportunity provides a research opportunity. Knowledge is created by planning on and solving real-world problems in collaboration with managers. In the context of the organisational performance improvement opportunity, the researcher is trying to understand the relationship among drivers-actions-results of organisational performance improvement (Kotnour, 2001). Action research, collaborative approach and multiple case studies are all inductive methods aimed at building but not testing generalisable theories. Figure 11 illustrates the different theory advancement logics as a continuum. When moving from left to right, understanding of specific systems decreases while generalisability to all systems increase. In summary, the collaborative approach provides a balance between understanding and generalisability. The collaborative approach is also expected to enhance relevance of the research (Hill *et al.*, 1999).

Theory advance-ment	Interpretive		Inductive		Deductive
Data sources	Interpretive case stydy	Action research	Collaborative approach	Multiple case study	Survey

Figure 11: Theory advancement logic and corresponding data sources.

A classifications made by Slack *et al.* (2004) helps in determining the right degree of involvement for this thesis. *Consolidation research* is appropriate when the level of competence is higher in practice than in academia. In consolidation research, the researcher will visit companies, collect best practices and disseminate them for the research community. A well-known example is the International Motor Vehicle Program in which researchers consolidated best practices that were already used in automobile assembly plants and published them as “lean manufacturing” (Womack *et al.*, 1990). The opposite situation is *application research,* where academia is ahead of practice. An example of application research is advanced planning and scheduling (APS), where software applications of today utilise algorithms that were developed in universities in the 1970s.

So, what is the situation in the areas of “product design for supply chain” and “product-focused supply chains”? As indicated in sections 2.4-2.5, quite many articles about the issue have been published in academic journals. Meanwhile, practical applications of supply chain modelling in product design are almost nonexistent (Appelqvist *et al.*, 2004). As far as one can generalise the latter finding that strictly applies to modelling only, best practices are not likely to exist readily in companies for collection and consolidation. Consequently, unobtrusive observation in a large number of case companies would not be an appropriate research design for theory building. On the other hand, the object of study is not a change process, for which action research would be appropriate. The collaboration model (Kotnour, 2001) is therefore selected as research design. This mix of inductive case research and action research is expected to generate theory that is novel, relevant for case companies and generalisable to other settings. The collaboration model responds to the call of Hill *et al.* (1999) for "plant-based" operations management research with high managerial relevance.

3.3.2 Number of cases

With a high level of involvement, and within the scope of a doctoral thesis, it is not feasible to complete the 6-10 cases that Eisenhardt (1989) recommends. However, one can still choose between allocating all efforts to one case or divide the effort among a few cases. Single case design gives greater depth of insights and increases internal validity because company effects are eliminated. Through an embedded design, it is possible to achieve replication also within a single case (Yin, 1989). Single case design, however, has limited generalisability. According to a strict positivistic paradigm, a single observation is not science at all (McGrath, 1982: 82). Analysis of multiple cases can lead to general conclusions, even though they are necessarily on a more superficial level (Voss *et al.*, 2002).

Answering the first research question about *relationships between offering portfolio, operations system design and operational efficiency*, requires a multi-case design, because otherwise it would be difficult to distinguish causal relationships from mere co-existence of constructs. The final number of cases was set to three, which provides a balance between deep enough involvement and some degree of theoretical replication.

3.3.3 Case sampling

In statistical sampling, the researcher identifies a population, and then selects a random or stratified sample from that population (Giere, 1996). However, in inductive case research, theoretical sampling is more effective in terms of insights gained per research effort (Eisenhardt, 1989). In theoretical sampling, the researcher selects cases where results are either similar to each other (literal replication) or contrary to each other but for predictable reasons (theoretical replication) (Yin, 1989). Schmenner and Swink (1998) recommend that one should start by defining the dependent variable; in operations management it is typically performance. A common method for theoretical sampling is to select cases were performance is high, select comparable cases where performance is low and look for constructs that explain the differences (*e.g.* Burgeois and Eisenhardt, 1988; Heikkilä, 2002). Sampling according to performance level, however, is not possible within the collaborative approach where a performance improvement opportunity provides a research opportunity, because resulting performance cannot be known ex-ante.

The research strategy selected for the research reported in this thesis is to study the same problem in different environments. To maximise insights gained, one needs a sample of cases that are diverse enough to provide rich data but still similar enough to enable meaningful comparisons. The balance is achieved as follows:

> *Rich data* is achieved by selecting cases from industries with different clockspeed; a construct that several studies have suggested to affect supply chain design choices (Fisher, 1997; Mendelsson and Pillai, 1999; Fine, 2000; Lamming *et al.*, 2000; Harland *et al.*, 2001; Childerhouse *et al.*, 2002; Heikkilä, 2002; Lee, 2002; Collin, 2003). Secondly, production volumes are expected to be important (Hayes and Wheelwright, 1979; Hill, 1994; Harland *et al.*, 2001; Childerhouse *et al.*, 2002; Salvador *et al.*, 2002). Volumes were included in case selection as a second discriminant construct.
>
> *Meaningful comparisons* are enabled by selecting companies that all have own product design and in-house operations including manufacturing. The products are sold under own brand names in a competitive market. The products are technically advanced. They consist of discrete parts, are not unique, and have approximately equal level of complexity.

Table 2 shows the case selection. The companies *Citius*, *Altius* and *Fortius* all design, assemble and deliver technology-intensive, discrete-part products. In the table, construct values are expressed as adjectives because they represent internal rankings rather than absolute values. Secondly, as this frame was used for case selection, the values are based on publicly available sources and initial discussions with company management rather the quantitative data that was collected later on. In practice, case selection was a convenience sample that was also much influenced by personal access to companies and ongoing development projects in these companies, that is, “improvement opportunities that provide research opportunities” (Kotnour, 2001).

Table 2: Case sampling frame and selected cases.

Criterion ↓	*Case* / *Industry*	*Citius* / *Consumer electronics*	*Altius* / *Consumer electronics*[7]	*Fortius* / *Industrial electronics*
Discriminant criteria	Industry clockspeed	High	Medium	Low
	Production volumes	High	Medium	Low
Common criteria	Product design in-house	Yes	Yes	Yes
	Manufacturing in-house	Yes	Yes	Yes
	Unique products	No	No	No
	Products sold under own brand name	Yes	Yes	Yes
	Product complexity	Medium	Medium	Medium
	Discrete-part products	Yes	Yes	Yes
	Technically advanced products	Yes	Yes	Yes

7 Citius and Altius are both in consumer electronics industry but their product portfolios are different. The companies are not competing with each other.

3.4 Data collection

In each case, customer needs, offering portfolio, operations system and performance were observed. In addition, a performance improvement opportunity was evaluated. In all cases, interview data was triangulated with quantitative analysis of delivery data. This section describes in detail how data was collected and processed in each of the case studies.

3.4.1 Citius

Case Citius spanned over 1.5 years from June 2003 to January 2005. Data collection included the following steps:

1. Definition of project targets through discussions with case company management (Finland: 1.4.2003, 26.05.2003).

2. Interviews with Citius directors (20 informants):
   a) Operations and logistics directors of different business units: Business unit E (Finland: 06.08.2003), business unit C (Finland: 12.08.2003), business unit D (Germany: 21.08.2003, teleconference), business units A and B (Denmark: 29.08.2003) and business unit F (USA: 13.10.2003, NetMeeting)
   b) Business development personnel, EMEA region: strategy and business development, distribution development, DSN development, logistics development business units, and operations process development business units (Finland: 05.08.2003, 06.08.2003, 12.08.2003,13.08.2003, 24.09.2003,)
   c) Manufacturing technology experts: design for logistics (Denmark, 29.08.2004), technology unit operations, final assembly & packing, manufacturing technology & processes (Finland: 12.09.2003) and packaging development (Finland: 15.10.2003).

3. Existing process definition and strategy documents were also used: manufacturing concept definitions, architecture descriptions, sales package requirements, and customization offerings.

4. Data and preliminary results were disseminated together with a senior manager from Citius manufacturing solutions (10.10.2003, 20.10.2003, 27.10.2003 and 4.12.2003), Gloco research group (8.12.2003) and Gloco steering group (19.12.2003). The recommendations arising from the analysis were included in the company's manufacturing strategy.

5. The second phase of the project was started in August 2004. The objective was to support implementation by verifying interview results with quantitative data. To verify interview results, order lines from the ERP system were collected and analysed. The data covers three European factories for the period January 2003 to December 2004.

6. The final data collection step consisted of three plant visits in different European countries. Each visit included a management workshop and a plant tour. Two researchers and 5-7 managers attended each workshop (North Europe: 24.11.2004, Central Europe: 09.12.2004, Eastern Europe: 10.01.2005).

7. Data and preliminary results from the second phase were disseminated together with personnel from Citius demand-supply network development and European time-zone management (Finland: 4.11.2004, 4.1.2005, 25.1.2005), Gloco research group (Espoo: 26.11.2004) and Gloco steering group (Espoo: 13.12.2004).

Interviews and workshops followed a structured interview guide that interviewees had received in advance. During interviews, notes were taken. After the interviews, usually within 48 hours, the notes were transcribed into an interview memo. At least two researchers attended each interview and crosschecked memos with notes. Memos were sent by email to interviewees for corrections and amendments. The same process was also applied for minutes from project meetings. All interviews were carried out in person and on site, unless mentioned otherwise.

3.4.2 Altius

Discrete-event simulation modelling was used in Altius case. The project was planned in autumn 2002 and carried out in spring 2003. During spring 2003, the author spent three months as a visiting researcher at Centre for Industrial Production at Aalborg University in Denmark. The project consisted of the following steps:

1. Definition of project targets through discussions with case company management (Finland: 27.11.2002; Denmark: 05.02.2003) and via email.

2. Process mapping and definition of simulation targets through interviews with logistics manager, supply chain design manager, purchasing (2 informants), retail development (2 informants) and a product manager (Denmark: 05.02.2003, 06.02.2003, 10.02.2003, 11.03.2003, 07.04.2003). The

three plants of Altius were also visited (Denmark: 06.02.2003, 17.02.2003, 27.02.2003).

3. Data collection from the corporate ERP system (SAP/R3).

4. Building, validating and running experiments on a simulation model of the complete supply chain for one example product, spanning from component suppliers to retail outlets (Denmark: 06.03.2003-28.04.2003).

5. Structured interviews with retail development managers for Denmark, France, Spain and the UK. Ebbe Gubi from Aalborg University carried out the interviews and has reported details in his doctoral thesis (Gubi, 2004).

6. Preliminary results were disseminated in project meetings with Altius management (Denmark: 05.03.2003, 27.04.2003), with colleagues at Aalborg University, Center for Industrial Production (Aalborg: 04.03.2003, 26.04.2003) and with Gloco steering group (Finland: 04.06.2003).

As the main intent of the interviews at Altius was to get acquaintance with the company, unstructured interviewing was used. During interviews, notes were taken. After the interviews, the notes were transcribed into interview memos, but memos were not sent to interviewees. All interviews were carried out in person and on site, except for some of the interviews with retail development managers. At least two researchers attended each interview and crosschecked memos with notes. The simulation model was validated against actual performance data, as will be described in section 4.2.

3.4.3 Fortius

Case Fortius was carried out from February to November 2002. It consisted of the following steps:

1. Two meetings with company management in which project targets were defined (Finland: 2.12.2001, 17.01.2002).

2. Process mapping at a case plant through unstructured interviews with the plant manager, marketing and sales manager, sales personnel (2 informants), supply manager, scheduler, design team facilitator, production manager, and Fortius's internal consultants (2 informants), (Finland: 20.3.2002, 13.03.2002, 03.04.2002, 21.08.2002).

3. Collection of delivery data for the case plant including all deliveries in the period 01.01.2001-30.04.2002 (N=101). For the studied product range (N=56), more detailed delivery data including 16 milestones were collected.

4. Supplier interviews in the following companies:
   a. A global producer of tap changers and bushings. 7 informants (Sweden: 26-27.08.2002).
   b. A local producer of expansion tanks. 3 informants (Finland: 28.08.2002).
   c. A global producer of CTC wire. 4 informants (Austria: 12.09.2002).
   d. A global producer of radiators. 4 informants (Germany: 13.09.2002).
   e. A local producer of strap wire. 4 informants (Finland: 20.09.2002).
   f. A local producer of steel sheets. 1 informant (Finland: 20.09.2002).

5. Customer interviews at the following companies:
   a. A utility company, 2 informants (Finland: 11.10.2002).
   b. A project consulting company, 3 informants (Sweden: 14.10.2002).
   c. A paper mill, 3 informants (Finland: 20.10.2002).

6. Preliminary results were disseminated in project meetings together with case company management (04.03.2002, 16.05.2002, 06.06.2002, 07.03.2002, 21.08.2002, 29.11.2002) and Gloco steering group (27.02.2002, 29.04.2002, 18.09.2002, 27.11.2002)

Interviews with suppliers and customers followed a structured interview guide that interviewees had received in advance. Interviews with case company management were unstructured. During interviews, notes were taken. After the interviews, usually within 48 hours, the notes were transcribed into interview memos. Memos were sent by email to interviewees for corrections and amendments. All interviews were carried out in person and on site. At least two researchers attended each interview and crosschecked memos with notes. The same process was also applied for minutes from project meetings.

3.5 Discussion of validity

This section describes actions taken to enhance validity of the research. This section follows (Stuart *et al.*, 2002) and (Voss *et al.*, 2002) that both are based mainly on (Yin, 1989). The validity of the resulting theory is discussed later, in section 6.3.

Construct validity is the extent to which we establish correct operational measures for constructs being studied, that is, if we have understood what was going on in the company. Construct validity was enhanced by collecting both qualitative and quantitative data. When possible, quantitative data (*e.g.* order data) was used for verifying information given by interviewees. In all cases, more than 10 informants were used, such that the same questions were asked from several informants. Interviewer bias was addressed by using two interviewers for each interview. Memos from individual interviews were checked by interviewees and summary results were reviewed together with company management.

Internal validity is the extent to which we can establish causal relationships between constructs, as distinguished from spurious relationships (Stuart *et al.*, 2002). Internal validity can be addressed through pattern matching, that is, literal and theoretical replication within and across cases (Yin, 1989). Internal validity was addressed by studying operations systems for different product families in each case and comparing their properties with operations systems for product families in other cases.

External validity is the extent to which the study's findings can be generalised beyond the immediate case study. Multiple cases have higher external validity than single cases (Voss *et al.*, 2002: 211). However, it is recognised that limited external validity is a weakness of the case study method. The same data cannot be used both for creating new theory and for testing its generalisability.

Reliability is the extent to which a study's operations can be repeated with the same results. Reliability is enhanced by storing raw data electronically and by carefully documenting all steps in data analysis (Stuart *et al.*, 2002: 430). Both pieces of advice have been followed.

4 CASE STUDIES

This chapter consists of three stand-alone case studies. In each case, the research problem "*Can a company produce and deliver a high variety of products while maintaining high operational efficiency?"* is studied by planning on and solving real-world problems in collaboration with managers of a company facing this challenge. A description of customer needs, offering portfolio, operations system and performance provides data for answering the first research question about relationships between these 'a priori' constructs. Secondly, the evaluation of a specific improvement opportunity provides data for answering the second research question about how to manage trade-offs between a broad offering portfolio and good operational performance.

The cases Citius (section 4.1), Altius (section 4.2) and Fortius (section 4.3) are presented in an order from high industry clockspeed and high volumes towards low industry clockspeed and low volumes.

4.1 Case Citius

In beginning of year 2003, the consumer electronics company Citius was foreseeing a number of challenges. Revenues had increased rapidly in the 1990s, but in the 2000s, the growth had flattened out. Trade customers were demanding product customisation and new services. As market penetration was high already in the traditional markets, Citius planned to respond with a product and service portfolio that was more diverse. This would mean more product introductions each year, a portfolio of products that are more different from each other than they used to be, and more customised variants of each product. The company was also piloting new channels of distribution.

The case project was initiated for answering the following question: *How should manufacturing support the increased diversity of products?* Company management expected that one or many new manufacturing concepts would be needed, but contents and requirements for the concepts were not known. The project spanned over 1.5 years and included three phases:

1) Characteristics and requirements of different products were collected in interviews with representatives of business units, marketing and channel development, and manufacturing.

2) Differences between product categories were verified using quantitative order data.

3) Finally, results from interviews, quantitative analysis, and other strategy work were reviewed in workshops with managers of three European factories.

4.1.1 Customer needs

A consumer can find the products of Citius in various retail outlets. Some shops specialise in the particular segment of consumer electronics, but the products can also be found in generals shops like department stores. Web shops are not yet an important channel of distribution.

Citius, however, does not interface end users directly. In Europe, products are sold to trade customers. The trade customers, in turn, sell products further to shops that sell to customers. Trade customers are divided into three groups: service providers, distributors and retailers. Interviews with Citius representatives of marketing and channel development indicate the following characteristics of trade customers in Europe:

> **Service providers** offer the physical product to consumers together with their services. In many countries, it is common that service providers subsidise the physical products in order to get or retain customers. Service providers are interested in product technology. They want insight into product development and they want to affect which features are developed. Service providers want their own brand to be visible. When the product is readily developed, they want custom versions. Service providers tend to buy in bigger lot size than other trade customers. Some service providers have own distribution centres while others have outsourced their logistics completely. In general, logistics is not the core competence of service providers.
>
> **Distributors** buy big volumes, have low internal cost and take a thin margin. Traditionally they have done box-moving, but today they are looking for more business. It could be customisation (*e.g.* putting something into the package) or education and distribution of promotional material. Distributors are concerned about inventory turnover, so they buy mainly high-volume products. For distributors, logistics is a core competence.
>
> **Retailers:** If a retail chain has high enough volumes to get volume discounts from Citius, it is approved as a direct customer. For Citius, retailers provide a way to affect how end customer experience buying the product.

Retailers also have the best view about end user needs and preferences. Retailers want Citius to provide user-training material. In general, retailers take any product, as long as Citius helps in promoting it.

In summary, trade customers in different categories tend to have needs that are different from each other. Service providers are most concerned about product customisation while distributors are logistically demanding. However, the needs are not contradictory. For example, service providers are also happy if they get good logistical service.

