HENDRIK BRUMME

Manufacturing Capability Switching in the High-Tech Electronics Technology Life Cycle

Manufacturing Capability Switching in the High-Tech Electronics Technology Life Cycle

Manufacturing Capability Switching in the High-Tech Electronics Technology Life Cycle

Het aanpassen van de vaardigheden van productiebedrijven tijdens de technologie levens cyclus van de high-tech electronica industrie

Proefschrift

ter verkrijging van de graad van doctor
aan de Erasmus Universiteit Rotterdam
op gezag van de rector magnificus
Prof.dr. S.W.J. Lamberts
en volgens besluit van het College voor Promoties.

De openbare verdediging zal plaatsvinden op
donderdag 3 april 2007 om 13.30 uur

door

Wolf-Hendrik Brumme
geboren te Sindelfingen, Duitsland

ERASMUS UNIVERSITEIT ROTTERDAM

Promotoren
Prof.dr.ir. J.A.E.E. van Nunen
Prof.dr.ir. L.N. Van Wassenhove

Overige leden:
Prof.dr. S.L. van de Velde
Prof.dr.ir. E. van Heck
Dr. M. Fleischmann

Erasmus Research Institute of Management (ERIM)
RSM Erasmus University / Erasmus School of Economics
Erasmus University Rotterdam

Internet: http://www.erim.eur.nl

ERIM Electronic Series Portal: http://hdl.handle.net/1765/1

ERIM Ph.D. Series Research in Management 126

ISBN 978-90-5892-150

Voor Heike, Lina, Piet

ACKNOWLEDGEMENTS

I dedicate this thesis to Heike, Lina and Piet. Their patience, understanding and support kept me going. I hope we can make up for the time I needed for this work. This research was inspired by Tom Viola, the worldwide Workstation Systems manufacturing manager at HP. The way he thinks and makes decisions has always impressed me and had a great impact on my own management style. I was offered the opportunity to write this thesis by Professor Jo van Nunen of the Erasmus University Rotterdam, the head of the Department of Decision and Information Management, as well as by Luk van Wassenhove, the Henry Ford Chaired Professor of Manufacturing at INSEAD. I derived great pleasure from conducting this research project and gained a lot of experience regarding academic thinking and working. Their very constructive and pleasant way of supervising always generated new insights and new impulses for the next step in the research process. The mix of scientific experience, genuine interest and pragmatism greatly helped me to carry out the research activities. I would particularly like to mention the many years of patience and encouragement I was shown by Luk, which always kept me going. I believe the greatest challenge for them was to help me switch from a managerial to a scientific way of thinking. I am truly indebted to more people who helped me to carry out the research: I want to thank Professors Eric van Heck, Moritz Fleischmann, Steef van Velden as well as Tony Hak for their responsiveness and overall support, which were of great value to me. Each feedback session gave me great new insights in how to work scientifically, and their challenging questions helped me extensively to move this research in the right direction. In addition, I want to thank the management in the companies evaluated, spending many hours explaining, correcting and interpreting the cases. My special thanks go to Jürgen Beck, Heinz Schmid and Walter Degle. I would also like to mention my colleague Manfred Estler, who evaluated all cases and helped me interpret the findings. He spent a great deal of time with me and his constructive and structured thinking was of great value to the research.

Hendrik Brumme
Herrenberg, February 2008

CONTENTS

LIST OF FIGURES

LIST OF TABLES

INDEX OF ABBREVIATIONS

Agilent	Agilent Technologies
ATP	Available to Promise
BU	Business Unit Manager
CAD	Computer Aided Design
CE	Concurrent Engineering
CIM	Computer integrated manufacturing
CIO	Chief Information Officer
CM	Contract Manufacturer
CPFR	Cooperative Planning Forecasting and Replenishment”
CRM	Customer Relationship Management
DF	Design for
DFM	Design for Manufacturing
DSL	Digital Subscriber Lines
DTS	Digital Theater Systems
DWDM	Dense Wavelength Division Multiplex
EMEA	Europe, Middle East and Africa
ERP	Enterprise Resource Planning
ESD	Electro Static Sensitive Device
ESG	HP Enterprise Systems Group
FA	Final Assembly
FSC	Fujitsu-Siemens Computers
HP	Hewlett Packard
HPC	Hewlett Packard Consulting Organization
HPS	Hewlett Packard Services Organization
HUM	Handling Unit Management
HW	Computer Hardware
ISDN	Integrated Services Digital Network
ISV	Independent Software Vendors

IT	Information Technology
LCD	Lowest Common Denominator
LSP	Logistics Service Provider
MRP	Material Requirement Planning
MPR II	Manufacturing Resource Planning
NPI	New Product Introduction
OEM	Original Equipment Manufacturer
OH	Overhead
OM	Operations Management
OTD	On-time delivery
PCA	Printed Circuit Board Assembly
PCB	Printed Circuit Board
PLC	Product Life Cycle
R&D	Research and Development
RoI	Return on Investment
SC	Supply Chain
SCEM	Supply Chain Event Management
SCM	Supply Chain Management
SKU	Stock Keeping Unit
SI	System Integrator
SMB	Small and Medium Businesses
SIC	Standard Industry Classification
SGI	Silicon Graphics Inc.
SME	Small Medium Enterprises
SMT	Surface Mounting Technology
SW	Computer Software
TLC	Technology Life Cycle
TQM	Total Quality Management
VAR	Value Added Retailer
VAD	Value Added Distributor

VMI	Vendor Managed Inventory
WAN	Wide Area Networks
WHU	Wissenschaftliche Hochschule für Unternehmensführung
WDM	Wavelength Division Multiplex
WDMA	Wavelength Division Multiple Access
WW	Worldwide

1 INTRODUCTION

1.1 Motivation

Responsible for running a $2.5 billion revenues HP factory for computer manufacturing in a high-cost country like Germany, the author perceived constant pressure defining new manufacturing strategies to keep the factory alive. This experience triggered the idea of finding out how best-in-class factories switch their capabilities, their roles, and their responsibilities over time to remain competitive and stay active.

Over a timeframe of ten years, the factory was in a continuing survival mode, facing the constant risk of being closed down and of being off-shored to low labor cost countries. It motivated the management and the employees to continuously review the business conditions and to be ready to accept constant changes in processes, jobs, skills, and the role of the factory. Consequently, management and engineers continued to adapt the factory capabilities in order to constantly retain a competitive advantage over all HP internal and external manufacturing alternatives around the world. Whenever the factory was reconfigured, a new factory name was created with a view to quickly etching the new strategy into employees' minds. After reviewing all these changes in 2003, the author realized that they were developing different capabilities in a certain sequence which could be explained by the enduring progression of the product technology. The factory passed through several evolution phases, which are shown in Figure 1. The X-axis represents the time. The Y-axis shows the main components of computer manufacturing. The shaded area shows the manufacturing depth of the factory, which was reduced over time due to outsourcing. The bold horizontal line shows the split between the push part of the supply chain, which was outsourced and managed globally, and the pull part of the supply chain which was managed locally. The phases can be summarized as follows: Phase 1 – the High-tech factory, with the simple goal of building complex, new and constantly changing products; Phase 2, the Distribution Center, where market cost pressure triggered outsourcing and the reduction of manufacturing depth; Phase 3, the Velocity factory, where speed, quality and cost competitiveness were important to compete with low labor cost countries in Europe; Phase 4, the Solution factory, where skills were added to be able to offer individual fulfillment services and the integration of highly customized solutions; and Phase 5, the HP Partner Park, which was a natural extension of the Solution factory, now offering solutions at more competitive prices by placing different supply chain partners with complementary skills physically into the factory.

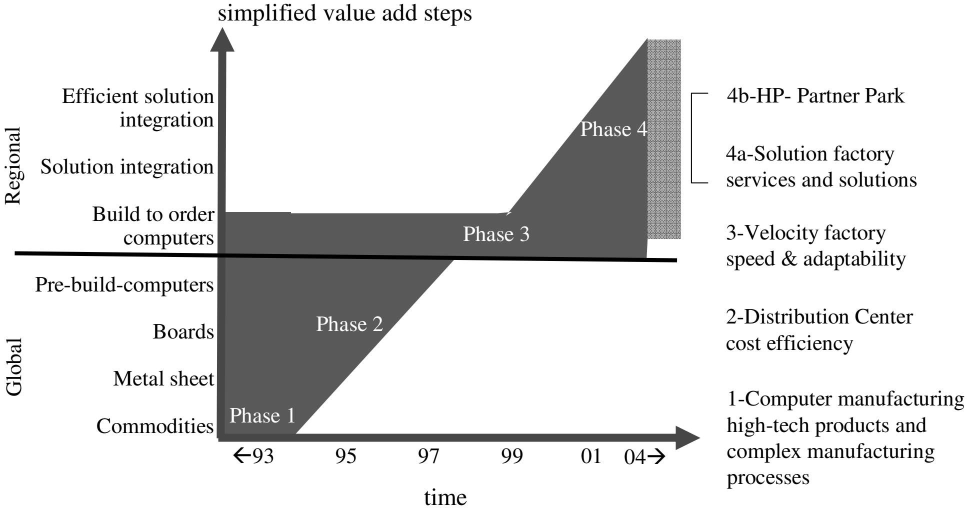


Figure 1: Factory evolution

Lessons learned - 1

The HP factory had gone through a chain of changes in order to survive and be successful, as described in Figure 1.

A few years later, the author reviewed the whole situation with the HP worldwide manufacturing manager, who had since retired. The manager explained in detail why particular supply chain decisions had been made on a worldwide level at that time, and at the end of the discussion a graph was drawn up as shown in Figure 2. It shows a Technology Life Cycle (TLC) as experienced by HP. We looked at computer performance versus time and plotted industry capabilities as well as customer requirements. Two major phases were identified which can be described as follows: In Phase 1, the firms were trying to develop the "Next Hot Box" and customers were immediately buying these new products to stay competitive. However, when the technology entered Phase 2, customer demand changed rapidly. They were now getting more performance than they needed and so they started to develop other preferences. We called this intersection point the "commodity intersection point" because, from then on, product commoditization, together with design, competitive prices and services and customer solutions, became relevant. This had a dramatic impact on the supply chain strategies and the factories.

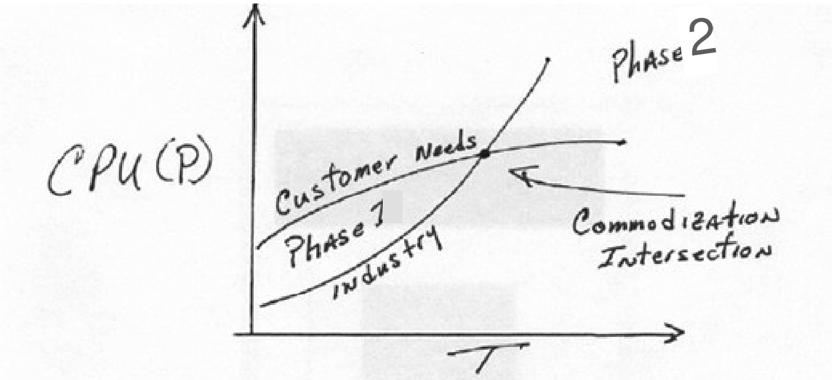


Figure 2: HP definition of a Technology Life Cycle (TLC)

The HP experience prompted us to further split Phase 1 into three phases, each of them different according to how customers value various aspects of the supplier's value chain (Figure 3).

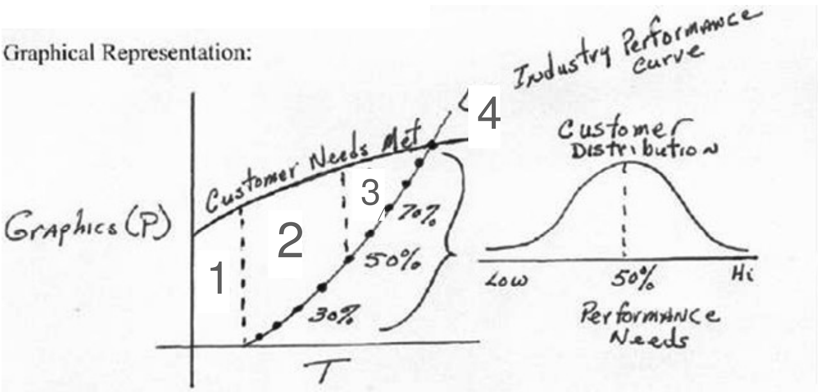


Figure 3: HP TLC – more detailed

The four phases described in Figure 3 will be discussed in more detail in Chapter 3 and Chapter 8.

Lessons learned - 2

If we interpret HP's history in terms of the TLC as described in Figure 3, we can detect a number (perhaps 4) of different phases.

When comparing both graphs [Lessons learned 1 and 2] we realized that HP's supply chain evolution with its four different phases explained by the TLC (Figure 3) exactly matched the evolution of the HP factory (Figure 1). Therefore, we assumed that there was a connection between them which could be explained and validated.

This assumption can be expressed in the following research questions:

- **What is the relationship between the TLC and the capabilities of the best-in-class local factory?**
- **How do best-in-class local factories switch capabilities during the environmental changes explained by the TLC?**
- **Why do they change and what are the triggers of change and the contribution of the local factory?**

We apply the following definitions: The combined capabilities of a factory define the type of factory. A local factory is close to the customer base and probably follows a different capability evolution than a global factory with its primary cost focus. Best-in-class manufacturing is defined in Section 3.3.