4.1.2 Offering portfolio

The products within the portfolio of Citius are targeted for different consumer segments, such as a 'sporting' and 'fashion'. The idea is to reach a maximum number of consumers with products that are applied for various special needs. Products for different segments have different designs. For example, in the sporting segments, rough designs for outdoor use are needed. In the fashion segment, on the other hand, aesthetics is more important than durability.

Characteristics of different products were identified by interviewing Operations & Logistics directors of the business unit responsible for each product category (Table 3). Product group A contains most of the products. The newly established business units B-E develop new technologies. Once the technology is mature enough, it is utilised also among other products. Business unit F is an exception: it develops products for markets in Americas and Asia. These products were not studied in the case project that focused on Europe.

Table 3: Product characteristics in Citius case.

Product group/ business unit	*A*	*B*	*C*	*D*	*E*	*F*
Existing/new	Existing	New	New	New	Existing	New
Sales argument	Features and fancy design	Basic functionality at a low price	Features, new technology, high quality	Features, new technology, high quality	Features, high quality	Conformance to trade customer's specs
Price sensitivity	Medium	High	Low	Medium	Low	Medium
Volumes	High	Very high	Low	Low	Low	Medium
Demand characteristics	High, irregular	Very high, stable	Low, irregular	Low, irregular	Low, stable	High, irregular
Difference between products in family	Small	Small	Large	Large	Large	Medium
Number of variants of each product	High	Medium	Low	Low	Low	Medium

Based on interviews, the product portfolio of Citius was divided into three categories: *alpha, beta* and *gamma*.

> **Alpha:** Consumers buy these products for their features and high quality; price is not a key buying criterion. The architectures are complicated and the products are quite different from each other. The number of variants per product is lower than in other groups. Product technologies are new and innovative.
>
> **Beta:** These products belong to the mainstream of the market. The products have many variants and volumes are high, although individual orders can be small. The differences between products and variants are small. Low cost is important but is not the main buying criterion for consumers. Product technology is mature.
>
> **Gamma:** Consumers buy these products because they need basic functionality at a low price. Product structures are simple and based on mature technologies. There are only a few products in this group and they are delivered in very high volumes.

4.1.3 Quantitative analysis

Interview results were verified using order data. The data set covers all order lines for European factories in 2003-2004. Spare parts and accessories were excluded from analysis. During the period, over 50 different products were produced in Europe. A team from Citius classified these products into the three categories: *alpha*, *beta* and *gamma*. The aim of the data analysis was to identify and quantify differences in demand patter for products in different categories.

The number of products in each category was calculated by week. In category beta, the number of products has remained stable since the beginning of the period. In the other categories, many new products have been introduced (Figure 12). Especially in the last quarter of 2004, many alpha products were introduced.

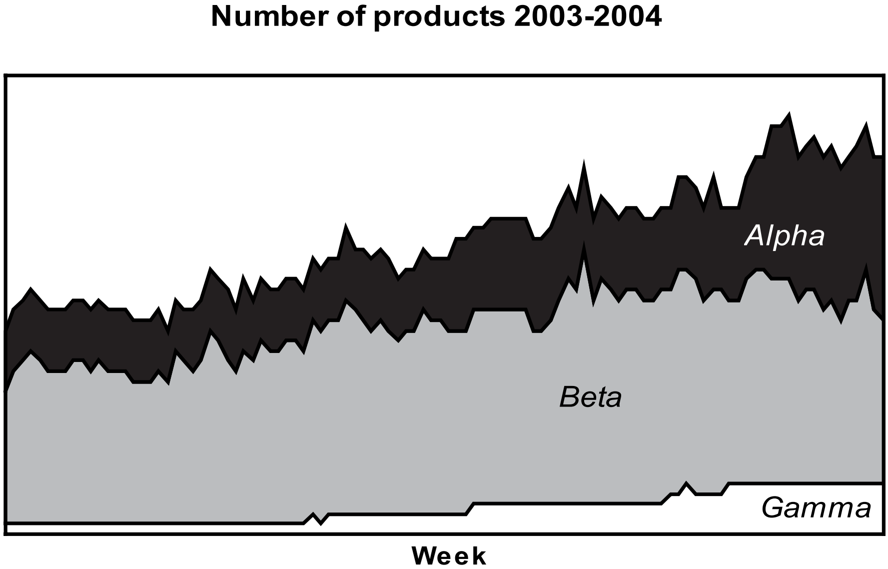

Figure 12: Number of products in different categories.

An analysis of lifecycles showed that in category alpha, many new products have been introduced recently while only a few have been ramped down. In category beta, many products have been introduced and ramped down each year. In category gamma, there have been only introductions but no ramp-downs. Among the products that were produced in the beginning of 2003, only one out of four product was still produced in the end of 2004.

Demand volumes were analysed by comparing sales per product, average number of variants, sales per variant and average order size for different product categories (Table 4). The quantitative results confirm interviews: product categories are different. In category alpha, products have low demand, few variants and small lot sizes. The opposite is true for category gamma. For confidentiality reasons, only rankings are showed in Table 4.

Table 4: Volume analysis for different product categories in Q4/2004 (3 = highest, 1 = lowest)

	Alpha	*Beta*	*Gamma*
Number of products	2.5	2.5	1
Sales per product	1	2	3
Variants per product	1	2	3
Sales per variant	1	2	3
Average order size	1	2	3

A two-sample t-test confirms that average weekly volumes for gamma products exceed the volumes for beta products (p<.001). Volumes for beta products, in turn, exceed the volumes for alpha products (p<.001).

Demand variability is different for different product categories. Relative to the average, demand varies most for products in category alpha and least in category gamma (Figure 13). In category alpha, it is common that products have a weekly demand of four times average weekly demand. In category gamma, the corresponding figure is two times average demand.

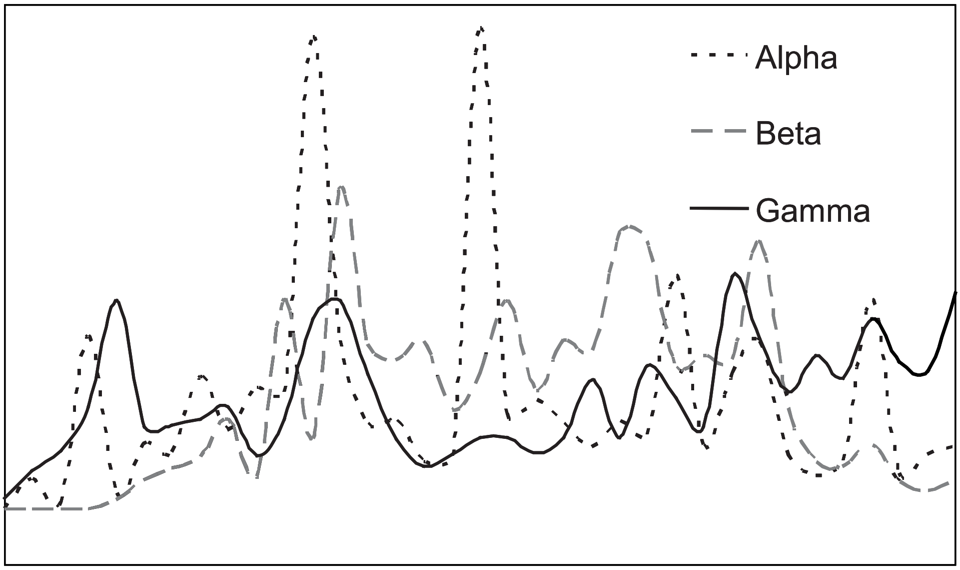

Figure 13: Relative demand variance for a typical product in each category (periods 1-8/2004)

A two-sample t-test confirms that coefficient of variance (standard deviation of weekly demand divided by average weekly demand) is higher for alpha products than for beta products (p<.01). The difference between beta and gamma, however, is not statistically significant.

Variations in total volumes depend mainly on variations for gamma and beta products, as these products have high absolute demand. Figure 14 shows total demand during a sample of 10 weeks in 2004. In the example, total demand in week 6 is 2.6 times the total demand in week 3. In the same example, the demand for alpha products in week 5 is 6.5 times the demand for alpha products in week 3. In short, total demand is highly variable, and demand for single product categories is even more variable.

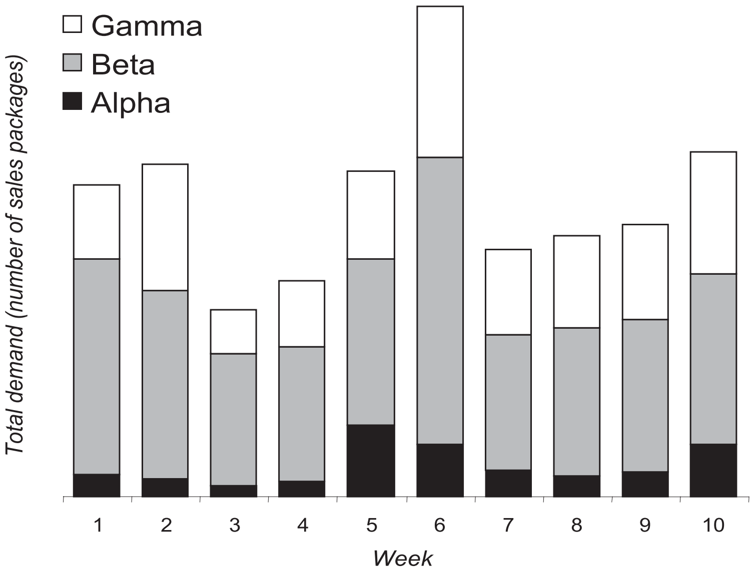

Figure 14: *Total demand by product category (number of sales packages requested). Sample of 10 consecutive weeks in 2004.*

The relationship between volumes and demand variation was analysed in further detail. Figure 15 shows coefficient of variance for each product that was delivered in periods 1-8/2004. The figure indicates that low demand is associated with high demand variation and vice versa.

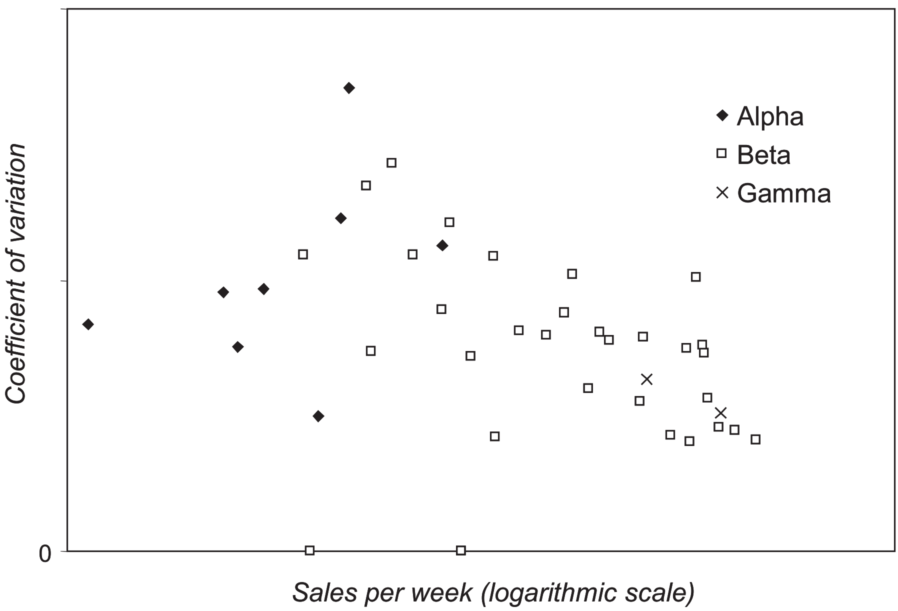

Figure 15: *Scatter plot of volumes and weekly demand variation, periods 1-8/2004. Each dot stands for one product.*

Customer groups were analysed with the aim to identify possible relationships between customer group and product category (Table 5). No significant differences were found, except for order sizes: service providers order large batches while distributors and retailers order smaller lots.

Table 5: Volume analysis for different customer groups and product categories in Q4/2004 (4 = highest, 1 = lowest)

	Service providers	Distributors	Retailers	Importers
Alpha products	1	2	3	4
Beta products	4	3	2	1
Gamma products	1	2.5	2.5	4
Average order size	4	2	1	3

Next, **product allocations to factories** were studied. In general, each product is made in only one factory. Factory 2 manufactures the largest number of products, of which most products belong to category alpha. Factory 3, on the other hand, focuses on beta and gamma products and has no alpha products. Factory 1 has all product categories and no particular focus (Table 6).

Table 6: Product allocation to factories in Q4/2004, number of products (3 = highest, 1 = lowest)

	Factory 1	Factory 2	Factory 3
Alpha products	1	3	0
Beta products	1.5	1.5	3
Gamma products	2	1	3
Total	1.5	3	1.5

An analysis of total volumes (number of sales packages requested) rather than number of products shows that Factory 3 has highest total volumes due to large volumes of beta products. Factory 2 is making the highest number of both alpha and gamma products, but has lowest total volumes.

Table 7: Product allocation to factories in Q4/2004, number of sales packages requested (3 = highest, 1 = lowest)

	Factory 1	Factory 2	Factory 3
Alpha products	1	3	0
Beta products	2	1	3
Gamma products	1	3	2
Total	2	1	3

Finally, **delivery speed, delivery reliability** and **unit cost** were measured for the three factories. No significant differences were found.

4.1.4 Operations system

Currently, all products are manufactured using an assemble-to-order (ATO) concept. The products of Citius have a generic, product-specific functional unit. Functional units are made to stock based on forecasted demand. Final assembly and packaging are performed based on customer orders. All variety is introduced in the final assembly and packaging stage, by adding mechanical components, software, and additional items in the sales package (Figure 16).

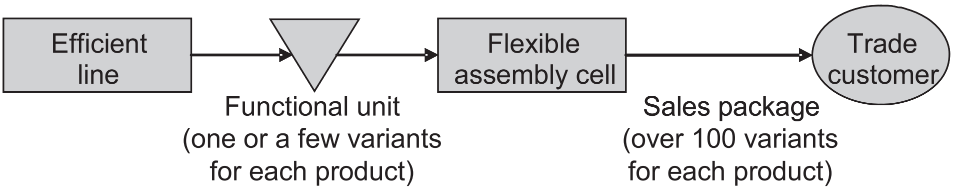

Figure 16: Existing assemble to order concept.

The ATO concept is a good example of match between product architecture and production process. It is possible to create all variety based on customer orders, because products have a separate, generic functional unit. The ATO concept is considered as one of the main reasons why the manufacturing costs of Citius are below the costs of its competitors. However, designing "ATO-compatible" products has its drawbacks. Especially for alpha products, it can be challenging to extract a generic functional unit and design all variety into swappable mechanics and software. Another drawback is that many products tend to look quite similar to each other. Making products look different from each other causes challenges in manufacturing.

To evaluate manufacturing implications of the new product categories alpha and gamma, workshops were arranged together with management of each factory. Five to seven managers and two researchers participated in each workshop. The visits also included a plant tour. The workshops were held in the end of the project when plant management already had got some experiences from new product categories.

Two of the factories had experiences from alpha products. In general, some special arrangements were needed for each product. The products have many mechanical parts. It is not intuitive how to assemble such a product; assembly requires good "hand skills". Material management is considered challenging because there are many parts and because of shortages and quality problems. Especially in ramp-up phase, immature materials are a problem. Currently there are no product-specific production technologies.

All three factories had experiences from gamma products. As they have simple architectures and few parts, less labour and fewer machines are needed than for other products. Otherwise, no special arrangements are needed in manufacturing. Volumes for gamma products vary a lot in absolute terms, therefore volume flexibility is important. As gamma products are easy to manufacture, they are currently used for capacity levelling. When demand is high, production of functional units is outsourced to contract manufacturers. When demand is low, functional units for gamma products are made in own factories. Final assembly and packaging always take place in own factories.

4.1.5 Focused concepts for each product category

Based on the current-state analysis, the case question "*how should manufacturing support the increased diversity of products?*" can be re-stated as two separate sub-questions:

1. What is the best manufacturing concept for each of the product categories?

2. How many manufacturing concepts should Citius implement?

The first of these sub-questions was answered based on the workshops, collected quantitative data, and other strategy work. Three product-optimised manufacturing concepts were identified, one for each product category. These manufacturing concepts are described below.

Category beta has existed for many years. The current assemble-to-order concept provides excellent support. Generic functional units are made in high volumes on highly automated manufacturing lines. As the number of products is large and life cycles are short, it is important that different products can be made using the same equipment. Final assembly and packaging is manual and is carried out based on customer orders. This is feasible as the number of sales package variants is very high.

In category gamma, products typically have even more sales package variants than in category beta. This means that assemble-to-order operational mode is needed also for these products. Furthermore, gamma products are often used in subsidised campaigns with special sales package variants. Therefore, final assembly and packing is equally challenging for beta and gamma products, even though the products themselves have simpler architectures. Consequently, assemble-to-order with manual assembly and packing is the best operational mode also for gamma products. Functional units for gamma products are less complex and are made in higher unit volumes than functional units of other products. In a new *high-volume* concept, functional units would be made on shorter lines with fewer machines. Labour content would be reduced via production automation. Testing would be less rigorous and tolerances a bit wider than for the more expensive products. As lifecycles are long, the same functional unit would be made on the line for a long time. On the other hand, demand variations are very high in absolute terms. The utilisation rate would not be very high for a dedicated production line, or alternatively, large stocks would be needed.

For products in category alpha, the current assemble-to-order concept is challenging. The alpha products do have sales package variants but sometimes also functional unit variants. Furthermore, functional units of different products are rather different from each other. Fitting these complex functional units into current manufacturing lines is challenging. Currently, problems are solved as they occur, often leading to long ramp-ups and special arrangements for each product. A robust *flexible concept* would make it easier to manufacture any product and enable faster ramp-ups. The flexible concept should support many operational modes: assemble-to-order, make-to-order and configure-to-order. The latter mode would be used for creating and delivering one-time campaign variants of products. The level of automation cannot be as high as in the previous concepts because manual assembly is usually needed for complex products. The new concept should not set too many restrictions for product development. The flexible concept should be flexible enough to accommodate new product- and production technologies that will be invented in the future.

4.1.6 Portfolio-level analysis

As expected, different manufacturing concepts are optimal for product categories with different characteristics. However, this does not necessarily mean that Citius should implement all the three different manufacturing concepts. How many manufacturing concepts should Citius implement?