1.2 Purpose and objective of our research

Since a competitive advantage does not last forever, it is important to recognize when an old competitive advantage has lost its strength (Christensen, 2001). Companies must read early-market signals to react quickly and get crucial information from the market to all participants in the supply chain (Mohr *et al.*, 2004). In order to stay competitive, management has to constantly change the competitive position. Thus the primary challenge is to respond adequately to uncertainty (Hamel and Prahalad, 1994). Manufacturing competences should be carefully aligned with what the market wants. The whole task of manufacturing strategy development is that managers must link the competences developed internally and the competitiveness required by the market (Corbett and Van Wassenhove, 1993). These are examples of statements regarding the importance of forecasting and adaptation. Especially in high-tech firms, these volatile market conditions, combined with the very short product life cycles of new technology, make planning in business and operations management the most challenging task. According to Christensen (2001), it is not sufficient to be only a good low-cost producer who sells current technology. In a high-tech environment, operations and supply chain managers must be able to understand and forecast the technological evolution of the products they manufacture in order to adapt the factory to the continuously changing needs by changing roles, responsibilities and capabilities.

This thesis intends to shed further light on this subject. It reports the results of a research project in which a theory was developed and validated to explain how the success of local factories, such as the German HP factory, is due to their continuous adaptation to the requirements of market conditions that change during the TLC.

Research objective

The research objective of this study is to contribute to the development of a theory of how local factories adapt to changes in market conditions as they move through the TLC in order to survive or, even better, to be successful.

Unit of analysis
The unit of analysis is about three local factories within the high-tech electronics industry in Germany. This industry represents dynamic and global markets with high uncertainty in technology and market demand combined with enhanced customer expectations.

Consequently, our research aims to obtain a depth of understanding of how local, successful factories in the high-tech electronics industry switch their capabilities during the lifetime transition of the product technology produced. The lifetime transition of a high-tech product is shown in the TLC. We will analyze the relationship between the phases of the TLC and the capabilities of best-in-class factories to see how they adapt their manufacturing capabilities during the TLC and to deduce the competitive importance of manufacturing through the phases of the TLC. After having validated this relationship, we will determine the value of the "local" factory, which we define as a factory in close geographical proximity to its customers.
In order to do this, we must be able to determine a technology's status within the TLC and determine the corresponding type of local factory. Therefore, our intermediate aim is to develop valid and reliable measures for the phases of the TLC and for factory types.

Further limitations
To reduce the complexity of the research, we limit the scope of this research in the following areas: We will not investigate factors which drive the "velocity" of capability switching, like speed of change of an industry, managerial capabilities or the company cultures. Furthermore, the characteristics and the capabilities of the types of factories will not be discussed exhaustively as this would easily go beyond the manageable scope of this research. Moreover, we will not provide answers for the consumer goods markets and industries with different markets, customers and products as stated above. In addition we only evaluate factories in Germany because of convenience reasons.

1.3 Research design

As we are validating a theory where we explain a relationship of variables between the TLC and the types of factories, an explanatory and qualitative case study research approach appears to be the best research methodology. This conclusion is based on the following particulars: The aim of our research is to develop a theory originating from the HP experience. We accomplish this by using an explanatory case study approach. First, we use an empirical and qualitative research tool in order to develop a well-grounded theory where our methods have to reflect the reality of the complex world of manufacturing and where we do not find standardized measures. In addition, we evaluate a relationship and complex interactions, thus making our data mostly qualitative. Second, we apply an explanatory type of empirical approach with a focus on how and why things happen. Our aim is to explain how factories transformed their capabilities and changed their roles over the TLC. Since we explain how the factories adapted, we have to understand why they had to adapt and we identify the triggers that led to the change. The cases will explain "when, how, where, and why events occurred" along the TLC. Third, within empirical research, a case study is an ideal methodology if a holistic, in-depth study is required (Feagin *et al.*, 1991). Case studies are a means to understanding why decisions were taken, how they were implemented and with what results. They identify a relationship of effect and seek to explain under what conditions a particular phenomenon is likely to be found or not to be found. Case studies contribute to theory building through observation of phenomena in the operations management (OM) world that cannot be studied empirically. The major concern of case study analysis is the pattern of results and the degree to which the observed pattern matches the predicted one (Stuart *et al.*, 2002, p. 422). All these criteria match our intentions. Our research aims to deal with relationship building, while noting any causal effect pattern, and we intend to explain the changes in local manufacturing and how companies react to them. Thus, we explain an assumed causal link of a real-life interference that is too complex for surveys and experiments, and our research looks at the full complexity of manufacturing systems where we illustrate the topics in a descriptive mode.

1.4 Research gap, outcome and contribution

Although there is a rich body of literature on manufacturing strategies and supply chain management, we are not aware of any research discussing the interconnection of the TLC and the related competitive needs for the capabilities of the local factory. Most quoted studies which are close to our research questions have been carried out by Fine (1998) and Utterback (1996). Fine uses the TLC and its impact on the structure of a whole supply chain (the double helix model). Utterback focuses on technology innovation regarding process and product technology of companies passing through the TLC. However, to date, considerations which discuss the potential of a conscious new allocation of capabilities during all phases of the TLC have not been taken sufficiently into account within the high-tech electronics industry. Because of the increasing maturity of product technology within the high-tech electronics industry, new superior manufacturing models describing capability switching must be developed.

Theoretical relevance: In operations management (OM) literature, several types of factories with specific capabilities for different industries have already been defined (e.g., Koerber *et al.*, 2003). We will develop and validate a theory about how such factories switch capabilities over time to adapt to particular customer expectations, explained by the TLC theory. We thus propose courses of action for capability switching in local manufacturing over the lifetime of a factory. We also provide valid and reliable measures of the phases of a technology's status within the TLC and the corresponding types of local factories which are necessary for developing successful manufacturing capabilities. A byproduct will be an explanation of how "local" factories within the high-tech industry add value to a company's success along the different phases of the TLC.

Managerial relevance: As concluded earlier, in a dynamic high-tech environment, accurate technological forecasting is vital. Practitioners within the high-tech electronics industry may use the outcome of our research to deduce a manufacturing and supply chain strategy which is necessary to develop best-in-class manufacturing. It may inspire them to make decisions early concerning when and how they adapt their local factory to the continuously changing needs. This can prevent management from continuing to invest in capabilities that are long past their prime. Thus, the value of "local" manufacturing along the TLC is an additional contribution of this research. The outcome should give managers insights regarding the importance of their local factory capabilities and how to maximize their value for the company and its customers. It should support decision making regarding two major strategic options: off-shoring of the factory and investment in new businesses.

1.5 Outline of this study

This dissertation is divided into nine chapters as described in Figure 4. In the current chapter we introduce the topic of our research by illustrating motivation and objective. We then give a quick overview of the literature in this context. Next we formulate the outcome of this study and the contribution regarding theory and management. Chapter 2 contains the theoretical foundation of our research and sets the basis for the conceptual model and research measurement model, which is developed in Chapter 4. We define high technology and discuss the most quoted theories on the TLC. In addition, we briefly discuss environmental dynamism to set the variables, based on which the phases of the TLC are described later in our research measurement model. The second section of Chapter 2 reviews the types of factories defined by Koerber *et al.* (2003) and further theories on supply chain integration and OM, to enrich the types of factory description. At the end of this chapter, we identify the gap in literature and the link to our research motivation. In Chapter 3 we explore, from the HP case, research propositions and a conceptual model. We evaluate the relationship between the capabilities switching of the HP factory in Germany with HP's TLC evolution. To better explain this relationship, a different view of a TLC model is drawn in this chapter, which we call "HP definition of a TLC" (see Figure 2 and Figure 3). After this examination of theory (Chapter 2) and of practice (Chapter 3) we further specify, in Chapter 4, the research measurement instrument. Chapter 5 provides the research methodology and its selection process, including the related criteria. We then carefully present the logic behind the choice of the research design and illustrate how we have ensured high-quality research. In Chapters 6 and 7 we will present the two validation cases: Fujitsu-Siemens and Agilent Technologies. The Agilent case is intended to be a "less likely case" to validate the borderlines and scope of our propositions. In an attempt to increase the clarity of the presentation of empirical research results, we have used a uniform format for all three cases. We start with a short description that provides the background information on the company and its major strategic moves. Next, we present a detailed description of the technological evolution of the products produced. The types of factories and how they developed are dealt with next. In Chapter 8 we present the empirical findings of the test cases and draw conclusions to shape our theoretical propositions. In Chapter 9 we summarize the major findings and the results of our research. We discuss the contribution and limitations of our conceptual model and conclude with an outlook for further research.

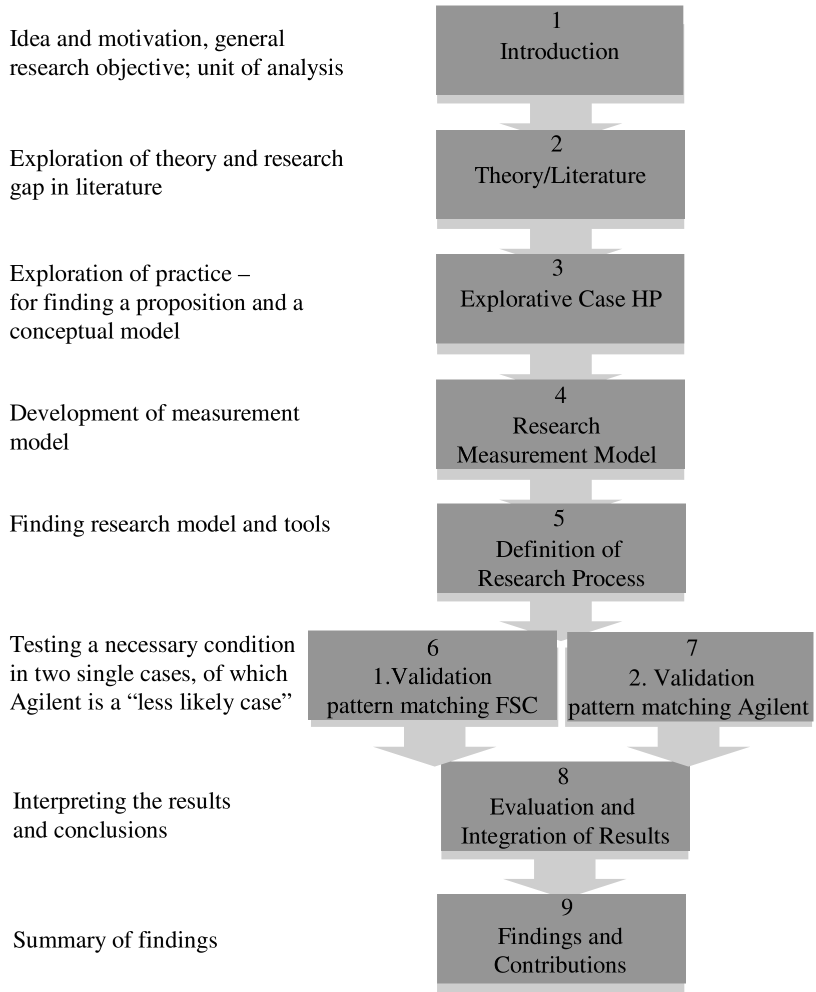


Figure 4: Research structure

Regarding the notation of the different time phases discussed in this dissertation, we wish to point out that the time segments measured in the cases are noted in Arabic numbers (Phase 1, Phase 2, Phase 3, and so on). The theoretical phases, as described in the TLC literature, are noted in Roman numerals (Phase I, Phase II, Phase III, and so on).

2 LITERATURE REVIEW

In this chapter of the research, we will explore the existing literature which is linked to our research goal and outline the gap in theory. The outcome of this section will set the basis for the conceptual model, along with the measurement system, and serve as the groundwork for data gathering and data analysis. Consequently, we structure this chapter according to the framework of the conceptual model. The literature supporting our findings is discussed in Chapter 8.

Our propositions address the relationship between the market evolution based on the technology adoption along the life cycle of a whole technology and the fulfillment capabilities developed by best-in-class factories. Hence, we will explore theory on two very different streams of literature. In the first section, we will discuss the major studies on technology adoption, described by the Technology Life Cycle (TLC). The outcome of this chapter will rigorously define the characteristics of each phase of the TLC. This section starts with an introduction to the ideas and thoughts in TLC research including an explanation about the difference between the TLC and the Product Life Cycle (PLC). We will end this first section by evaluating the most significant literature about environmental dynamism. The outcome here will give us the variables which we will measure along the transition from phase to phase of the TLC. In the second section of this chapter, we discuss manufacturing capabilities which can be strategically adapted to the dislocation caused by the changing environment. A cluster of these manufacturing capabilities can be defined as a type of factory. We will put special emphasis on the types of factories defined by Koerber *et al*. (2003) and supporting literature to extend Koerber's descriptions. In the last part of this section, we will sum up the findings and then discuss the gaps in the literature.

Figure 5 shows these two streams of literature and how we link them. Some of the authors are exemplified.