Fitting complex products into lines suited for less complex products is challenging. Consequently, a new *flexible concept* for category alpha products would help in avoiding current problems. In the long term, a flexible concept would make it possible to develop better products, without current restriction such as "only one functional unit version per product". A dedicated concept would make it possible to produce a wide range of complex products in low unit volumes without disturbing other manufacturing.

On the other hand, technically it is not difficult to make simple gamma products on a line suited for the mainstream beta products. Currently, product categories beta and gamma use the same capacity. The current ATO concept is extremely cost efficient already. Simple product architectures do not mean idle machines along the line because machines can be shifted between lines on a short notice. Labour can also shift between lines. The number of sales package variants is very high for both categories beta and gamma, so assemble-to-order mode is feasible for both. In the end, despite serious efforts, we found no ways in which a dedicated concept would significantly reduce manufacturing costs for category gamma products, assuming current product- and production technology. On the contrary, the current practice of manufacturing simple products on advanced lines when demand is low should be maintained.

In summary, the analysis showed that:

1. A dedicated flexible manufacturing concept is needed for complex products.
2. A dedicated high-volume manufacturing concept is not needed for gamma products.

The analysis gives a clear recommendation for the company about where to focus development efforts and, later on, investments in production assets. Achieving further cost savings in manufacturing of beta and gamma products is probably still possible, but a manufacturing concept level re-organisation is not needed.

4.2 Case Altius

The consumer electronics industry is characterised by high product variety, short product lifecycles and decreasing prices (e.g. Fisher, 1997). In retail, product availability is extremely critical, as consumers tend to choose substitutes if one product is out of stock (Christopher, 1998). On the other hand, high product availability requires a large investment in shop inventory (Bowersox and Closs, 1996; Dubelaar *et al.*, 2001). This poses challenges for retailers who need to provide high product availability but keep shop inventories at an acceptable level. The case company Altius is a Danish producer of high-end consumer electronics. At the time of the case study, Altius utilised a delivery concept where products were assembled to order in a factory. This case study presents results from a project with the aim of evaluating the benefits of postponing some final assembly steps to retail outlets. The case study is based on an article in *International Journal of Retail & Distribution Management* (Appelqvist and Gubi, 2005)

4.2.1 Offering portfolio

The product portfolio of Altius includes music systems such as MP3 and CD players, televisions, loudspeakers, telephones, and the AltiLink system that integrates the products with each other. The products belong to the upper price segment in the market, focusing on a unique design and value-added service. Retail prices are in a range from a hundred euros for small products such as phones to thousands of euros for large plasma televisions. Volumes vary correspondingly from a few thousand units per year for the most expensive products up to 100 000 units for the cheaper ones. Products are typically sold for about 12 years, although minor technology updates are performed more frequently.

Most products have many variants. When entering the shop, a customer usually does not know exactly what he/she is looking for. Most customers are not interested in specific technologies. The customer will visit the shop, discuss with the salesperson and try the products. In the ideal case, the customer will tell about his life, his home and his needs, *e.g.* listening to music while cooking. Through this discussion, the salesperson should be able to suggest the most suitable product, without having to bother the customer with many technical details. To facilitate this need-based product choice, a large variety of product options are needed, both on the technical side (*e.g.* satellite receiver) and related to product placement (*e.g.* different stands depending on whether the customers plans to put the TV on the floor or in the bookshelf). Geographical variants are needed because of local standards. For example, in the US, plastics need to be fireproof. Finally, Altius provides products in many different colours in order to match preferences of individual customers, match with the interior of customers' houses, and to make the shop look nice.

4.2.2 Operations system

Altius sells its products through a network of over 1200 dedicated retail outlets all over the world. The network is operated according to a franchising concept where independent entrepreneurs own the shops but product assortments and shop interiors are decided centrally. Products are distributed exclusively through these concept stores; and the stores carry only Altius products. In larger cities there might be several stores competing with each other.

Retailers order the products from an assembly plant that is situated Denmark. Close to the assembly plant, Altius has two other plants for in-house manufacturing: a "mechanics plant" for machining and mechanical subassembly work and an "electronics plant" for surface mounting and electronic subassembly. Components and other subassemblies are sourced from suppliers worldwide (Figure 17).

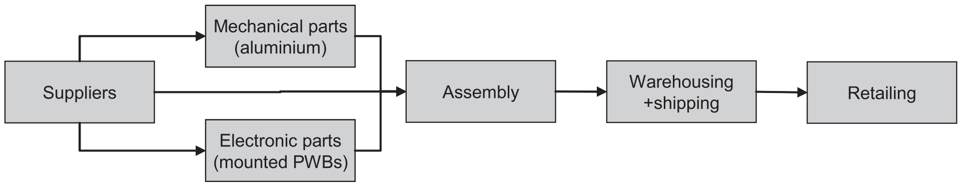

Figure 17: Altius supply chain.

In the assembly plant, each product concept is made in a dedicated work-cell or line. The production control principle is a combination of make-to-stock for high-volume variants and make-to-order for low-volume variants. This gives some short-term volume flexibility. Seasonal variations are handled by the use of temporary labour.

4.2.3 Customer needs

To access needs for logistical service, retail development managers responsible for Denmark, France, Spain and the UK were interviewed. The semi-structured interviews contained questions about current stocking policies in retail outlets, the value of product variety and estimated delivery time expectations of consumers. The retail development managers answered these questions after contacting retailers in their area. The data collection was deliberately designed to avoid promoting postponement.

According to interviewees, consumers have different expectations of delivery time for different products. Consumers expect to get small, low-variety products directly. If consumers cannot get these products directly, they tend to change their mind, buy a competing brand, or try to find the same product at a competing retailer. For more customised products, longer waiting times are acceptable. Waiting some time for a customised product gives the consumer an impression that the product is built specifically for him/her. A practical concern is that a big product such as a TV requires home delivery and installation.

The following quotations present some response to the question of how long consumers are willing to wait for products. For confidentiality reasons, product names are replaced by product descriptions in brackets.

> *Phones are pure "cash and carry". For [a high-class TV] customers can very well wait up to 2 weeks. Customers expect to get other TVs directly, but they accept waiting some time if it's a special colour (Retail development manager, Denmark).*

For smaller products, like [a radio/CD player], [an MP3 player] and phones, customers expect the product right away. For bigger products like [a TV] and [a high class TV], they accept to wait (Retai development manager, Spain).

[Acceptable delivery time] varies according to product, i.e. phones same day, for [an audio system] and [a high class TV] 7-10 days is OK (Retail development manager, UK).

When asked about stocking policies, it turned out that in response to customer expectations, retailers were actually stocking most of the low- and midrange products. Retailers felt that they needed to provide instant handover to customers for these products. Contrary to official policy, retailers invested in shop inventory in order to increase sales. Some retailers had even found out a way to create product variety in the shop. They ordered products in basic colours and with standard features. In addition, they ordered additional coloured parts and feature modules as spare parts. In this way, it is possible to create product variants in the shop, if the product has a modular architecture. When asked, also other retailers were interested in this possibility to create variety in shops.

4.2.4 New delivery concepts

According to the official delivery concept, the retail outlets were supposed to act as show rooms, not as stockholding points. In the framework of Pagh and Cooper (1998), this is a combination of logistical postponement and full postponement (upper-right and lower-right quadrant in Figure 7, page 24). However, interviews had indicated that in fact also full speculation and form postponement were in use. It was decided to study the performance implications of these different delivery concepts quantitatively.

The following delivery concepts were defined (Figure 18):

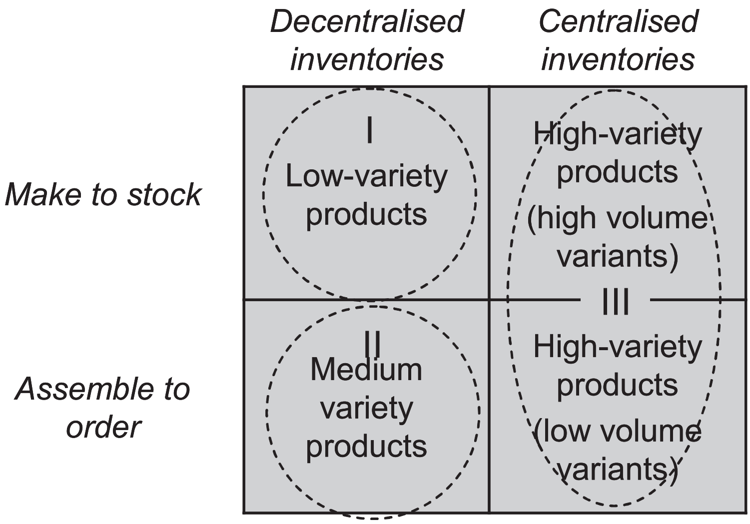

Figure 18: Emerging delivery concepts.

I. Full speculation: For the least expensive products, *e.g.* phones, the retailers would in any case keep an operating stock of all colours.

II. Form postponement: For the mid range, a form postponement concept would provide direct hand-over to customers without too much investment in shop inventory. In most of these cases, the final configuration is created by attaching a coloured front cover.

III. Logistical/full postponement: For the upper price segment products, with both colours and feature variants, the customers are willing to wait 1-2 weeks for delivery. Retailers would therefore order these configurations from the factory, rather than stocking them. From a retailer perspective, logistical postponement and full postponement provide approximately the same service level as final assembly takes very short time compared to transportation time.

The division of products is based on customer's relative expenditure compared to other products, rather than on absolute product price. For example, compared to ordinary phones, the phones of Altius are very expensive. However, compared to other products in Altius' portfolio, phones are not as expensive.

4.2.5 Simulation model

The pre-study reported above indicated that form postponement would be beneficial for products with medium price and medium variety. However, form postponement requires a modular product structure that can be costly to develop. In addition, introducing and operating many delivery concepts increases complexity and requires investments in staff training for the retailers and changes in information systems for the manufacturer. The critical question is not whether there are benefits at all, but to quantify the benefits so that they can be compared to additional efforts and costs. To get quantitative evidence, a simulation study was carried out. A simulation model provides a convenient lab environment for testing the effects of different factors (Småros *et al.*, 2003) and is useful for critically evaluating possibilities to improve supply chain performance (Maloni and Benton, 1997).

AltiSound, a stand-alone CD-player with radio tuner was chosen for simulations. The product has five colours and eight country variants, which makes it possible to study impact of different kinds of variety. The product has no feature variants. At the time of the simulation project, the product had been on the markets for one year, meaning that a sufficient amount of demand data was available. On the other hand, many years of the life cycle remained, making it possible to benefit from improvement potential. Finally, the turnover from the product is rather high, making results interesting from business viewpoint.

The bill of material of the product includes about 300 components. The assembly plant handles 16 modules while all subassemblies are outsourced. Of the 16 modules, 7 vary by country and 1 by colour. In total, 33 module variants were included in the simulation model.

Order lines from one year were used for demand modelling. The data set was retrieved from the company's ERP system. The data set consists of over 11 000 order lines including the following information: product variant, country, quantity, ordering date, requested shipping date, confirmed shipping date, and actual shipping date. Figure 19 shows shipments from Denmark by week since the product introduction in the beginning of year 2002. The demand peak in weeks 33-38 is explained by a campaign but also without this peak, demand variations are considerable. The high season is in the autumn. The trend is increasing throughout the year, which can be confirmed using regression analysis ($R^2 = .43$, $p<0.01$).

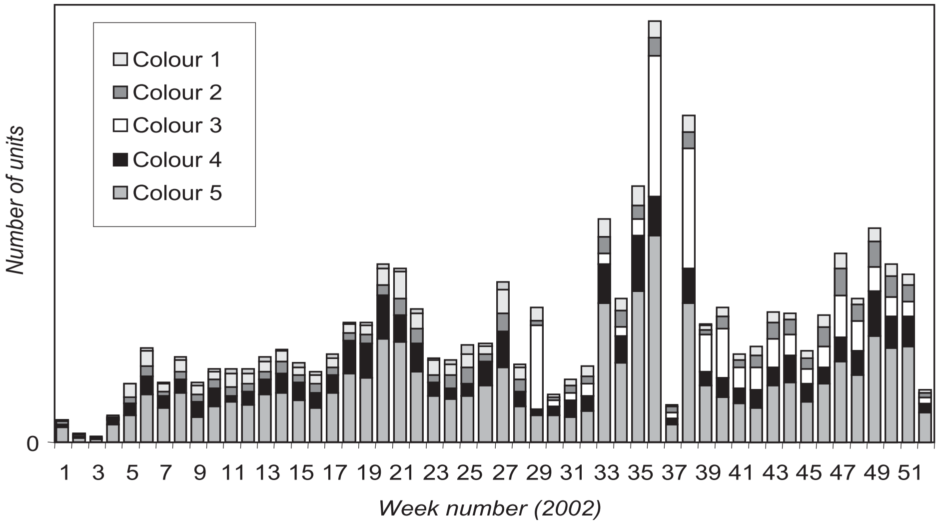

Figure 19: Actual weekly demand for the simulated product in 2002 (shipments from Denmark, N=11871 order lines)

For each week, the difference between expected demand and observed demand was calculated using regression analysis. The point estimate for distribution of differences is *Normal (0, .406)* percent of average demand. For the simulations, it was decided to use a fixed average demand that was equal to the average weekly demand for the period. Thus, seasonality was omitted from the model, which is motivated by the fact that seasonality is well known and can be anticipated for by all parties. Weekly demands were drawn from the distribution *Average demand * max[0, Normal (1, .406)]*. These weekly demands volumes were converted into order lines by allocating the weekly volumes to colours, countries, weekdays, order quantities and shops according to observed distributions. Five demand data sets of 400 weeks each were created using this technique.

The model contains a supply chain with the following actors: about 1200 retail outlets, 1 finished goods warehouse, 1 assembly plant, 2 subassembly plants and 11 suppliers (Figure 17). In the simulations, operations of each actor is simulated with a one-day accuracy (T = 1 calendar day). Model operation is based on interviews with personnel.

For component suppliers, historical delivery performance records were used to determine delivery time distribution and delivery reliability. Component inventories are managed using a periodical review policy with daily ordering for local suppliers and weekly ordering for other suppliers. The inventory control parameters (expected delivery time, inspection time, minimum lot, rounding value and safety time) were taken from the company's ERP system.

The subassembly plants and the final assembly plant have limited capacity. Products are assembled if there are both parts and capacity available. Products are assembled according to orders either from retailers or from the finished goods warehouse. Orders from retailers are prioritised over inventory replenishment orders. The finished goods warehouse is used as a capacity buffer. If demand is lower than maximum capacity, idle capacity is used for inventory replenishment of some high-volume variants. When demand exceeds capacity, high-volume variants can be taken from stock while lower-volume variants are assembled to order.

Sales of each retail outlet were estimated based on a two-month data set of shipments from Denmark. Customers arrive to the shops according to the demand scheme described above. If the customer requests a product that is not available on the shelf, the retailer orders it from Denmark. If it is available, the customer gets is directly while the retailer orders the same product as replenishment. This inventory control principle is rather common in low-volume consumer electronics retail.

The model was tuned and validated by comparing such model performance as delivery times, delivery reliability and inventory levels with actual supply chain performance for year 2002. Figure 20, for example, shows a comparison of throughput time performance of the assembly plant in the model and in reality. The technique is called input-output transformation validation (Banks *et al.*, 2003: 378-393). In addition, the model was reviewed in a structured walk-through with company management.

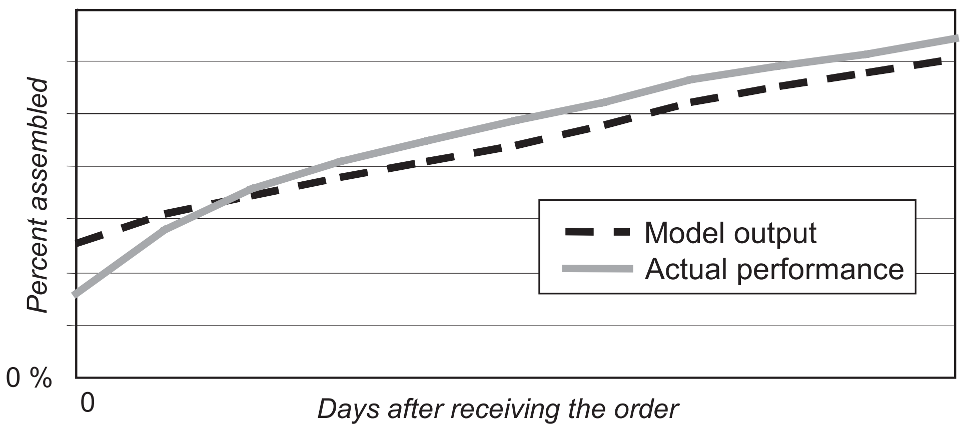

Figure 20: Chart used for validating throughput time performance of the assembly plant.

The aim of the simulation study was to measure fill rate versus total inventory for different delivery concepts. Delivery precision from the assembly plant was treated as a control variable. It was set to the corporate target level: 95% of order lines shipped within 3 days.

Table 8 summarises the simulated scenarios that are named according to Pagh and Cooper (1998). In *full speculation*, retailers keep an inventory of readily assembled units for immediate customer handover. In *form postponement*, retailers assemble the final configuration based on customer choice. Finally, in *logistical/full postponements*, retailers order products from the factory.

Table 8: Experimental setup.

Delivery concept	*Full speculation*	*Form postponement*	*Logistical/full postponement*
Customer experience	No waiting	Wait 10 minutes	Wait 1-3 weeks
Shop inventory	Selection of readily assembled units	Blank CD-players + selection of colour fronts	No inventory

In all scenarios, the factory ships high-volume variants from a central warehouse and assembles low-volume variants to order. For the consumer, full speculation and form postponement provide direct hand-over. Logistical/full postponement was used mainly for model validation, as the pre-study had shown that it is not appropriate for the simulated product.

In full speculation scenario, order-up-to levels for shop inventory were set to 5, 6, 7, 8, 9, 10, 12, 14, 16, 18 and 20 units (11 different levels) at each of the over 1200 retailers. In form postponement scenario, the first simulation run had one blank unit and one colour front in each colour (1 blank + 5 fronts in total). The number of blanks was then increased from 1 to 10 in steps of 1, while the number of fronts was increased from 5 to 20 in steps of 1 or 2. Five replications were run for each inventory level in each scenario. In total, this means 11 x 5 = 55 runs for full speculation scenario and 10 x 11 x 5 = 550 runs for form postponement scenario. Each replication consisted of a 100-day warm-up period and a 1000-day steady-state run. In each run, daily inventory and service level were recorded for each actor. For the over 1200 retail outlets, figures were aggregated by shop size for further analysis.