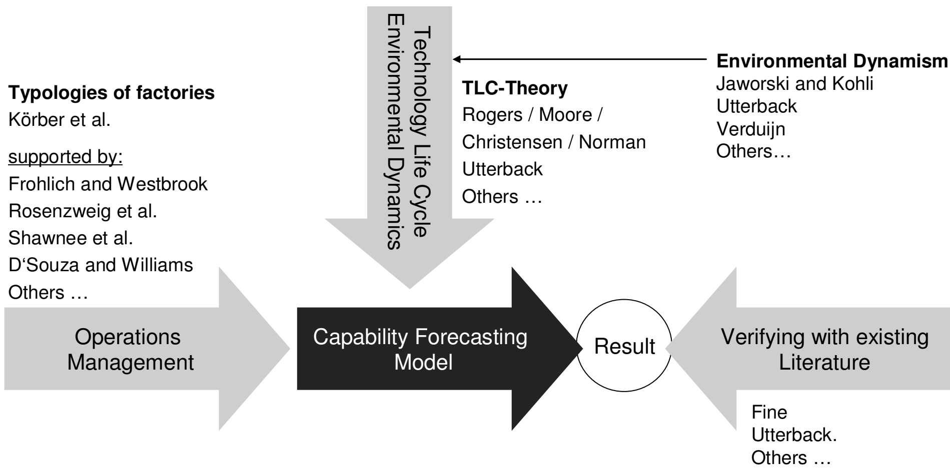


Figure 5: Linking two streams of literature

2.1 Technology Life Cycle (TLC) theory and environmental dynamism

A growing body of research addresses areas ranging from understanding the sources of innovation to the determinants which drive industry change (Schumpeter, 1934; Abernathy and Utterback, 1978; Christensen, 1997). Others look at the impact of innovation on existing markets (e.g., Foster, 1986; Henderson and Clark, 1990) or the role and impact of customer adoption in disseminating technological innovation (Rogers, 2003; Moore, 2002). In addition, studies have addressed the organizational aspect of innovation regarding the implementation and execution (e.g., Tushman and O'Reilly, 2002; Chesbrough and Teece, 1996). In the following sections we will limit our focus to those researchers who put their emphasis on customer adoption and innovation as it corresponds with the scope of our study. We start with an overview about what high-technology is and give an introduction to these TLC theories. We then present those studies which discuss how high-tech markets evolve over the life cycle of a technology. Then, we cover those streams of literature which discuss the linkage of product and process innovation. Finally, we present research in the area of how companies can be successful during the transition points over the TLC – moving from technology-centered to human-centered products.

2.1.1 Definition of high-technology

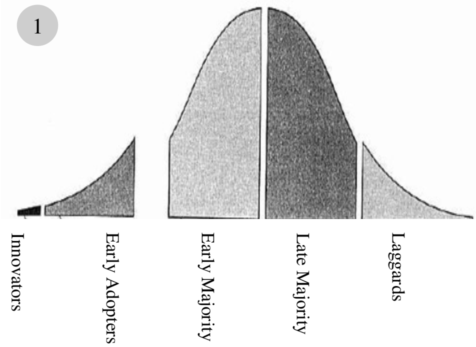
Technology-driven companies use new technology and new knowledge to offer new products or services that customers want. Technological innovation triggers an enormous amount of uncertainty and complexity, and gives rise to countless constraints. Webster's II New Riverside Dictionary describes technology as "*the application of science knowledge, especially in industry and business*". Some technologies are simple and are easily understood. However, when several new technologies are considered as a whole, this kind of integration is called high technology. A classification by US Congress Office of Technology Assessment (US Congress, 1982), defines high-technology industries as "*those engaged in the design, development, and introduction of new products and/or innovative manufacturing processes through the systematic application of scientific and technological knowledge*". Definitions of high technology vary not only in the field of the subjective but also of the quantitative. The US Bureau of Labor Statistics classifies high technology according to the number of technical employees and the amount of reach and development expenditure in a given industry compared to the average for all US manufacturing (e.g., Shanklin *et al.*, 1985). If an industry is to qualify as a high technology industry it must have twice the number of technical employees and double the R&D outlays of the US average. Mohr *et al.* (2004) define high-tech products as products which are introduced in turbulent and chaotic environments where the probability of success is often low. However, none of these definitions are all-inclusive.

2.1.2 Introduction to the TLC theory

It is generally recognized that the marketing of high-technology products differs significantly from that of traditional products. Most new technologies follow a life cycle which is similar to a Product Life Cycle (PLC), but relate to an entire technology or generation of a technology. Looking at the history of a large number of past technologies indicates that this is not a random process, but rather follows a certain pattern. Consequently, the TLC is an important concept to be taken into account when formulating

a business or technology strategy. In each of the phases of the TLC, firms must organize technical progress differently. This has an impact on marketing, R&D and the operation, and thus the factory.
However, high-technology markets function differently from consumer markets. While consumer marketing uses the PLC as the basis for understanding product and market behavior, the use of PLC in industrial and high-tech markets has received little attention (Ryans *et al.*, 1984). The PLC combines three basic elements in the marketplace: fashion, technology, and benefits required by the marketplace. For consumer goods, the form or fashion can be the essence of the product and therein can be the driving factor of the consumer PLC (Popper, 1992). Consumer marketing may benefit from the separation of these three factors. The same three factors are also involved, to some extent, in high-tech markets. However, in high-tech markets there is a tendency for customers to put much less emphasis on fashion in the products they purchase. It may become more important in the later stages of the TLC. It is apparent, for example, that the curve over time for personal computers is quite different from the pattern for designer clothes. We conclude that the PLC might not be sufficient to analyze high-technology markets. In addition, high-tech companies often fail to understand the drive for innovation that consumers seek. For these companies, the TLC can be used to better understand the changing market conditions and to adopt the whole company strategy accordingly. The technological evolution of mobile phones and the corresponding changes of customer requirements can be cited as one example.

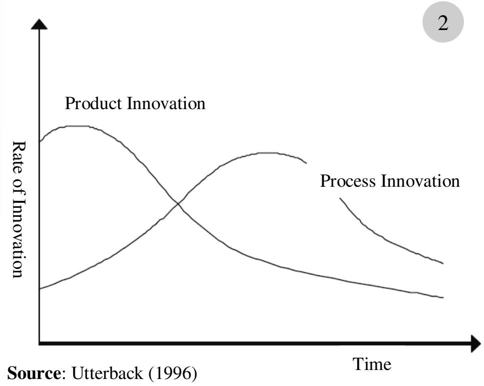
Looking at the TLC literature in more detail we find that various streams exist. Many of these academic studies can be traced back to the innovation diffusion theory (Rogers, 2003). Some researchers evaluate the adoption of product technology and process technology, while others focus on market development and customer characteristics and how they change over time.
Figure 6 gives an overview of the models which are discussed in more detail in the following sections.



Source: Moore (2002) (first edition in 1991)

Approach: Market segments based on the innovation diffusion theory by Rogers (1962), but being introduced with gaps between two market segments.

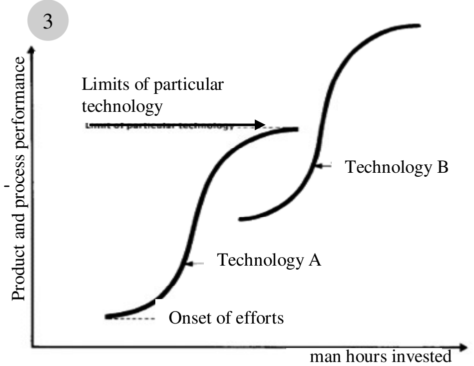
Conclusion:
Marketing approach: Target a market. Create the whole product. Define marketing portioning: Product centric value attributes to market centric ones; direct sales.



Source: Utterback (1996)

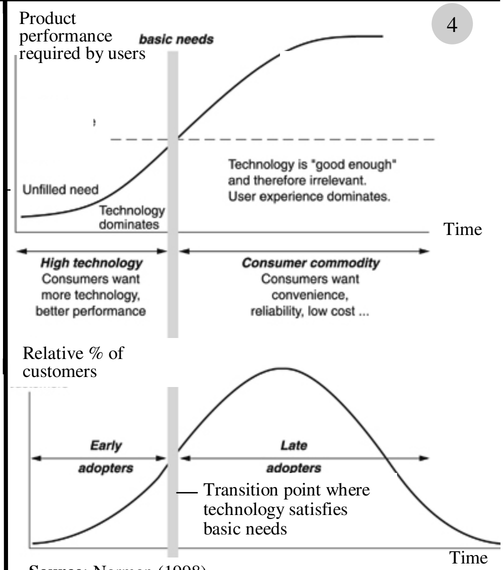
Approach: Technology development approach. Three phases: The fluid phase; the transitional phase; the specific phase.

Conclusion:
The linkage of product and process innovation. Before the occurrence of a dominant design, product innovation is the emphasis of high-tech companies. After that, process innovation dominates. During the process innovation, reductions of production costs is the main concern of a high-tech company.



Source: Christensen (1997)

Approach:
Traditional S-curve. Introduces the concept of destructive technology, and he stresses emphasis on technology development rather than on low –cost manufacturing.
Conclusion:
Keep close to customers and analyses conditions. Good allocation of resources, Matching market and technology. Take distinctly different position, addressing a disruptive or a sustaining technology.



Source: Norman (1998)

Approach: Integration of Moore's and Christensen's theory.
Conclusion:
Three legs of human centered product development. Technology, marketing and user experience are important.

Figure 6: Overview of major TLC models

2.1.3 The diffusion of technology innovation – The first step in TLC research

The original diffusion research was formulated in 1903 by the French sociologist Gabriel Tarde who drew the original S-shaped diffusion curve in describing how an innovation diffuses over time. Tarde's S-shaped curve is of importance because, as he explained, "Most innovation has an S-shaped rate of adoption." The vertical axis shows market share and illustrates the innovation, which gradually achieves a growing market share until it plateaus at a certain point of the total market potential. The variance lies in the slope of the S. For some products, the innovation process has a slower rate of adoption, creating a gradual slope in the S-curve. The horizontal axis shows the time spread.

This market view has been extended by several researchers regarding the evolution of a technology over time. One important work is that of Foster (1986), who modifies the S-curve and describes the product performance improvement in a given period and how it differs as technology matures. This "technology S-curve" has been used for decades to represent the technology and innovation progress and forms the centerpiece when discussing technology strategy. It highlights the importance of considering returns to innovation effort in assessing competitive threats and investment priorities.

Rogers (2003) – who is universally recognized as the most influential researcher whose theory can be applied to products in high-tech markets – looks at technological evolution more from a market perspective. Beginning in 1962, he categorized different types of customers for high-tech products and their changing requirements and behavior over time. Rogers states that adopters of any new innovation can be categorized as innovators (2.5%), early adopters (13.5%), early majority (34%), late majority (34%) and laggards (16%), based on a bell curve. Each adopter's readiness and ability to adapt to an innovation depends on their awareness, interest, evaluation, trial, and adoption. At first, the rate of progress in technical performance is rather slow. Technology in this phase does not meet all the expectations of its customers. Leading-edge and early adopters need the technology and its performance, and they are willing to accept inconvenience, difficulties and high cost to get it. They continue demanding better technology and higher performance. After an initial period, as the technology becomes better understood, the rate of technological improvement will accelerate. Over time, the technology matures and performance and reliability improve while prices decrease. In its mature stages the technology approaches a natural or physical limit and additional efforts to innovate yield only marginal improvements in technical performance. When the technology reaches the point where it satisfies basic needs, improvements in the technology make no sense. At this point, customers start to look for efficiency, reliability, low cost and convenience.

Rogers identifies the following characteristics per category: "*Innovator: venturesome, desire for the rash, the daring, and the risky. Early adopters – social leaders, popular, educated. Early majority – deliberate, many informal social contacts. Late majority – skeptical, traditional, lower socio-economic status. Laggards – neighbors and friends are main info sources, fear of debt.*" The diffusion time that elapses from innovators through laggards can be short or long. The essential point is that there are significant differences among buyers in the various categories that can be meaningful for high-tech marketing and operations management strategy. According to Rogers, the specific characteristics for each adopter category are of significance to the company that is interested in creating an integrated marketing plan, targeting a specific customer.

Criticism
Moore (2003) started a discussion of the technology adoption life cycle in the early 1990s (see
Figure 6). He argues that the basic flaw in Rogers' "innovation diffusion model" implies a smooth and continuous evolution across segments over the life cycle. The components of Rogers' life cycles are not changed but a gap (the chasm) has been introduced between the components. Each chasm segments very different types of customers with very different expectations concerning new technological products. It represents a potential danger for a company to miss the transition to the next market segment. On each side of the chasm, a company must take a very different attitude toward its market and its approach to the design of the products. They must develop their marketing strategy and choose the most appropriate distribution channel. The most significant gap is the "chasm" that divides the early adopters from the early majority. According to Moore, this is by far the most difficult and dangerous transition in the TLC. The transition problems occurs because in the first two stages of the TLC, customers are sophisticated and able to buy based on their understanding of the product's technological attributes. The engineering skills required to develop the product are often not sufficient to market the product. With the development of the larger market, customers are much less sophisticated but seek the benefits offered by the new technology. Nevertheless, the high-tech company, at this phase, often overemphasizes the market potential for their high-tech products and continues to focus on further product innovations.