The same five demand data sets were used for all replications. This technique is known as correlated sampling and provides a high statistical confidence level in scenario simulation (Banks *et al.*, 1996: 481-484). All results reported below are statistically significant at the $p<.05$ level.

4.2.6 Simulation results

Figure 21 shows service level as a function of average shop inventory in *full speculation*. As expected, service levels and required inventory levels correlate positively. For example, with an average of five units on shelf, a big shop will reach a service level of 85% (85% of the customers will find the product in the colour they prefer) while ten units are needed for a 95% service level. In a smaller shop, a lower number of units are sufficient for providing the same service levels. However, if measured by inventory turns rather than absolute number of units, a big shop needs to carry less inventory to reach a given service level.

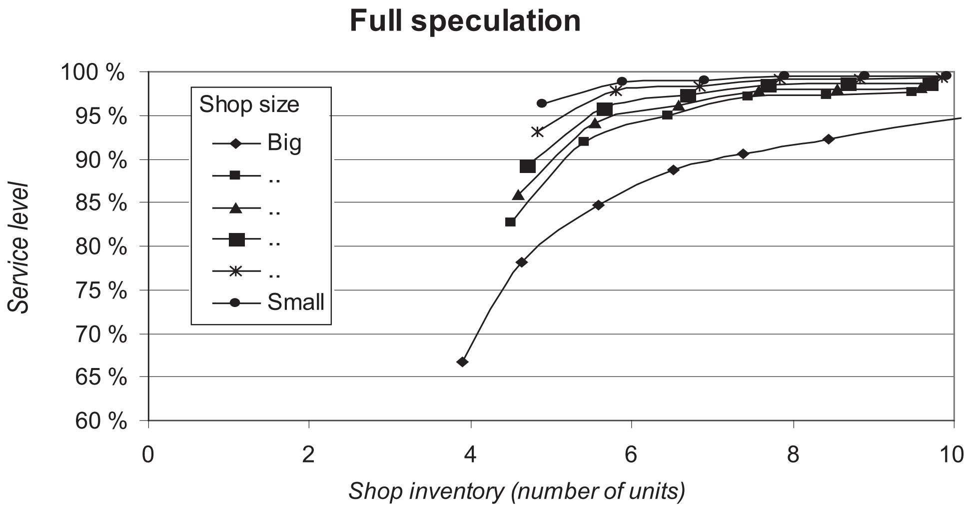

Figure 21: Service level versus inventory for different shop sizes in the full speculation scenario (absolute number of units).

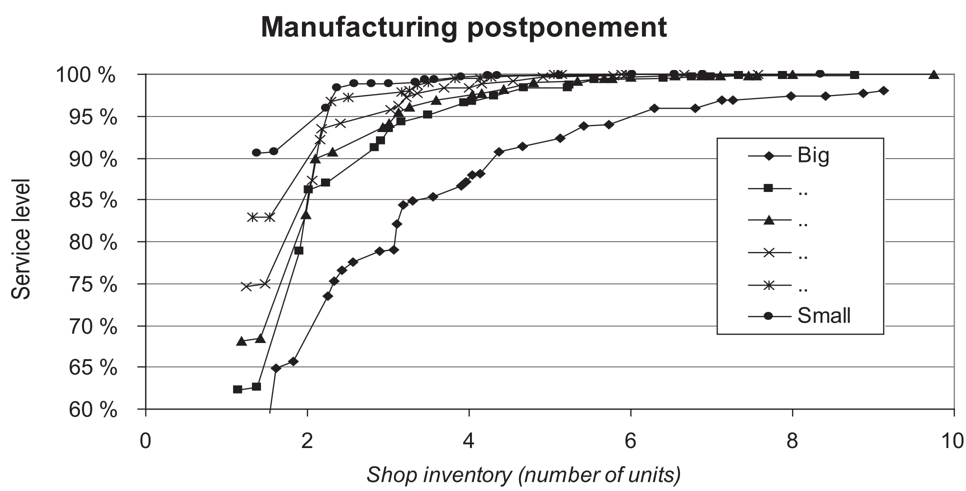

Figure 22: Service level versus inventory for different shop sizes in the form postponement concept (absolute number of units).

In *form postponement*, less inventory is sufficient for providing and a given service level (Figure 22). For example, a big shop will reach the 85% service level by storing parts with a value corresponding to only two complete units. In practice, this means 1-2 "blank" CD players and 7-8 front assemblies in different colours. "Number of units" is calculated as value of parts, *i.e.* a blank CD player is 89% and a colour front is 11% of the value of an assembled unit. The curves are not as smooth in Figure 22 because of stepwise inventory increases, *i.e.* a retailer pursuing an effective stocking policy can improve service level marginally by stocking another cheap front, but after some limit it is more effective to stock another expensive blank CD player. Also in the form postponement concept, the required inventory measured as inventory days of supply is lower for big shops than for small shops.

Figure 23 compares service level/inventory requirement for form postponement with the one for full speculation. On average, a big shop can reach any given service level with approximately 40% less inventory in shelf by moving from full speculation to form postponement. For smaller shops, the proportional savings are larger, up to 80%.

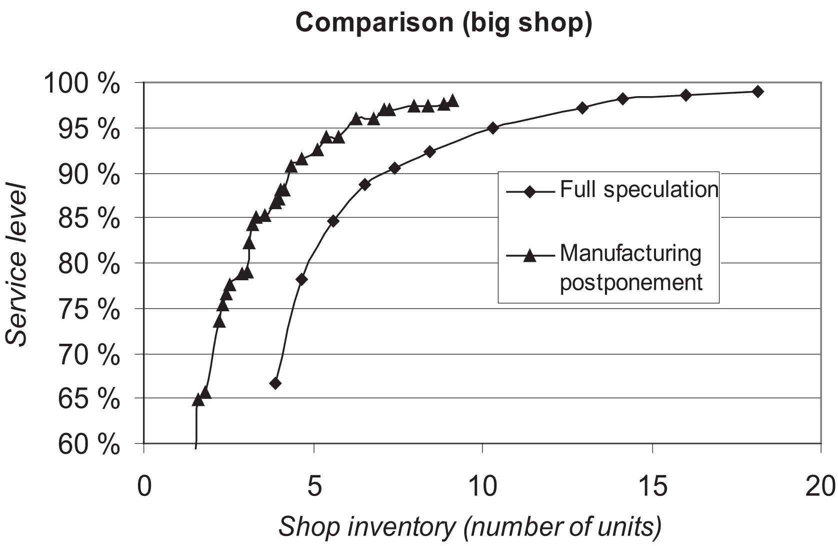

Figure 23: Comparison of service level versus inventory in different concepts for a big shop

Finally, it is possible to calculate total supply chain inventory required for achieving any specific service level. This is done by multiplying inventory in each shop by number of shops in each size category. Centralised inventories located in the finished goods warehouse are also available from the simulation model. Figure 24 shows a comparison of concepts at a 90% service level. The total potential for reduction of supply chain inventory is approximately 60%. Another insight from Figure 24 is that the centralised finished goods warehouse contains only a small fraction of total supply chain inventories. Consequently, development efforts should focus on decreasing shop inventories.

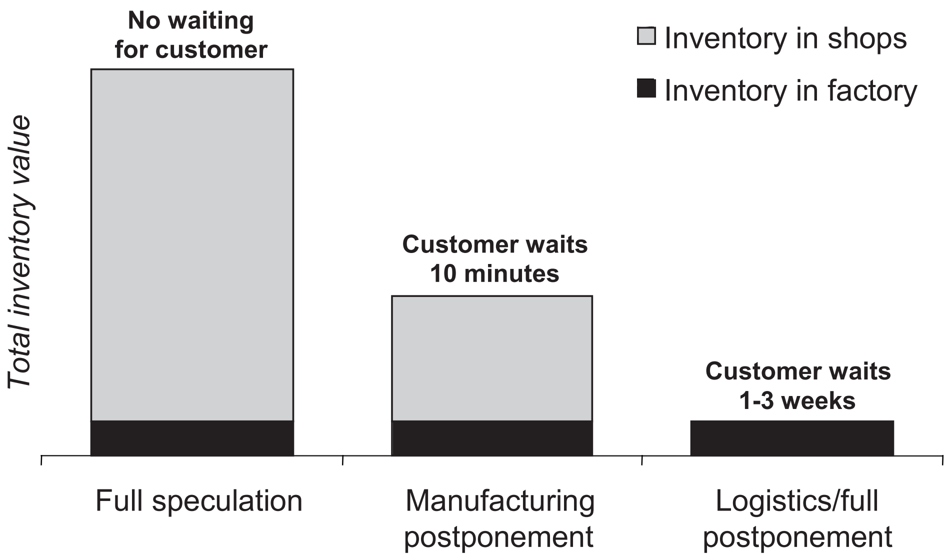

Figure 24: Total inventory investment required to reach a 90% service level

4.2.7 Managerial implications

As expected, the simulations show that it is possible to save a considerable amount of inventory by postponing creation of variety. For the case company, the simulation project was a success that triggered implementation of a new delivery concept. The idea had been suggested for some time but not implemented due to lack of quantitative evidence. According to the new policy, the most likely delivery concept (Figure 18) for a new product is decided in a meeting between representatives of operations, product development and product marketing. The meeting takes place once the product concept report is available for a new product. The chosen delivery concept determines priorities in product design. To retailers, the new concept will be introduced when new postponement-compatible products are released.

4.3 Case Fortius

A common approach in analysing interrelationships between product designs, supply network and manufacturing is to study successful companies in the fastest changing industries (Fine, 1998). Case Fortius takes a different approach. The case study presents results from a pre-study about restructuring of a big producer of industrial goods in a mature industry. The case provides an example of a successful company that competes through high product variety and cost focus rather than speed and product innovation. Fortius produces power transformers in over 20 assembly factories worldwide. Transformer technology is over 100 years old and one transformer is typically used for over 40 years.

At the time of the case project, Fortius followed a multi-domestic plant strategy, in which each factory served its local market, plus some other dedicated markets, with transformers of all sizes. In the restructuring plan, the product portfolio would be divided into three or four size ranges. In each main market region there would be one or two focused factories per size range, assembling and delivering transformers to customers across the whole region (Figure 25). The managing director for Europe stated the strategy as follows:

> *"Today, customers in industrialised countries don't care where their transformers are manufactured. We have been more of a multi-domestic company but now we must move into operating globally. Our plants are smaller than those of our competitors, which currently gives us a cost disadvantage. We should focus our operations to fewer and more efficient plants. In each plant, we should get the volumes up and the costs down."*

The targets for the re-structuring project were to reduce costs by 30% and to reduce order-to-delivery times by 75%. In implementing these changes, the objective was to double the global market share. Means to achieve targets were to redesign and standardise the product, focus production into larger units and to introduce automation.

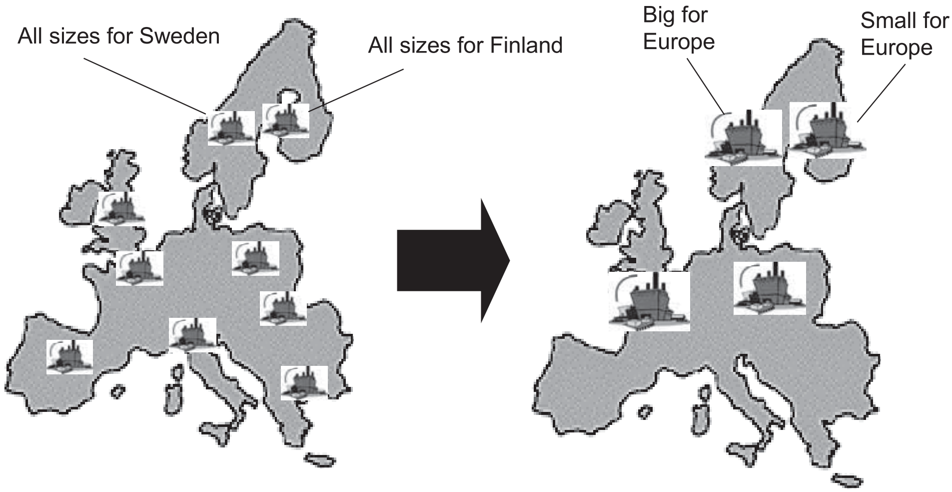

Figure 25: Restructuring plan in case Fortius.

In our research, we set out study how to make the most out of this restructuring effort. We studied how manufacturing practices, supply chain architectures and product architectures should be configured in order to implement a focused factory strategy on a global scale. Interviews with company management, suppliers and customers were used as main data sources.

4.3.1 Offering portfolio

Transformers are used for changing electric voltage. For example, to charge a mobile telephone, one needs a transformer that changes the 220V from the wall into 3.7V that is more suitable for the phone. Transformers for voltages of 10 kV and above are called a power transformers The middle picture in Table 9 on page 72 shows an example of such a transformer. All power transformers consist of certain building blocks such as a tank with three copper coils (Figure 26) but the product and its components are defined by hundreds of parameters. For example, tap changers are defined by 31 parameters and 2-5 options for each. Bushings have 3000 alternative configurations. Copper wire (CTC) is defined by 10 parameters with unlimited range of options (*e.g.* length = X meter). In practice, this means that power transformers are usually engineered to order.

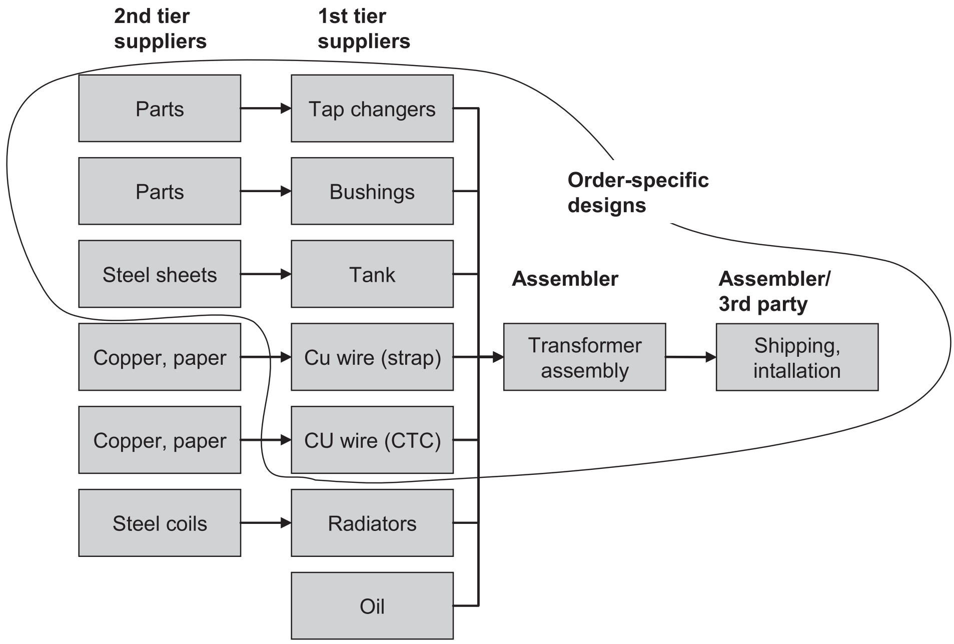

Figure 26: Bill-of-materials for power transformers (main components).

4.3.2 Customer needs

In case Fortius, customer needs were assessed in a few focused interviews with representatives of three customers: a Swedish company that delivers electricity distribution substations, a Finnish utility company and a Finnish paper mill.

For end users, product functionality matters. A manager of the substation company described the needs of his customers as follows:

> *For customers, the transformer is a big, non-intelligent but expensive box. The main requirement is that it stands there and works. Customers do not interfere much with the transformer. They care more about user interfaces such as control software.*

Interviews with end users confirmed the description. Customers define equipment in terms of functionality, *e.g.* size in MVA, high voltage, low voltage and load loss, and interfaces to other equipment. The specifications depend on where and how the transformer will be used. For example, voltage varies depending on national standards of different countries. Some customers produce power, some distribute power and yet others consume power. All this has implications on the functional specifications.

A specification can be more or less detailed. Some customers buy a complete substation while other customers are buying only the transformer. Some customers tell their needs directly to the equipment suppliers while other customers involve a third-party consultant who makes up a detailed specification. Thirdly, some customers want specific interfaces between elements in order to be able to switch elements between sites *e.g.* in case of equipment breakdown. In the latter case, the elements do not need to be identical as long as their interfaces are identical.

As transformers are expensive, customers typically use tendering. Two to four potential suppliers are responding to a specification. The main criterion in selecting supplier is lifetime cost. Customers calculate lifetime cost based on such factors as initial price, load loss, forecasted price of electricity and internal interest rate. Supplier reputation, a good relationship and availability of maintenance services are all order qualifiers – if they are not perceived as good, the customer will drop the supplier from tendering.

Requirements for delivery speed depend on schedule of the larger project where the transformer will become a part. In building a pulping line for a paper mill, the transformer with a delivery time of 6-8 months is not a bottleneck, as building the line takes 18-20 months. In a substation project, the transformer is the bottleneck element as other main elements arrive in 4-5 months. Finally, for diesel plants that are built in 6 months, pre-defined transformers are delivered in 3-4 months.

The needs of customers in different segments are illustrated in Table 9. As a generalisation, the more standardised product, the faster delivery is required.

Table 9: Customer segments identified in Fortius case (Appelqvist and Heikkilä, 2003)[8].

Project type	 *Standard green-field*	 *Customised green-field*	 *Customised complement*
Example	Diesel plant	Electricity substation	Paper mill
Price sensitivity	High	High	High
Quality sensitivity	High	High	High
Typical duration of whole construction project	6 months	12 months	18-22 months
Typical delivery time for transformer	4 months	8 months	12 months
Product specification by customer	Predefined specifications, size defined	Functional specifications, interfaces defined	Detailed specifications, even parts defined

4.3.3 Operations system

The e*nd users* of transformers are companies in various industries that produce, distribute or use electrical power. Those end users that buy equipment only occasionally often involve a *third-party consultant* in the acquisition project. The consultant specifies the product according to the needs of the end user and often runs the installation project. The *assemblers* define and assemble transformers. They also provide consulting but there are independent consultants at well. The assemblers buy a large proportion of their components from specialized *component suppliers*. Components are made from basic raw materials such as steel sheets, copper wire and paper made by *raw material producers*. Figure 27 shows the supply network for power transformers.

8 Photographs courtecy of C Bergesen (left), VA TECH Transmission & Distribution (mid), and Stora Enso (right).

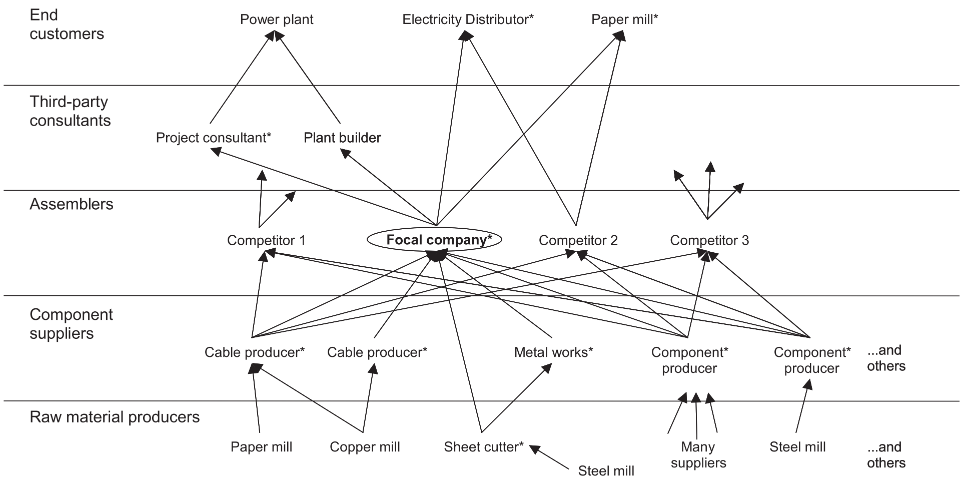

Figure 27: Supply network for power transformers

The main operational mode for delivering a power transformer is engineer-to-order. A specification of the product reaches the assembler either directly from the end user or via a consultant. The first step is electrical engineering in which the engineer creates a mathematical model for a transformer with the required performance. The next step is mechanical engineering that results in specifications for all components and drawings for some components. Specifications and drawings are sent to component suppliers. All main components, except for transformer oil, are made to order.

To some suppliers, a pre-booking is sent almost immediately while detailed specifications and quantities are sent as the engineering proceeds. Suppliers book capacity as they get the pre-booking or the purchase order. The components are defined in one of the following ways:

1) By selecting from a number of pre-defined configurations (*e.g.* radiators)
2) By defining parameter values (*e.g.* CTC copper wire)
3) By custom-drawing the component (*e.g.* tank, tap changer motor)

Due to the high variety, it is not feasible to stock transformer components. The suppliers make parts to order and dispatch them to the assembly factory shortly before final assembly. Finished products are tested and shipped to the customer's site. The final step is to install the equipment and train the customer's personnel to use and take care of it. The whole process takes approximately 8 months of which 3 months is engineering, 2-3 months material lead-time, one month for assembly and 1-2 months for shipping and installation.

In summary, the operations system for delivering power transformers is able of accommodating an almost infinite level of product variety. Inventory is earmarked to final customers upstream in the supply chain at suppliers or second tier suppliers. For tap changers and bushings, sourcing of custom-drawn parts stand for the majority of lead-time. Tap changers and bushings have order-specific parts that are sourced from second tier suppliers. Many of the first tier suppliers (radiators, CTC wire, bushings) have very large market shares globally and thus high bargaining power. They have dedicated resources that run with high utilisation rates. The production systems of suppliers are adapted for one-of-a-kind production. All these practices contribute to keeping prices low, on the expense of a delivery time that is very long.

4.3.4 Quantitative analysis

Current performance was measured using quantitative lead-time analysis, *i.e.* LOGI-analysis (Jahnukainen *et al.*, 1995). The average delivery time for engineer-to-order transformers is 194 calendar days = 28 weeks (period = 1.1.2001–30.4.2003; N=56; Figure 28). The delivery time consists of:

1. The time lag from customer order to design start is 6 weeks (42 days).

2. Engineering takes 3.7 weeks (26 calendar days) on average, where the duration is defined as time from start of engineering until issue of the first material order. In practice, some detailed engineering can take place also after this, but once materials are ordered, engineering is no longer on the critical path. Engineering is currently done by modifying an old drawing of a previously delivered transformer.

3. Sourcing is the most time-consuming step with an average duration of 16 weeks (110 calendar days). However, supplier visits and analysis of historical delivery performance of suppliers showed that all suppliers except for one had technical capability to deliver within 6 weeks, assuming current product design and production technology.

4. In assembly, the average throughput time is 4.5 weeks (32 calendar days). The variations around the average are small. The process seemed rather efficient

5. The average waiting time of 10 days before shipment is mainly due to a small percentage of transformers that wait very long, *e.g.* because the facility where they will be installed is not ready.

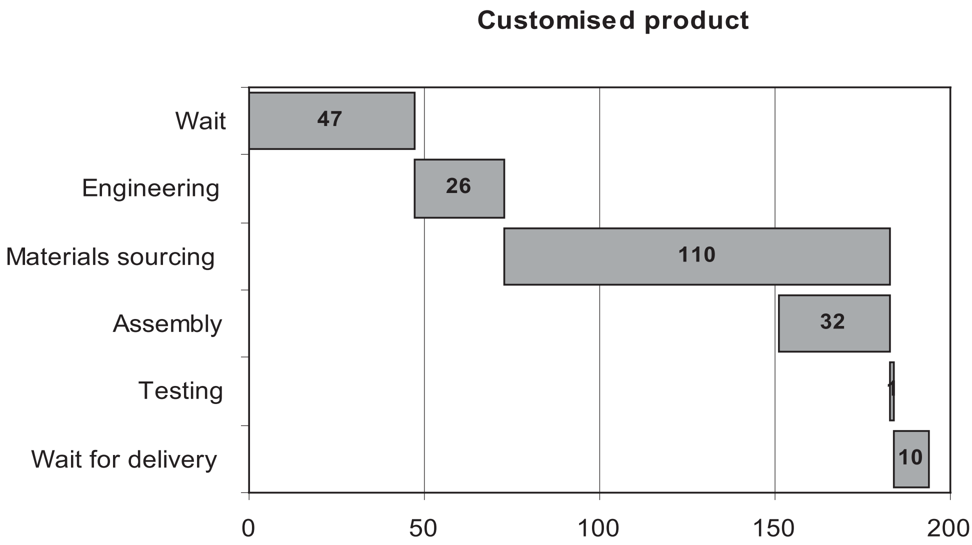

Figure 28: *Delivery time breakdown for engineer-to-order transformers (N = 56).*

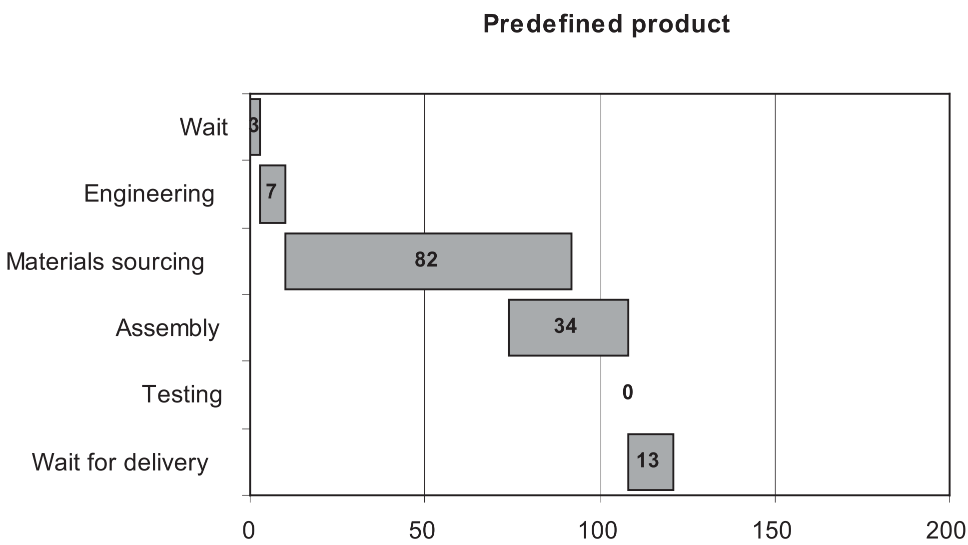

Figure 29: *Delivery time breakdown for pre-defined transformers (N = 6).*

One of Fortius' customers sells diesel plants where the transformer is a part. Total delivery time for a diesel plant is 6 months (26 weeks), which means that the delivery time for the transformer must necessarily be less than 26 weeks. A separate LOGI analysis was performed for these deliveries.

The average delivery time for pre-defined transformers is 122 calendar days = 17 weeks (period = 1.1.2001 – 30.4.2003; N=6; Figure 29). The faster delivery time is achieved as follows:

1. Little time (3 days) is spent before start of engineering.

2. One week (7 days) is spent on engineering. Product designs are mostly predefined which is possible as diesel plants have standard designs.

3. Sourcing takes 12 weeks (versus 16 weeks for order-engineered products).

4. The final steps (assembly, test and wait for delivery) take equally long as for engineer-to-order products.

As sourcing represents a major part of the lead-time, especially for pre-defined configurations, the possibilities to speed up sourcing were investigated more in detail. We visited six major component suppliers. The suppliers were chosen such that they stand for a large proportion of purchase value (64 %). Three of the suppliers are domestic; the other three are located in Austria, Germany and Sweden. Three of the suppliers belong to Fortius group while the other three belong to other companies.

Average delivery times for components vary between 6 and 15 weeks. However, interviews indicated that there is considerable slack in delivery times, that is, suppliers provide slow deliveries because Fortius is asking for slow deliveries. The fastest actual delivery times that vary between 2 and 10 weeks can therefore be considered a better measure of supplier capability at the time of data collection. Table 10 summarises delivery times. The first two columns (fastest time and average time) are based on delivery data. The next four columns (lead-time structure) are based on supplier interviews. The final column (actions needed to reach a 4-week delivery time) is based on the researcher's judgement after a plant visit and discussions with supplier representatives.

Table 10: Lead-times for transformer components.

	Fastest time	*Average time*	*Engineer-ing*	*Sourcing*	*Scheduling*	*Manufacturing*	*Actions needed to reach 4 weeks target*
Radiators	10 weeks	15 weeks			10 weeks	3-4 weeks	More capacity Better management
Copper wire (CTC)	7 weeks	12 weeks			2 weeks	3-4 weeks	Faster production Priority for Fortius
Tap changers	6 weeks	10 weeks	2 weeks	4-5 weeks		1-2 weeks	Off-the-shelf parts
Bushings	6 weeks	10 weeks		4-5 weeks		1.5 weeks	Off-the-shelf parts
Tank	3 weeks	6 weeks				2 weeks	-
Copper wire (strap)	2 weeks	11 weeks[9]				1-2 weeks	-

[9] The average lead-time for Copper wire (strap) is long because they are delivered by call-off once all other parts have arrived.

4.3.5 Product configurability and order fulfillment lead-time

For customers that buy a given transformer configuration more than once, it is clearly beneficial to pre-define the configuration rather than having it defined inside the order cycle. The other steps – sourcing, assembly, testing and wait before delivery – are equally fast for predefined configurations as for engineer-to-order configurations. These steps could be made faster as follows:

According to the project manager for product re-design, a modular or parametric product architecture, clear design rules and appropriate software tools are expected to cut engineering time to approximately 2 weeks. Sourcing lead-time could be cut to approximately 6 weeks by utilising quick-wins such as simply asking for faster delivery or pre-booking capacity. However, to reach the target lead-time on 4 weeks, some components need to be standardised to avoid order-specific engineering and purchase-to-order materials. Final assembly time could be cut from 4.5 weeks (32 calendar days) to 2 weeks through investments in production automation. Production automation would also require a product that is modular/parametric rather than custom-drawn.

In summary, total lead-time could be reduced from the current average of 27 weeks to 15 weeks (.5 weeks wait + 4 weeks engineering + 6 weeks sourcing + 4.5 weeks assembly + 0 weeks wait) with current product architecture. However, to reach the target of 75% lead-time reduction to 8 weeks, the product would need to be more standardised.

An analysis of recent transformer deliveries of Fortius showed that customer needs could have been met by a configurable solution for 33% of the deliveries. In 67% of the deliveries, one or several special requirements would still require custom engineering. Increasing the percentage of needs that can be covered by assemble-to-order solutions is an engineering issue. Furthermore, a market study indicated that in Europe, only 36% of the customers are happy with any technical solution that fit their needs. 64% of the customers want to affect the technical solution. Convincing customers that a configurable solution will fit their needs as well as a customer-engineered solution is of strategic importance. It will be easier if the engineer-to-order solution is cheaper and can be delivered faster. Finally, the assessment of customer needs indicates that the customers with most standard needs are usually most concerned about short order fulfillment lead-time (section 4.3.1 and Table 9).

4.3.6 Managerial implications

The target of the pre-study was to identify how to save cost and cut delivery time by 75%. The pre-study indicates that it is possible to achieve the target by:

1) Utilising a number of operational changes, especially in sourcing.
2) Creating a configurable product architecture.
3) Investing in production automation.

Currently the product is custom-drawn due to very specific customer requirements – the more detailed specification, the more difficult to fulfil it with a configurable solution. The level of detail in specifications depends partly on when the supplier gets involved. The later the supplier gets involved, the more detailed is the specification. It seems that earlier involvement in the purchase process of the end user would allow for standard technical solutions. This relationship is illustrated by arrow (1) in Figure 30.

A configurable product would reduce order-specific engineering at the assembler and reduce or eliminate the order-specific engineering of the suppliers. The order penetration point (the point where materials become earmarked to final customer) could be moved downstream in the supply chain. A configurable product would also make it possible to improve efficiency in production (arrow 2 in Figure 30).

Finally, a downstream order penetration point and efficiency in production would increase speed and reduce cost of the complete supply chain (arrow 3 in Figure 30)

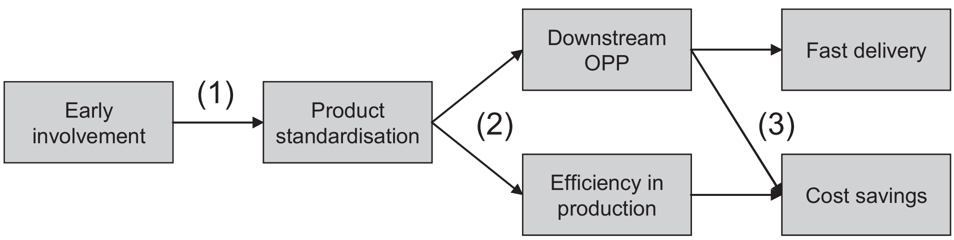

Figure 30: Suggested improvement model for Fortius case.

However, a configurable transformer would fulfil the needs of only one customer out of three. Furthermore, for customers with special needs, the current long lead times are not considered as a problem. These customers could be served from other factories that focus on special transformers.

5 CONCLUSIONS

This chapter will use data from the previous chapter for answering the research questions through cross-case analysis. The first research question "*What are the relationships between offering portfolio, operations system design and performance?* is answered by identifying constructs, that is, broad mental configurations of given phenomena (Bacharach, 1989) (section 5.1), and then outlining relationships among the constructs (section 5.2). The second research question *"How can a company manage trade-offs between a broad offering portfolio and high operational efficiency?"* is then answered by evaluating efficacy and use criteria of different tactics for mitigating the negative effects of high product variety (section 5.3).

5.1 Identification of constructs

The literature study (chapter 2) ended up in a conceptual framework containing three 'a priori' constructs: customer needs, offering portfolio and operations system. In this section, observations from cases will be used for identifying final constructs that capture and operationalise the three 'a priori' constructs.

5.1.1 Customer needs

In all three cases, customer needs were assessed, with an emphasis on need for product variety and logistical requirements. A general observation was that some customers tend to require a standard product on a short notice while others are willing to wait for a product that is more customised. Table 11 summarises the observations by comparing two groups of customers from each case.

Table 11: Customer needs observed in cases.

Case	*Customised product delivered after some waiting*	*Standard product delivered on a short notice*
Citius	**Customer group** Service providers **Product specification** Negotiate customer-specific configurations. **Delivery requirement** Delivery reliability is important. Short order fulfillment lead-time not as critical (1-3 weeks accepted).	**Customer group** Distributors **Product specification** Select from pre-defined configurations available to all customers. **Delivery requirement** Short order fulfillment lead-time and high delivery reliability are both important.
Altius	**Customer group** Buyer of high-end entertainment electronics **Product specification** Functionality defined by choosing among options **Delivery requirement** 1-3 weeks delivery time accepted. Delivery reliability is important.	**Customer group** Buyer of less expensive entertainment electronics **Product specification** Functionality defined by selecting from configurations on the shelf. **Delivery requirement** Immediate hand-over expected.
Fortius	**Customer** Industrial customer (paper mill) **Product specification** Detailed specifications, even for single parts. Customers have company standards for interfaces. Each order is unique. **Delivery requirement** Delivery reliability is extremely important. Short order fulfillment lead-time is not critical.	**Customer** OEM customer (diesel plant builder) **Product specification** Functional specifications, standard solutions. Products are pre-defined. Configurations are re-ordered. **Delivery requirement** Short order fulfillment lead-time is extremely important. Delivery reliability is also important.

When reading Table 11 from top to down, one can conclude that the customers of Citius and Altius are mostly satisfied with choosing from options or among predefined configurations while the customers of Fortius have specific requirements for products. Secondly, case results indicate that customers with less detailed requirements are more concerned about fast deliveries. Customers who have specific requirements are willing to wait some time but are very concerned about getting the product when promised.

Why does this pattern emerge? An explanation is that customers on the right-hand side of Table 11 are purchasing the product as a stand-alone transaction while customers on the left-hand side of the table are purchasing the product for making it a part of a larger whole. For a service provider purchasing Citius' products, the physical product is just a part of a total offering where services play the main part. For a distributor, on the other hand, selling the physical product is the main business. In case Altius, the configuration of a large television depends on issues ranging from type cable network to the interior of the customer's living room. These considerations are not present when buying a pocketsize MP3-player. Finally, configurations of transformers for industrial use depend heavily on the industrial facility as a whole, while a diesel plant builder can design the plant to fit with the transformer.