Moore developed a technology adoption strategy and designed the competitive-positioning compass to define the marketing position of high-tech firm. As products progress through the TLC, their value to customers changes. In the early market, where decisions are dominated by technology enthusiasts and visionaries, the key value domains are technology and product. In the mainstream, where decisions are dominated by pragmatists and conservatives, the key domains are market and company. Crossing the chasm represents a transition from product-centered to market-centered values. Product centric means unique functionality and easy-to-use products. Market-centric products are *de facto* standardized, have a large installed base and many third-party supporters. Moore argues that the fundamental principle for crossing the chasm is to target a specific niche market and focus all resources on achieving the dominant leadership position in that segment. The next step to crossing the chasm is creating solutions. A solution should include everything to increase customer value. Solutions are easy to buy, include customized services, training and support, etc. The third step of Moore's approach is market positioning, pricing, supply chain structuring and using a direct sales force for creating demand. He argues that a direct sale is the optimal sales channel for high-tech products to cross the chasm.

Links to our research
The five phases of Rogers' diffusion of innovation theory of 1962 (Rogers, 2003) is used here to evaluate capability switching of the factory. Moore extends the characterization of the five phases of the diffusion of Rogers' innovation theory to deduce a comprehensive measurement model including different standpoints discussed in the literature. This enables us to enrich the criteria database of our measurement model and to improve it. Second, we use Moore's conclusion – especially his findings regarding product solutions,

supply chain restructuring, and the positioning compass – to cross-check our findings. The resulting measurement model with its five phases is defined in detail in Chapter 4.

2.1.4 Mastering the dynamics of innovation

In his research on technology innovation, Utterback (1996) identifies changes in the rate of innovation for separate cycles of product and process innovation. Regarding the dynamics of technological innovation, he develops a practical model which supposes that new products and their related process innovations follow a general pattern over time. He uses the model of the dynamics of innovation where product and process innovation correlate over time. These, in turn, are linked to important changes in the characteristics of product and process (see also Abernathy and Utterback, 1978). Utterback identifies changes in the rate of innovation for separate cycles of product and process innovation. It is also a model that attempts to cut through the life cycle of technology. He uses the concept of the technology development along the TLC to describe this process. According to Utterback, product innovation is the driving factor in the early phases of a new technology and process innovation, like manufacturing and supply chain processes, are not the center of interest. Product and process innovation are still interdependent. Later in the TLC, innovation, which leads to better product performance, becomes less likely. Then, firms attempt to maximize revenues by developing products which clearly focus on potential customers, and a growing rate of process innovation evolves. We now explain these phases and the definition of a dominant design in more detail.

Utterback defines three significant phases. The first phase is the fluid phase, in which lot of change takes place at once, and whose outcomes in terms of product, process, the supply chain structure, the management of firms and the competition are highly uncertain. A firm develops its initial new product technology. A growing market begins to take shape around that product, and new competitors are motivated to enter the marketplace. At this early stage, no firm has a strong position in the market. No company's product is really perfect and no dominant design has been installed. No single firm has mastered the process of manufacturing, or achieved control of their distribution channels. While this is not efficient in terms of modern production standards, it does make the cost of process flexibility low, and process change is frequent at this stage because of the rapid evolution in product technology. In a second phase, if the market for a new product grows, the industry may enter what could be called a transitional phase. Market acceptance of a product technology takes place and a so-called "dominant design" emerges. Utterback introduces the definition of dominant design when customers form their expectations concerning a product in terms of features and form: *"A dominant design in a product class is the one that wins the allegiance of marketplace, the one that competitors and innovators must adhere to if they hope to command significant market following.*" (Utterback, 1996, p. 125). Before a dominant design can emerge, many companies enter the marketplace with countless different versions of the product. In the case where a dominant design appears, more competing firms leave the market and a general consolidation of the industry takes place. Thus the emergence of a dominant design marks an important change in the evolution of an industry, and effective competition begins to take place on the basis of cost and scale as well as on the basis of product performance. Since the appearance of a dominant design reduces uncertainty as well as the need for flexibility, the focus shifts from product innovation to process innovation, which affects the economies and scale of production. Firms begin to focus on their factory capabilities, where large-scale production of innovative products must be worked out. It is during this phase that product and process innovations start to become more tightly linked, and materials and equipment become more specialized. The third phase is called the specific phase. “Specific” is used rather than “mature” because the fabrication of assembled products aspires, over time, toward very specific products at a high level of efficiency. Products in this phase become very well defined, and the differences between competitor products are often small. The linkage between product and process is now extremely close.

	Fluid Phase	**Transitional Phase**	**Specific Phase**
Product	The rate of product change is expected to be rapid. Product technology is crude, expensive, and unreliable, but the technology is able to fill a function in a way that is highly desirable in some niche markets.	The emergence of a dominant design.	A dominant design has been accepted by the market.
Process	Process innovation is generally not so important to product innovation. Process change is frequent at this stage owing to the rapid evolution in product technology.	Product and process innovation becomes more tightly linked.	The linkage between product and processes is extremely close.
Manufacturing	Manufacturing uses general-purpose equipment and skilled labor and is conducted in small-scale plants, generally located close to the source of the technology.	Manufacturing becomes the focus of a company. Large-scale production evolves. Material becomes more specialized.	Producing specific products at high efficiency.
Market	No one controls the market.	Product is accepted and the market growth.	Product is accepted, market has matured.
Customer	Customers have not yet developed their own sense of the ideal product design or what they want in terms of features of functions.	The needs of those users become more clearly understood.	Normally adopt the standard product at low cost.
Competitor	Functional product performance is the basis for competition. The number of competitors is small, but rises as the product technology gains a market that pushes new entrants with newt approaches.	The competitive emphasis in is on the production of products for more specific users as the needs of those users becomes more clearly understood.	quality, cost and differentiation becomes basis of the competition.

Table 1: Product and Process Innovation (Source: Utterback, 1996)

Any change in the product or its related processes is difficult and therefore expensive as it requires a corresponding change in the manufacturing process. Utterback also mentions that the specific phase of production is not the end of a technology. There is a way to break out of this highly capitalized, highly controlled, and generally not innovative mode of production. Flexible manufacturing and the strategy of mass customization could be a solution to this problem.

Table 1 summarizes the characteristics of these three phases. They will be used to extend the definition of our research measurement model.

Link to our research
Utterback's research on technical innovation contributes important aspects to our research since it discusses the evolution of a technology and its impact on process technology innovation and product technology innovation. In addition, he describes the changing conditions of manufacturing, the market, customer expectations and the competition. These extend the selected variables which are based on the diffusion of technological innovation theory. Therefore, Utterback's descriptions contribute to the structuring of the criteria database from which we deduce the research measurement model and formulate the interview questions.