Based on the discussion above, the construct *demand source* is defined. Demand source takes values ranging from *primary demand* to *derived demand*. The construct is explained as follows:

> *Primary demand* emerges when a customer is buying a product for its own sake. The customer will prefer maximum product performance but not pose very detailed specifications. The sooner the product arrives, the better. High delivery reliability is desirable but not critical.
>
> *Derived demand* emerges when a product is needed as a part of a larger whole. Product specifications are strict. Required order fulfillment lead-time depends on the execution of a larger project. High delivery reliability is extremely important because a late delivery can cause delays in larger project execution.

Primary demand expresses high-level needs, such as "impress the neighbours" (Altius' MP3 player) or "sell products in high volumes and with a decent margin" (Citius' products for distributors). Derived demand additionally includes detailed needs, such as "has satellite receiver and top-set box" (Altius' TV-set) or "supports our new XYZ service" (Citius' products for service providers).

The construct *demand source* is operationalised by three variables: detail of specifications, order fulfillment lead-time requirement and delivery reliability requirement (Table 12). The two latter terms are chosen according to SCOR reference model (SCOR, 2003: 7); alternative terms would be "delivery speed" and "delivery accuracy" or "delivery dependability", respectively.

Table 12: Operationalisation of the construct "demand source".

Variables	*Primary demand*	*Derived demand*
Detail of specifications	Low	High
Order fulfillment lead-time requirement	Fast delivery required	Depends on execution of larger project
Delivery reliability requirement	High delivery reliability is important but not critical	High delivery reliability is critical.

5.1.2 Offering portfolio

Offering portfolios of case companies were analysed with an emphasis on sources of product variety. Table 13 summarises observations from cases.

Table 13: Offering portfolios observed in cases.

Case	*High-variety products*	*Low-variety products*
Citius	**Product** Alpha products **Variable features** Functionalities (high diversity), colours, languages, settings. **Range of functionality** Pre-defined discrete options **Customisation** Pre-defined configurations. Some configurations are trade customer specific.	**Product** Beta/gamma products **Variable features** Colours, languages, settings. **Range of functionality** Pre-defined discrete options **Customisation** Pre-defined configurations. Some configurations are trade customer specific.
Altius	**Product** Large, expensive products, *e.g.* TV-set **Variable features** Size, colour, optional functionalities Geographical versions (*e.g.* voltage, manual) **Range of functionality** Pre-defined discrete options, *e.g.* 2 sizes and 6 alternative colours **Customisation** All permutations are pre-defined and available to all customers.	**Product** Small, less expensive products, *e.g.* MP3-player **Variable features** Headset included / not included. Geographical versions **Range of functionality** A few pre-defined packages. **Customisation** All permutations are pre-defined and available to all customers.
Fortius	**Product** Power transformer (engineer-to-order) **Variable features:** *E.g.* effect, load loss, short-circuit impedance (independent options) **Range of functionality** Pre-defined, *e.g.* effect = 10-70MVA. Unlimited step-size **Customisation** Customer- and order specific configurations	**Product** Power transformer (pre-defined) **Variable features:** *E.g.* effect, load loss, short-circuit impedance (bundled options) **Range of functionality** Pre-defined, *e.g.* effect = 10-70MVA. Unlimited step-size **Customisation** Pre-defined, customer-specific but not order-specific configurations

As a general observation from Table 13, all companies offer a large number of products and variants. However, the products are different from each other in different ways. A product of Citius might have 100 different sales package variants that all include the same core product. On the other hand, each transformer of Fortius represents a unique engineering effort with custom-drawn parts. To operationalise these differences, the construct *offering uniqueness* is defined. Offering uniqueness takes values ranging from *generic offering* to *unique offering* and expresses the degree to which each delivery is different from other deliveries. To arrive at an explicit operationalisation of offering uniqueness, the products in Table 13 were analysed. The aim was to identify ways in which products are equal to or different from each other. The dimensions should ideally be distinguishable both within the offering portfolio of each company and across cases. However, not all dimensions of offering uniqueness vary within each single case. For example, in case Citius, product-level variety does not vary much between product categories. The next paragraphs present the operationalisation and illustrate it with examples from cases.

Number of variable features is the first dimension of offering uniqueness. For example, a product with colour and size variety has higher offering uniqueness than a product with size variety only. In the cases, power transformer have the highest number of variable features; there are literally hundreds of parameters ranging from main functionality such as effect to details such as the colour of each part. At the other extreme, a distributor purchasing something from Citius needs to define only a few issues, typically colour and geographical version. There are also differences within cases: Altius' TV sets have a higher number of variable features than Altius' MP3 players have.

Range of functionality is a distinct dimension. For example, a product with five alternative colours has higher offering uniqueness than a product with only two colours. In case Altius, high-end, expensive products typically have a broader range of options for each variable feature than less expensive products have.

Step-size of functionality: When functionality varies within a specified range, the step-size provides another dimension of offering uniqueness. For example, today a customer can choose any size for the transformer tank. However, it would be possible to reduce the variety to discrete steps, *e.g.* small, medium and large.

Customer-specific configurations: From the supplier's perspective, there is a difference between customer-specific and generic configurations. In the cases, Fortius' transformers and some of Citius' sales package versions are (trade) customer specific. Meanwhile, any customer can order any version of Altius' products.

Order-specific configurations: Finally, if a product is defined separately for each order, it can be regarded as having higher offering uniqueness than a re-ordered product. In the case data, Fortius' engineer-to-order power transformer is the only order-specific product. For all other products, engineering is performed outside the order cycle.

In summary, the construct offering uniqueness is operationalised by five variables: number of variable features, range of functionality, step-size for functionality, customer-specific configurations [yes/no], and order specific configurations [yes/no] (Table 14).

Table 14: Operationalisation of the construct "offering uniqueness".

Variables	*Unique offering*	*Generic offering*
Number of variable features	Many	Few
Range of functionality	Broad	Narrow
Step-size for functionality	Many steps or continuous range	Few discrete steps
Customer-specific configurations	Yes	No
Order specific configurations	Yes	No

5.1.3 Operations system

Finally, operations systems of case companies were analysed. In the cases, new operations concepts were developed to meet the needs of different customers and/or different products. Operations concept is defined as a bundle of principles for how to run the operations of a company. Table 15 summarises the existing and new operations concepts in the cases.

Table 15: Operations systems observed or developed in cases.

Case	*High-variety concept*	*Low-variety concept*
Citius	**Operations concept** New flexible concept **Operational mode** Mixed modes in functional unit manufacturing. Final assembly to order. **Volumes** Low **Equipment** Very flexible equipment. Possible to use "plug-in" product-specific production technologies.	**Operations concept** Current ATO-concept **Operational mode** Make-to-stock in functional unit manufacturing. Final assembly to order. **Volumes** High **Equipment** Dedicated to beta/low products but common for all products in the categories.
Altius	**Operations concept** Current assemble-to-order concept **Operational mode** Assemble-to-order or ship-to-order from central location **Volumes** Low **Equipment** Product-dedicated equipment in assembly plant	**Operations concept** New postponement concept **Operational mode** Assemble-in-shop. **Volumes** Medium **Equipment** Product-dedicated equipment in assembly plant. Generic equipment in shop.
Fortius	**Operations concept** Engineer-to-order concept **Operational mode** Engineer and purchase to order **Volumes** Low **Equipment** Generic	**Operations concept** New concept for configurable products **Operational mode** Purchase to order **Volumes** Medium **Equipment** Dedicated to configurable products

The operations system of Fortius provides a very high level of product flexibility; Fortius can provide each customer with unique products. Citius' operations system enables mass customisation but differences between products are not very large. Although none of the case companies runs traditional "one-size-fit-all mass production", there are differences in product flexibility between the cases. The same differences are also present within cases: the operations concepts on the left-hand side of the table are more flexible than the concepts on the right-hand side of Table 15. Based on these observations, the construct *operations flow* is defined. The construct takes values from *project-oriented operations* to *process-oriented operations*. By definition, a project is a coordinated effort to produce unique output. A process, in turn, has standard inputs and outputs.

The differences in product flexibility show up as differences in location of order penetration point. In the extreme case of engineer-to-order transformer production, the high level of product customisation requires the order penetration point to be located far upstream in the supply chain, in component manufacturing. On the other hand, in Citius current ATO-concept, all customer-specific variety is added in final assembly. Thus, the order penetration point of Citius is located downstream in the supply chain, although not as far downstream as would be possible for a completely standardised product. In the cases, low product variety is also associated with high volumes and specialised equipment while the opposite goes for the high-variety concepts (Table 15). In summary, the construct *operations flow* is operationalised by three variables: operational mode, volumes and production equipment dedication (Table 16).

Table 16: Operationalisation of the construct "operations flow".

Variables	*Project-oriented operations*	*Process-oriented operations*
Operational mode	OPP is located far upstream in the supply chain	OPP is located far downstream in the supply chain
Volumes	Low	High
Production equipment dedication	Generic	Dedicated to a narrower product range

5.1.4 Measurement instrument

Constructs that have been derived via case research or from literature should ideally be verified empirically (Chen and Paulraj, 2004). This is typically done through large-sample surveys. For this purpose, a draft of an instrument was developed, although undertaking the data collection was left outside thesis scope. Table 17 presents the instrument. Three constructs are operationalised as eleven variables that in turn are measured by two items each. Most items are statements that the respondent rates on a 7-point Likert scale from "strongly disagree" to "strongly agree". The exceptions are question 17 where the respondent chooses from discrete options and in question 18 where the respondent gives a number.

Table 17: Measurement instrument for construct verification.

Construct	*Variable*	*Questions*
Demand source	Detail of specifications	1. Our customers give very detailed specifications for how to build the products 2. Our customers are usually satisfied with our standard product offering (R)[10]
	Order fulfillment lead-time requirement	3. Our customers want very their products as soon as possible after ordering. 4. Fast delivery is a key success factor in our industry
	Delivery reliability requirement	5. Delivering exactly when promised is more important than delivering with a short lead- fast 6. If we miss a delivery date, it would seriously harm the business of our customer.
Offering uniqueness	Number of variable features	7. Our products have many variable features. 8. To order one of our products, the customer must make a large number of choices.
	Range of functionality	9. Different product configurations are very different from each other (Example: very small to very large) 10. Differences between products are mainly cosmetic (R).
	Step-size for functionality	11. Functionality of our products are defined in predefined steps (Example: light-bulbs are available as 40W and 60W but not as 44W) 12. Our product configurations are defined by choosing among pre-defined options (R).
	Customer-specific configurations	13. Most of our product configurations are customer-specific. 14. Any customer can order any of our product configurations (R).
	Order specific configurations	15. A given product configuration is typically ordered only once or a few times. 16. A small number of product configurations stand for a large proportion of our volumes (R).
Operations flow	Operational mode	17. When are products allocated to specific customers (direct customers, not end users)? a) When purchasing materials b) When starting manufacturing c) In final assembly d) When shipping
	Volumes	18. Please estimate the number of product units manufactured annually.
	Production equipment dedication	19. The machines of our plant can be used for manufacturing many different products (R) 20. The machines of our plant are dedicated by product family

[10] (R) = Reversed item, *i.e.* the variable gets a high value if the respondent disagrees.

5.2 Relationships between constructs

The previous section summarised observations of 11 variables and reduced those into three constructs that capture customer needs, offering portfolio and operations system, respectively. As a summary, the constructs are plotted into the conceptual framework that was introduced in section 2.6 (Figure 31).

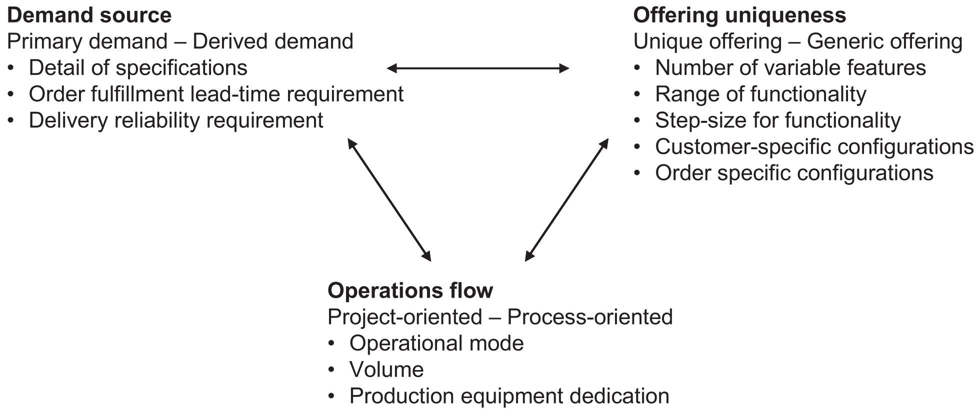

Figure 31: Summary of constructs and their operationalisation.

As an empirical generalisation, certain types of customer demand, offering portfolio and operations system tend to occur together (Table 11-Table 16). Primary demand is satisfied by delivering generic offering using process-oriented operations. High efficiency results from this setup. Derived demand, on the other hand, is satisfied by unique offerings delivered through project-type operations. The result from this system is not maximum efficiency but fit with heterogeneous customer needs. These relationships are summarised in Table 18.

Table 18: Identification of relationships between customer demand, offering portfolio and operations system.

Construct	*Low variety system*	*High-variety system*
Demand source	Primary demand	Derived demand
Offering uniqueness	Generic offering	Unique offering
Operations flow	Process-oriented operations	Project-oriented operations
Performance	High efficiency	Fit with heterogeneous needs

The next step is to express the relationships as a causal model. In management research, a practical format for such models is the technical norm, expressed as "If you want A, and you believe that you are in situation B, then you ought to do X" (Niiniluoto, 1992). The model consists of situational factors (B), means (X) and ends (A). The model developed here regards demand source as a situational factor because it is difficult for an individual company to affect. Offering uniqueness and operations flow, on the other hand, are design issues that management can affect. Finally, the ends are performance in terms of efficiency and fit with heterogeneous needs (Figure 32).

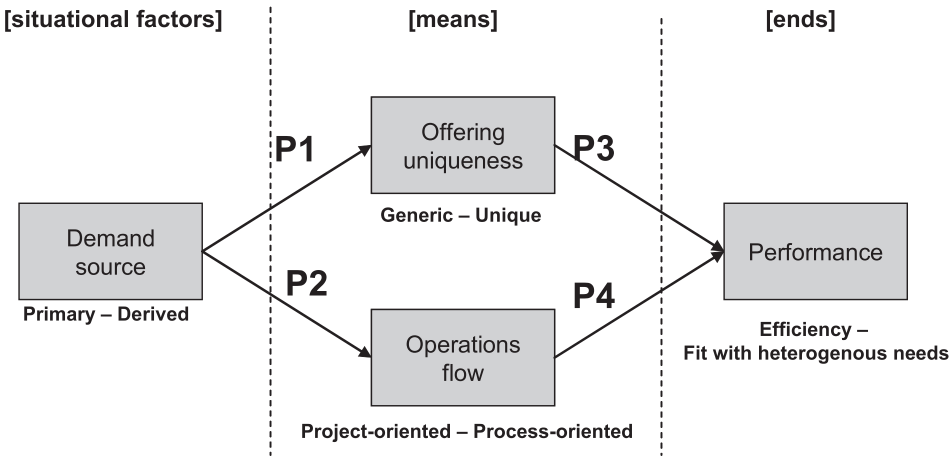

Figure 32: Causal relationships between demand source, offering uniqueness, operations flow, and their link to organisational performance.

In addition to the graphical representation, a causal model can be expressed as a set of propositions, that is, statements about causal relationships between theoretical constructs (Bacharach, 1989). These propositions will be presented and motivated by findings from the case data:

Proposition 1a: Primary demand enables generic offerings.
Proposition 1b: Derived demand requires unique offerings.

Logic: Primary demand expresses high-level needs that do not vary much between customers. For example, customers of Fortius need to transform electricity and retail customers of Citius want to sell any product with a decent margin. Such primary demand can be satisfied with a generic offering. For example, Fortius has developed a generic substation package with a standard transformer. However, if the product is needed a part of a larger whole, it is less probable that a generic offering will fit many customers. For an industrial transformer buyer, the design of the industrial facility restricts the design of the transformer. For a service provider, the services it plans to offer sets requirement for the physical product it purchased from Citius. Hence, to satisfy derived demand, unique offerings are needed.

Proposition 2a:	*Primary demand enables process-oriented operations.*
Proposition 2b:	*Derived demand requires project-oriented operations.*

Logic: Offerings and operations are highly interconnected. The more homogeneous demand, the better possibilities there are to fulfil demand using process-oriented operations. For example, those customers of Altius that do not have very special needs can be served directly from retail outlets. This in convenient for the consumer and eliminates customer-specific actions upstream in the supply chain. On the other hand, to provide unique output for each customer, every delivery needs to be handled as a project. In the extreme case of Fortius' custom-engineered transformer, delivering the product takes many months because needs of individual customers are taken into account throughout the supply chain.

Proposition 3a:	*Unique offerings enable fit with heterogeneous needs.*
Proposition 3b:	*Generic offerings do not enable fit with heterogeneous needs.*

Proposition 4a:	*Process-oriented operations have a positive impact on efficiency.*
Proposition 4b:	*Project-oriented operations have a negative impact on efficiency.*

Logic: High performance is a common end for most companies. The proposed combinations of demand source, offering uniqueness and operations flow all lead to high performance. However, the dimensions of performance are different. Unique offerings fulfil special needs of individual customers but are costly to produce. Generic offerings, on the other hand, enable efficient operations but are not able to serve customers with special needs. For example, in case Fortius, possibilities to standardise transformers were investigated. It was concluded that a more standardised transformer would enable efficient operations but would not fit the needs of all current customers. Citius, on the other hand, is broadening its product range in order to reach customers with special needs, but with some expense in efficiency. The proposition that process-oriented operations with low variety of inputs and outputs, fast throughput and high volumes are efficient has strong support in literature (Holmström, 1995; Hopp and Spearman, 1996; Schmenner and Swink, 1998; Schmenner, 2001; Schmenner, 2004)

Finally, in order to emphasise the need for balancing between two ends, the four propositions are illustrated as a nomological network with two branches (Figure 33). According to the upper branch, unique offerings will give competitive advantage due to a good match with heterogeneous customer needs. According to the lower branch, process-oriented operations will give high efficiency. Consequently, the branches are in contradiction with each other: a company needs to balance between serving individual customers with unique offerings and maintaining high productivity through process-type operations. Understanding demand source is a key to determining which branch to emphasise when designing offerings and operations systems.

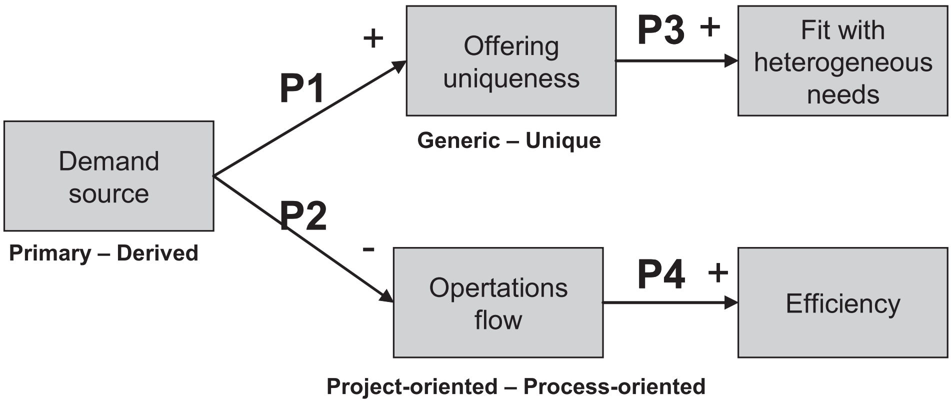

Figure 33: Causal relationships between demand source, offering uniqueness, operations flow, and their link to organisational performance.

The model presented in Figure 33 is descriptive. It can be used for explaining differences between different industries. However, the model also formalises a trade-off that, according to observations in case companies, is of strategic importance. Citius wants to increase fit with heterogeneous needs without compromising on efficiency. Altius wants to provide each customer group with the service that they desire and design the operations system accordingly. Finally, Fortius wants to become more efficient without compromising on fit with heterogeneous customer needs. The next section will provide some tactics for managing this trade-off.

5.3 Managing a broad offering portfolio

The second research question *"How can a company manage trade-offs between a broad offering portfolio and high operational efficiency?"* is answered based on observations from three case studies.

5.3.1 Pre-defined configurations

Pre-defined configurations are expected to decrease order fulfillment lead-time. In case Fortius, delivery times for pre-defined configurations were compared with delivery time for engineer-to-order configurations. The differences in delivery times were approximately equal to engineering time for engineer-to-order deliveries (Figure 28 and Figure 29). The result supports the assumption about a relationship between offering portfolio, operations system and performance. In the case, changing only the product did not affect performance much. To improve performance radically, a corresponding change in operations system is needed.

5.3.2 Configurability

Configurable products are assembled from pre-defined parts rather than custom-designed parts (Salvador and Forza, 2004). Limiting the offering portfolio to configurable products reduces the need for order-bound engineering, shortens order fulfillment lead-time and makes it easier for sales personnel to sell products without involving engineering personnel (Salvador and Forza, 2004).

Product configurability was studied in case Fortius. Results indicate that product configurability can bring the following benefits in an engineer-to-order environment:

1) Reduced engineering time, as it is possible to introduce clear design rules and appropriate software tools.
2) Reduced sourcing time, as suppliers do not need to engineer and purchase material separately for each order.
3) Reduced assembly time via investments in production automation.

Figure 34 shows the expected benefits from product configurability as a soft system model.

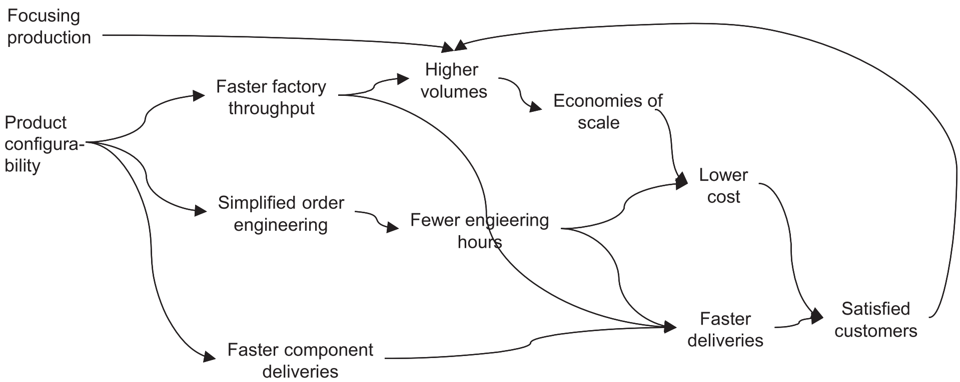

Figure 34: Benefits of product configurability in an engineer-to-order environment.

Results from case Fortius indicate three use criteria for product configurability.

1) Product specifications from customers are not too detailed.

2) Volumes are high enough to justify the development of a configurable product architecture and the investments in production automation.

3) Sales personnel succeeds in convincing customers that a configurable product will serve their needs as well as a custom-engineered product. This is easier if the configurable product is cheaper and can be delivered faster than the custom-engineered product.

Case results also indicate that demand for very special products cannot be served by a configurable solution. Furthermore, customers that asked for uniqueness know their need well in advance – fast deliveries do not provide competitive advantage in this market segment. Consequently, in case Fortius thre is a market opportunity also for products that are not configurable.

5.3.3 Form postponement

According to literature, form postponement provides an excellent way to reduce risk and inventories while still providing high product variety and acceptable response times (Hoek, 2001). Form postponement was studied via discrete-event simulation in case Altius. The following variables were observed or measured: order penetration point, degree of postponement, delivery time and inventories (Table 19).

Table 19: Summary of results from case Altius.

Delivery concept	*Order penetration point*	*Form postponement*	*Delivery time*	*Inventories (value)*
Full postponement	Central location	No	1-3 weeks	0
Logistical postponement	Central location	Yes	1-3 weeks	0.1
Form postponement	Shop	Yes	-	0.7
Full speculation	Shop	No	-	1.9

Table 19 illustrates the well-known trade-off between low inventories and fast deliveries. It is possible to provide fast deliveries by keeping high inventories, or to save inventories by increasing delivery time. The table also shows that form postponement provides a way to manage this trade-off. Through form postponement, it is possible to reduce delivery time without investing in too much inventories.

In addition to these basic relationships, however, case results indicate a number of use criteria for form postponement.

1) Form postponement is useful when customers require a delivery time that is too short to enable ship-to-order from a central location. Otherwise, it is more efficient to ship products to order from a central location.

2) Product value must be high enough to justify additional efforts in retail outlets. Otherwise, it is more efficient to keep readily assembled and packed products on shelf.

3) Product variety should be medium. If products are very different from each other, it is not feasible to keep parts for all products in the shelf. In case of no variety, there is nothing to postpone.

4) Finally, in case Altius, postponement turned out to be most effective in shops with low sales. In a small shop, already a cycle stock of "one of each colour on the shelf" is high compared to daily sales. A large shop will need to stock at least one of each colour anyhow.

5.3.4 Focused versus generic resources

Unlike for the other ways of managing the trade-off between high product variety and high operational efficiency, the literature study did not give a clear candidate for how to organise manufacturing. On the one hand, by dividing manufacturing into focus units it is possible to acquire equipment and practices that best fit the needs of each product group (Skinner, 1974; Hayes and Wheelwright, 1984; Bozarth and Chapman, 1996; Sheu and Laughlin, 1996; Bozarth and McDermott, 1998). On the other hand, generic equipment and practices are expected to reduce cost by spreading fixed costs over a larger number of products and reduce risk by not depending on a few products or customers (Schlie and Goldhar, 1995; Bhattacharya *et al.*, 1996; Bozarth and Edwards, 1997; Mukherjee *et al.*, 2000).

In case Citius, it was concluded that a separate manufacturing concept is needed for complex products. The project ended up in a list of new competences that are needed for effective handling of these products in manufacturing. It was also suggested that a separate manufacturing concept is not needed for the simple gamma products. Based on case material, it is possible to identify factors that one should consider when choosing between many focused concepts and one or a few generic concepts:

1) Separate resources are feasible when products are very different from each other. In particular, it is challenging to make complex products on manufacturing lines that are designed for products with lower complexity.

2) Generic resources are feasible when demand variability is high. Generic resources make it possible to switch product between factories and change degree of outsourcing depending on demand level.

3) Finally, generic resources are feasible when industry clockspeed is high. The strength of Citius has been to design products to fit with existing lines, rather than designing a new line for each product. The higher clockspeed, the more important re-use of resources becomes.

Case Fortius provides theoretical replication (Yin, 1989). Currently, all transformers of Fortius are assembled using the same generic equipment. However, dedicating some factories to configurable products is expected to increase total efficiency. Investing in dedicated equipment is not as risky in low-clockspeed transformer industry, where customer needs are not expected to change much during the next ten years.

6 DISCUSSION

The purpose of this last chapter is to establish the link between previous theory and findings of the research reported in this thesis. In the chapter, the following vocabulary will be used to distinguish between different degrees of novelty and empirical grounding (Perry, 2002).

> *Theory advances* are conclusions that arise directly from research results and support previous research. Cumulative research is important, because successful replication of previous findings provides greater insights and can add depth to understanding (Frohlich and Dixon, 2003).
>
> *Theory contributions* are conclusions that arise directly from research results and add something new to previous research. Such contributions can either be in contrast with previous research or add a new aspect that has not been considered before in mainstream literature.
>
> *Implications* arise from conclusions rather than research results. Implications bring the conclusions out of the research setting and into a larger perspective.

Theoretical contributions are first presented (section 6.1), followed by implications for practice in general (section 6.2.1-6.2.3) and for the case companies (section 6.2.4). The final sections discuss limitations of the research (section 6.3) and suggestions for further research (section 6.4).

6.1 Theoretical contributions

The question about how to design the best supply chain for delivering a product with given attributes has gained considerable attention in the last ten years, resulting in many articles in academic journals (Fisher, 1997; Fine, 2000; Lamming *et al.*, 2000; Childerhouse *et al.*, 2002; Lee, 2002; Salvador *et al.*, 2002; Olhager, 2003). In addition, many doctoral theses about the topic have been written in Nordic countries (Lehtonen, 1999; Arlbjørn, 2000; Heikkilä, 2000; Kaski, 2002; Collin, 2003; Persson, 2003; Gubi, 2004). Actually, there are two separate streams of literature that attempt to answer the underlying question. The market perspective takes market characteristics and the value proposition of a product as a starting point while the engineering perspective starts from the product architecture (Gubi, 2004). Based on this observation, two separate research questions were formulated for this thesis. In this section, theory advances and contributions within each perspective will be pinpointed, along with implications for more general theories about co-managing customer demand, offerings and operations.

6.1.1 Market perspective

Research within the market perspective strives to identify important product- and market-related issues and relationships among them. Previous research has focused on the question about how to choose between a responsive/agile and a cost efficient/lean supply chain strategy. Research has brought a large number of issues to keep in mind when making this important decision. Management research should address issues that have practical utility and help managers in managing better (Skinner, 2004). Considering the large number of issues that have already been identified, a new study should ideally end up in fewer, not more, issues for a manager to consider. Secondly, an explicit definition of relationships is more valuable than a mere lists of constructs (Sutton and Staw, 1995). Relationships among constructs were found to be unclear in existing literature. With these considerations in mind, the following research question was formulated:

Question 1: *What are the relationships between offering portfolio, operations system design and operational performance?*

To support systematic data collection, a conceptual framework was created (Figure 8, page 27). The conceptual framework contains three 'a priori' constructs: customer needs, offering portfolio and operations system. The framework makes a conceptual contribution by developing the original framework of Fine (1998). In the new framework, customer needs are explicitly included. In-house operations (process) and operations performed by network partners (supply chain) are considered as one operations system. As such, an updated framework is not a significant contribution to theory, but it can help in theory building by bringing new insights for collection and interpretation of empirical data.

Based on case studies, final constructs were identified and operationalised. Unlike the 'a priori' constructs, the final constructs are measurable. For example, one can say that Fortius provides higher "offering uniqueness" than Citius does, which is not possible using the 'a priori' construct "offering portfolio". The answer to research question 1 is that primary demand enables generic offerings and process-oriented operations. Derived demand, on the other hand, requires unique offerings and project-oriented operations. Unique offerings are able of fulfilling heterogeneous customer needs while process-oriented operations are positively related with efficiency. Table 20 summarises 'a priori' constructs, final constructs and their operationalisation.

Table 20: Summary of constructs and their operationalisation.

'A priori' construct	*Final construct*	*Operationalisation*
Customer needs	Demand source	• Detail of specifications • Order fulfillment lead-time requirement • Delivery reliability requirement
Offering portfolio	Offering uniqueness	• Number of variable features • Range of functionality • Step-size for functionality • Customer-specific configurations • Order specific configurations
Operations system	Operations flow	• Operational mode • Volume • Production equipment dedication
Performance	Fit with heterogeneous needs	• Not operationalised in this thesis
	Efficiency	• Not operationalised in this thesis

The model (Figure 33) provides four theory advances by supporting the following previous findings (section 2.4):

1) Order fulfillment lead-time requirement of customers is an important issue affecting operations system design, especially choice of operational mode (Childerhouse *et al.*, 2002; Heikkilä, 2002; Olhager, 2003).

2) There is positive relationship between production volumes and a downstream order penetration point (Childerhouse *et al.*, 2002). The model also supports the statement about a relationship between "process volume" and "operations process dynamics" (Harland *et al.*, 2001).

3) There is a positive relationship between high product variety and need for flexible, project-oriented operations. However, process-oriented operations result in higher efficiency. Process-oriented operations are preferable as long as they are able of fulfilling customer needs (Schmenner and Swink, 1998; Fisher and Ittner, 1999; Harland *et al.*, 2001; Schmenner, 2001; Childerhouse *et al.*, 2002; Lee, 2002; Ramdas, 2003)

4) There is a positive relationship between industry clockspeed (rate of change and demand uncertainty) and flexibility focus rather than cost focus (Fisher, 1997; Lee, 2002; Collin, 2003).

Due to the chosen research design, the study does not bring any conclusions about product complexity and product uniqueness that were taken as control variables in cases selection; and buyer-supplier relationships that were not observed.

The model brings the following four contributions to theory:

1) Variables are chunked together into three constructs: demand source, offering uniqueness and operations flow. Each of the constructs are operationalised and empirically measurable, which is a sign of a good theory (Bacharach, 1989).

2) Causal relationships between constructs are defined. Specifically, he model formalises one way of taking customer needs as a starting point, something that recent research in demand chain management strongly recommends (Vollmann *et al.*, 2000; Hoover *et al.*, 2001; Heikkilä, 2002; Lee, 2002; Collin, 2003)

3) Product variety is thoroughly operationalised as offering uniqueness. Many previous contributions within operations management literature have suffered from loose definitions of product variety or implicit assumptions that arise from studying only one type of products (Ramdas, 2003).

4) Performance is defined in two dimensions: fit with heterogeneous needs and efficiency. The dimensions resemble Porter's (1980) classical differentiation/low cost classification, that is also distinguishable in Fisher's (1997) responsive/efficient and Towill and Christopher's (2003) lean/agile. However, the fit/efficiency classification is based on customer needs rather than business strategy (Porter, 1980) or industry characteristics (Fisher, 1997; Towill and Christopher, 2003).

6.1.2 Co-managing offering and supply chain

Demand chain management is a strategic-level, customer-focused way of building the supply chain to meet customer needs for products and services (Vollmann *et al.*, 2000). A basic requirement for successful demand chain management is to listen carefully to customers and act accordingly (Christopher, 1998). The model developed in this thesis (Figure 35) takes customer need as a starting point. Customer needs are operationalised as detail of specifications, order fulfillment lead-time requirement and delivery reliability requirement. *Demand source* was selected as a summarising label for the construct. The outcome of the model is fit with heterogeneous needs and efficiency. Both outcomes are elements of good customer service, that is, "significant value-adding benefits to the supply chain in a cost-efficient way" (Bowersox and Closs, 1996: 66).

Value offering point literature suggests that it is beneficial for a supplier to join the decision making process of a customer early. For example, a food supplier can benefit from joining the assortment planning of a retailer (Hoover *et al.*, 2001) and a telecom equipment supplier can benefit from joining the network planning of an operator (Collin, 2003). This thesis provides an explanation why early involvement is beneficial: joining early has the effect of getting closer to primary demand. Removing factors that the supplier cannot affect makes it possible to design process-type operations that are efficient but still able of fulfilling customer needs.

Fisher (1997) stated that the priorities in supply chain management should be different depending on industry characteristics, which inspired much research around the millennium shift (Lehtonen, 1999; Arlbjørn, 2000; Childerhouse and Towill, 2000; Heikkilä, 2000; Lamming *et al.*, 2000). A common approach was to compare operations of companies in different industries. A common conclusion was that operations are different, especially if industry clockspeed is different. The research reported in this thesis has taken a slightly dissimilar approach by working on a common problem in different environments. Results indicate that challenges and solutions are rather similar regardless of the industry. All companies need to balance between serving individual customers with tailored offerings and achieving maximum efficiency. However, technical solutions are different depending on industry-specific issues such as production volumes.

Previous studies have studied the fit between offerings and operations. Marshal Fisher (1997) asks "What is the right supply chain for your product?" Based on this research, one could ask: "What is the right offering/operations portfolio for fulfilling the needs of your customer?" Studying individual products is not enough. As Salvador *et al.* (2002) suggest, it is beneficial to study many product families rather than individual products. This thesis suggests that one should not look for individual solutions for each product, especially not in high-clockspeed industries. Even when one solution does not fit all products, two or three solutions are usually enough. A limited amount of solutions gives economies of scale and better volume flexibility than a large amount of product-specific solutions.

6.1.3 Engineering perspective

Research within the engineering perspective takes a proactive approach in looking for ways to design better products and better operations systems. The thesis started with a pre-understanding that the trade-off between product diversity and operational efficiency constitutes an important business challenge today. The following research question was formulated:

Question 2: How can a company manage trade-offs between a broad offering portfolio and high operational efficiency?

Based on the literature study, it was recognised that variety could be handled by affecting the offering, the offering/operations interface or the operations system. Specific tactics are limitation of external variety, customisation, design for supply chain, form postponement, focused manufacturing, and flexible manufacturing. The tactics were mapped into the newly created conceptual framework (Figure 9, page 33). The figure suggests that the two research questions could be answered using the same data.

In the three cases, different tactics for managing trade-offs between a broad offering portfolio and high operational efficiency were evaluated, depending on the business situation of each case company. The final tactics are concrete and measurable, unlike the initial candidates. For example, "pre-defined configurations" is a concrete way of "limiting external variety". The answer to research question 2 is that pre-defined configurations, product configurability, form postponement and generic resources are good tactics for managing the trade-off between a broad offering portfolio and high operational efficiency. Effect and use criteria were evaluated in the cases. Table 21 summarises tactics, effects and use criteria.

Table 21: Summary of tactics for managing negative effects of a broad offering portfolio.

Tactic	*Effect*	*Use criteria*
Pre-defined configurations	• Reduced engineering time • Efficiency in manufacturing	• Configurations needed more than once • Corresponding changes made in sourcing and manufacturing
Product configurability	• Reduced engineering time • Faster sourcing • Faster manufacturing throughput	• High-enough demand volume • Customer needs that are not too specific • Need to convince customers that a configurable product fulfils their needs
Form post-ponement	• Fast delivery with less inventory than other-wise	• Fast delivery required by customers • High product value • Medium product variety • Low sales volumes per shop
Generic resources	• Volume flexibility • Risk reduction	• Not too large differences between products • High demand variability • High industry clockspeed

The use criteria can also be used for determining when to use the opposite tactics: order-specific configurations, products made from custom-designed parts, full speculation/full postponement, and focused resources. For example, focused resources are expected to be appropriate when there are large differences between products, demand variability is low and industry clockspeed is low. In such situations, cost efficiency is more important than volume flexibility and risk reduction.

The research provides theory advances by supporting the following previous findings (section 2.4):

1) Customisation is needed for meeting heterogeneous customer needs. Degree of customisation influences operations system design and thereby efficiency (Lampel and Mintzberg, 1996; Safizadeh *et al.*, 2000; Ramdas, 2003; Salvador and Forza, 2004; Sievänen, 2004).

2) Product configurability reduces engineering time, manufacturing throughput time and sourcing time but restricts ability to meet customer needs that are very special (Salvador and Forza, 2004).

3) Case Altius provided a piece of evidence supporting form postponement as a good tactic for providing customers with product variety at a moderate cost (Christopher, 1998; van Hoek, 2001; Forza *et al.*, 2004).

4) Generic flexible resources can reduce cost by spreading fixed costs over a larger number of products and reduce risk by not depending on a few products or customers (Schlie and Goldhar, 1995; Bhattacharya *et al.*, 1996; Bozarth and Edwards, 1997; Mukherjee *et al.*, 2000).

No specific conclusions were drawn about option bundling, product modularity or product development process. This is because setting a strict research agenda is not possible within the collaborative approach. If a given tactic does not seem to bring benefits in a given business case, it is not possible to study it.

The research brings the following theory contributions:

1) Use criteria for form postponement in a distribution and retail environment were identified.

2) Industry clockspeed is suggested to affect the choice between focused, specialised operations and generic, flexible operations in manufacturing.

One can notice that the list of contributions is shorter within the engineering perspective than within the market perspective. This was expected, as research within the engineering perspective has already proceeded to the theory testing phase, which is indicated by many calls for theory testing rather than explorative research (Mukherjee *et al.*, 2000; van Hoek, 2001; Ramdas, 2003; Pil and Holweg, 2004; Salvador and Forza, 2004).

6.1.4 Managing product variety

In existing literature, there have not been too many contributions about product design for supply chain that are based on real business cases (Appelqvist *et al.*, 2004). The simulation study at Altius responds to several calls for empirical research about postponement (van Hoek, 2001; Ramdas, 2003; Forza *et al.*, 2004). In the case, postponement was found to be beneficial, but only under certain conditions. This provides one explanation why form postponement has not reached the popularity that Christopher (1998) predicted. The use criteria are rather strict: customers require fast delivery, product value is high, product variety is medium and sales volume per shop are low. If one of these use criteria does not apply in a given case, other distribution concepts are better.

In addition, case Altius provides a logic for deciding about product architectures. According to Olhager (2003), a modular product architecture is associated to assemble-to-order product delivery. The order or reasoning can also be reversed by taking customer expectations as a starting point: If customers require direct handover, shop inventory is needed. This inventory can be reduced through a combination of modular product architecture and manufacturing postponement.

Manufacturing focus is another way of reducing negative impact of product variety on operations. The concept of focused factory prescribes that factories should ideally focus on one or two strategic targets at a time (Skinner, 1974). This is typically achieved by assigning a narrow product mix to each factory (Bozarth, 1993). In conceptual operations strategy literature, focused factory is generally considered as a best practice, while in real world many factories and supply chains are not focused (Ketokivi and Jokinen, 2003). In the high-clockspeed case Citius, it was concluded that gamma and beta products are different, but they should still be made using generic capacity. The conclusion was that high industry clockspeed and demand uncertainty are reasons to avoid product-based focusing. The conclusion has three alternative implications. One possibility is that focus is not a good idea in all environments, as Bozarth and Chapman (1996) suggest. Alternatively, focus is always a good idea but should not necessarily be interpreted as dividing products among factories. According to Skinner (1996a: 11), focus is a broad concept, "a state of mind". For example, one could say that a factory focuses on mix flexibility. A third possibility is that the plant-level concept "focused factory" cannot directly be applied in a multi-plant setting.

The conclusion that generic resources are to prefer in a dynamic environment gets support from another discipline of management research: organisational ecology (Hannan and Freeman, 1977). Organisational ecology theory states that specialists tend to outperform generalists in stable environments, while the opposite is true in dynamic environments.

6.1.5 Three-dimensional concurrent engineering

The thesis started from the observation that product variety has emerged as a source of competitive advantage as companies are responding to requests for increasingly customised products and services (Hayes *et al.*, 2005; examples in section 1.1). Meanwhile, coping with high variety within one operations system without compromising on efficiency is challenging. The research problem was defined as follows:

> *Can a company produce and deliver a high variety of products while maintaining high operational efficiency?*

The simple answer is *yes*. However, case studies indicate that it is not easy; the problem is relevant even for the best companies of today. Flexible technology and advanced information systems have not made the trade-off between product variety and efficiency obsolete, as some researchers believed in the mid 1990s (Schlie and Goldhar, 1995; Dermott *et al.*, 1997). Mass customisation is rapidly replacing mass manufacturing (Silviera *et al.*, 2001) but is able of providing customers with only a limited degree of choice.

The research reported in this thesis has resulted in definition of five constructs, four relationships and an evaluation of four tactics (Figure 35). The model formalises the trade-off between serving each customer individually and achieving maximum efficiency. The model provides a tool for the "balanced" emphasis on products, processes and supply chain design that Fine (1998) recommends.

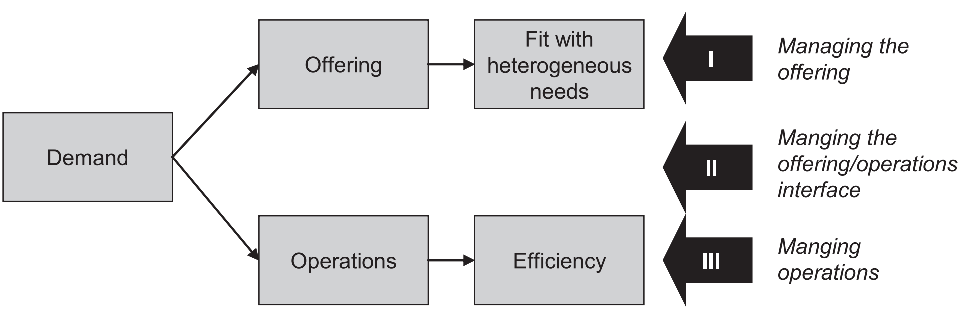

Figure 35: Unifying model for solving the research problem.

6.2 Implications for practice

Any company wants to serve its customer better, run its operations more efficiently and generate higher profits. Unfortunately, some of these aims are traditionally considered as contradictory. The model developed in this thesis suggests two directions for performance improvement: one of generic offerings and process-oriented operations and another of unique offerings supported by project-oriented operations. In both cases, the trade-off between high variety and high efficiency should be managed pro-actively. This section will outline strategies for performance improvement. In addition, practical implications for the case companies will be summarised.

6.2.1 Generic offering strategy

A global trend in service business is that successful high-growth companies tend to offer less customisation and faster response than other companies do (Schmenner, 2004). For example, fast-food chains tend to grow more quickly and get larger market shares than gourmet restaurant chains. Historically, the most successful companies have created new offerings that provide superior value to a large number of customers and, simultaneously, reduce cost of operations (Kim and Mauborgne, 2004). As a growth strategy, generic offerings and efficient operations appear to be better than maximised offering uniqueness.

How can a company implement a generic offering strategy? Business is always about fulfilling customer demand. This thesis suggests that there are two sources of demand: primary demand and derived demand. Primary demand emerges when a customer is buying a product for its own sake. The customer will prefer maximum product performance but not pose very detailed specifications. Targeting primary rather than derived demand appears as a key contributor to the success in a generic offering strategy. This can be done in many ways:

1) *Early involvement*: To promote a generic offering, the supplier should try to get involved as early as possible in the decision making process of the customer.

2) *Total offering* is a related strategy. Today, manufacturers are increasingly providing their customers with complete systems and service packages rather than single pieces of equipment (Mathieu, 2001; Oliva and Kallenberg, 2003). If successfully implemented, the result will be higher value for the customer and more efficient operations for the supplier.

3) *Going downstream* in the supply chain has the same effect: larger markets and fewer constraints (Wise and Baumgartner, 1999). For example, the

mapping of the supply network for power transformers (Figure 27) showed that each transformer assembler has established their own consulting company for promoting their transformer designs.

4) *Standardisation* also provides a way of reducing heterogeneity of customer needs. An industry standard improves possibilities to provide a generic offering to many customers.

In summary, a generic offering strategy is not equal to a customer-ignorant mass manufacturing strategy. On the opposite, in many cases it is possible to provide more value at lower price. However, this requires good knowledge of true customer needs.

6.2.2 Unique offering strategy

Not all companies have the skills or opportunities to create generic offerings that provide customers with superior value at a cost below competition. Most companies are more or less dependent on demand characteristics that they cannot affect, which requires a certain degree of product variety and customisation as part of the offering. The research in this thesis has evaluated some tactics for providing variety but minimising its negative impact on operations. The following tactics are available:

1) *Manage the offering:* Unlimited variety does not fit with industrial-scale operations (Hayes and Wheelwright, 1979). Depending on customer needs, it is possible to have only a limited number of variable features, limit the range of variety, or defined discrete steps for variety. On the other hand, if one dimension of variety brings competitive advantage, variety can be increased on that dimension.

2) *Manage the offering/operations interface:* Ideally, high product variety should be supported by a low-variety process. Design for supply chain methods are available for accomplishing this (Kaski, 2002).

3) *Manage operations:* Once a given range of mix flexibility is designed into manufacturing, variety that falls within the range is not a problem (Safizadeh *et al.*, 2000). Advanced production technology contributes to widening the range of variety that can easily be manufactured (Dermott *et al.*, 1997). Even if products are rather different from each other, they can still be manufactured using the same resources, if resources are flexible enough.

6.2.3 Mixed strategy

Pure generic offering strategies and unique offering strategies are not expected to be very common among companies. Rather, a company has many alternatives for positioning its offering along a continuous range from generic offering to unique offering. The research did not indicate that a "stuck in the middle" strategy would be any worse than a strategy closer to one of the extremes.

Furthermore, it is possible for a company to implement several operations concepts. For example, Fortius is planning to have one operations concept for configurable transformers and another for engineer-to-order transformers. This is in accordance with recent research on "focused supply chain": as one size does not fit all, products with different characteristics need different operations concepts (Childerhouse *et al.*, 2002; Gubi, 2004). A high-variety customisation concept makes it is possible to meet demand for all products, but prices and delivery times will not be competitive among customers who need standard products. An efficiency-oriented concept, on the other hand, will support customers with generic needs but not customers with special needs. However, with two or three concepts in one company, it is possible to serve both groups of customers.

The fact that different concepts would be optimal for different products does not necessarily mean that all concepts should be implemented. The thesis suggests industry clockspeed as a variable influencing the decision about how many concepts to implement. If industry clockspeed is low, focused concepts and dedicated resources are more appropriate than if industry clockspeed is high.

6.2.4 Implications for case companies

In all three cases, the researcher had the opportunity to work together with successful, globally operating companies. The case projects had impact on the demand-supply chain strategies of these companies. This section summarises lessons learned for the companies.

In case Citius, the starting point was the observation that products were getting more and more different from each other, and a feeling that manufacturing should respond in some way. In the case, product characteristics were collected via interviews and via quantitative data analysis. Product characteristics were compared with current capabilities in manufacturing. Contrary to expectations, the existing manufacturing concept was found to be flexible enough to accommodate most of the products. A new concept will not be needed for gamma products, which saves considerable investments in fixed assets.

In case Altius, the company had an official policy of assemble-to-order for all products. Meanwhile, management was concerned that contrary to the official policy, products were being stocked in retails outlets. The case study shoved that for less expensive products, a small shop inventory should be allowed. In addition, efficient shop operations could be supported by a combination of modular product structure and a form postponement concept. The case company implemented the new delivery concept. The company will also take the new concept into account in future product development.

In case Fortius, company management was planning for a considerable re-organisation of the manufacturing network, along with product standardisation. Supplier visits showed that suppliers had slow operations but were well adapted to one-of-a-kind production. Customer visits, on the other hand, indicated that customers with special needs were not very concerned about short order fulfillment lead-time. In summary, by standardising the products, Fortius would probably win customers that are concerned about speed, but at the same time, lose customers that need individual solutions. In the end, the focusing strategy was changed: the case plant will not focus on small products; it will focus on products for very special needs that require extensive engineering efforts.

In summary, the business driver for undertaking a case project was different in the three cases; Citius was introducing a large amount of new products, Altius was developing downstream distribution and Fortius was restructuring manufacturing. However, by approaching the three business situations via Fine's (1998) product, process, and supply chain framework, it was possible to develop a model that applies to all three situations. Instead of a general "everything affects everything", the model provides managers with a structured way of thinking about the complex issues involved in design of offering portfolios and operations systems. The starting point is customer demand. Altius implemented this approach in a formal way in their product creation process. In the beginning of this process, a product concept document is written. This document has been extended with a section about logistical requirements of the targeted customers. Also Citius has been re-thinking their operations strategy of one operation concept for all products, as the product portfolio is extended to a larger range of different needs.

6.3 Limitations

The research material for this thesis includes about 100 interviews in three industries and six European countries, notes from 14 plant visit and a large amount of data from ERP systems. In data collection, recommended practices have been followed, as described in sections 3.4 and 3.5. The data has been interpreted and used for creating a general model for matching customer demand, offering portfolio and operations system. Are the conclusions true? This section discusses the strengths and weaknesses of the research.

Research should ideally conform to three scientific ideals: accuracy to describe a specific system (relevance), applicability to other systems (generalisability) and simplicity (parsimonity) of the resulting theory (Weick, 1979: 35-42). However, as the ideals are conflicting, one needs to choose one or two ideals at a time

(McGrath, 1982). In this thesis, the selected research strategy was inductive case research. Case research is best suited for theory building, even though it can also be used for theory testing (Eisenhardt, 1989; Stuart *et al.*, 2002; Voss *et al.*, 2002). The benefit of case research is deep understanding of specific systems. A special version of case research, the collaborative approach, was expected to enhance relevance of the research (Hill *et al.*, 1999). However, the approach is work intensive, which limits the feasible number of cases. Control of research settings is limited: keeping a strict research agenda is not possible. Consequently, the three cases in the theses are not replications of each other; they only have a common theme. All this restricts generalisability. The model generated in the thesis represents an interpretation of data collected in three companies in technology-intensive industries. The model is offered to the academic community for testing with other data.

In case Citius, most of the data was qualitative. Based on the data it was possible to identify a number issues that affect each other, but quantifying the effects was not possible. Case Altius, on the other hand, included detailed quantitative analysis and resulted in quantitative estimates of the benefit of form postponement. However, only one product was simulated – generalisability to other settings remains to be evaluated.

All cases ended up in a recommendation that was well received by management and at least partly implemented. Hence, the weak market test has been passed for case conclusions. Proving strong market test is difficult. Even though the companies would perform well in coming years, it will not be possible to tell whether the success is due to case recommendations. The model in chapter 5, however, was developed after finishing the cases. Thus, the model has not passed any market test. Publishing the model will make it possible for the academic community to evaluate it.

6.4 Further research

Theory that has been created using case research can be novel and interesting. The main weakness of case research strategy is that theory is created after data collection. In principle, only good imagination is required for creating a theory that explains observations (Giere, 1997). Eisenhardt (1989) addresses this problem by adding more cases until theory saturation is reached, that is, new cases do not bring anything new to the theory anymore. In this thesis, however, the scope of each case was so large and the number of cases so small that theory saturation was not reached. Consequently, the created theory is grounded in empirical observations, but it is not possible to tell how much the theory would change by incorporating even more observations. A possible next step in theory advancement would be to carry out a series of confirmative case studies. Another possibility is to test current constructs and relationships among in a large-sample survey, using the instrument drafted in section 5.1.4. This would help in distinguishing general relationships from co-incidences in the case sample.

The theoretical domain of this research was delimited to operations management. However, in the research, demand source was found to be of fundamental importance. Greater theoretical insights could be achieved by interpreting the collected data through the eyeglasses of marketing management, including industrial marketing, customer relationship management, brand management and assortment planning. Another possibility is to look deeper into the engineering perspective. While the research tells something about desirable product architectures, it does not address the question of how to achieve these architectures in the product development process. Finally, the research indicated relationships between manufacturing focus, demand variability and clockspeed. Operations research modelling could be a promising approach for further research on this topic.

Finally, understanding the world better is important but not enough. The next step is to make the world better. We now know a little bit more about how decisions in product design, process design, and supply chain design should be coordinated to maximize operational and supply chain performance. The next challenge is to apply this new knowledge in industrial settings.

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