2.1.5 Disruptive Technologies

A model about new disruptive technology was discussed by Christensen (2003) using the traditional S-curve approach. He states that observing the TLC is the best way for a company to see if a product or process is risky. He puts more emphasis on the technology itself, focusing on the critical differences between a sustaining technology and a new, so-called disruptive technology. Christensen tracks the patterns of innovation and describes both the processes through which disruptive technologies replace older technologies, and the forces behind markets and technology changes that prevent well-managed companies from developing disruptive technologies. Disruptive technologies are generally not well commercialized, they serve new customer value, they are cheaper and simpler, and they are rejected by those customers who are unable or unwilling to adopt unconventional products.
Christensen builds on the theory of earlier research concerning the characteristics of the different phases (e.g., Rogers, 2003; Moore, 2002). When the technology exceeds the basic needs of most of its customers, the high-technology company has to evolve toward a new behavior since customer needs and expectations change significantly. In this situation, an organization's structure must adjust to establish a system which can facilitate the design of its dominant product. Christensen found that many companies failed to do this. His model is shown in
Figure 6. The horizontal axis shows the efforts that have been put into a new technology, such as the total R&D cost. The vertical axis refers to a product's performance. Technology develops slowly at first, followed by intense and heavily financed R&D which increases performance significantly. Finally, the performance reaches an area of stability as the technology reaches its performance limits. Now, a so-called disruptive technology might already have been launched, winding its way through its own S-curve, a curve that starts out at a performance level far above the current technology. For a while the two technologies compete and their s-curves overlap to the point where the superior and newer technology eventually wins.
Christensen proposes a four-step approach to better manage this situation. First, the company must keep close to its customers. Strategy maps can help to see in which situation a company finds itself. Second, the company must manage the resource allocation process to allow a good allocation of resources within the company's mainstream value network. Third, successful companies have a practiced capability in taking sustaining technologies to market, giving their customers more features and better products. This is an important capability for managing sustaining innovation. Fourth, companies need to take different positions depending on whether they are addressing a disruptive or a

sustaining technology. In other words, they should not plan to be always a leader or always a follower.

Criticism and further research

Christensen's approach has been discussed from several different perspectives. Markides (2006) argues that his theory can not be applied to all kinds of disruptive innovations, i.e., technology innovation, product innovation and business models innovation. He argues that different kinds of innovations have different competitive effects resulting in different kinds of markets and therefore need different theories. Iansiti (2007) argues *"… that the technological life cycles may be better viewed as interacting cycles of assimilation and specialization"* (p. 39). Rather than disrupting the existing *status quo*, innovations are often assimilated into an existing familiar technology.

Recent research in TLC theory based on the traditional S-curve by Adner (2004), discusses a demand-based perspective on the TLC, considering the relationship between consumers' valuation of performance improvements and technology development over the TLC. His study explores how the character of the TLC's maturity, the nature of competitive threats, and firms' innovation incentives all change when consumer demand for performance matures in advance of a technology's performance trajectories. Adner argues that a focus on consumer value thus suggests demand maturity as an additional metric of progress along the TLC. According to the shift in customer demand, a high-tech company should implement a corresponding technology and market strategy. He suggests considering the potential for demand maturity, rather than technology maturity. His theory offers a new logic for understanding the empirical observation of innovation patterns over the TLC.

Link to our research

Christensen concludes that high-tech companies must spend more time analyzing their technology life cycle and stresses the fact that low-cost manufacturing in combination with current technology delivery is, for the most part, not sufficient to be competitive. This statement matches our research proposition of switching capabilities along the TLC to be best-in-class. Christensen again explains the different characteristics of the customer, the technology and the market but with a special focus on the later part of the TLC, the moment when a new disruptive technology appears. We will take his findings to define the criteria database for our measurement model for the later phases along the TLC. This is of special value since switching manufacturing capabilities will be especially critical in the later phases of the TLC.

2.1.6 Moving from technology-centered to human-centered products

On the basis of the theory of innovation diffusion, Norman (1998) comments that a high-tech company must move from "a technology-centered youth" to a "consumer-centered maturity". He finds that it is important to make the transition from technology-centered development to human-centered development, based on the example of the computer industry. This transition point as part of his theory can also be seen as a shift from the supply side of high-tech marketing to the demand-side of high-tech marketing.
Norman links and extends analyses both from Moore (2002) and Christensen (2003).

Figure 6 shows the early-adopters who want the most cutting-edge technology while the late adopters want convenience, low cost, and a good user experience. It demonstrates the change from technology-driven to customer-driven and human-centered products. These two different types of customers build a transition point. He argues that this is also the location of the chasm along the TLC, which is in line with Moore's theory. Norman's description of the phases is very similar to Rogers' description, so we pass over it. Norman states that the problem faced by the high-tech company is in the way they deal with the customers since it requires different strategies. He observes that the selling point at the beginning phase of a new technology is the technology itself. Companies stress the function and capability of the new technology when they promote it. At the maturity and the late phase of a new technology, the selling points require that the attributes of the technology be minimized. The buyers now focus on price, solutions and convenience, and on the experience with the product. Norman argues that, facing the transition point in the market from the early adopter to the late adopter, the technology-driven company should make the transition to a customer-driven company and toward a human-centered product development in order to maintain success in the high-tech market. Like Moore, Norman emphasizes the fact that a whole product concept should be considered. This means that a product should include all the factors of customer needs, not only technology, but also price, appearance of product, and after-sales-service, etc. (Norman, 1998, p. 40).

Link to our research

Norman supports the findings from Moore and Christensen but puts more emphasis on the two different types of customers. The description of these types of customers and how they change over time is integrated into our measurement model. All three researchers discussed above indicate that there is a major transition point during the TLC. We include their market- and technology-oriented findings to compare the supply chain structural changes of three real life cases to see how the factories switched their capabilities along this transition point, or the commodity intersection point, as described in Chapter 6.

2.1.7 Environmental Dynamism

The TLC discussion provides us with a definition of the phases of technology adoption and therefore the structure of our contextual framework and the first part of our measurement model. To be able to track the changing environment described by the TLC, it is important to understand the market dynamics in high-tech markets. The environmental dynamism literature provides us with the variables which we use to describe the TLC phases in a structured way. The selection of these variables is discussed in detail in Section 4.1. In the following section, we provide a very limited insight into this whole branch of research.

(Teece and Pisano 1994, p. 537) defined dynamism as a force triggering a development or motion of a system. The term 'dynamic' refers to the changing environment. Fine (1998) found that the dynamics of an industry are probably a bigger threat to a competitive advantage than any competitor. This is especially true in the high-tech industry because it is considered as a fast-moving industry. Thus, the challenge to high-tech companies makes the adoption of their capabilities in manufacturing even more important. Environmental dynamism has been researched, for example, by Peterson *et al.* (2002), Dougherty *et al.* (1998), Teece *et al.* (1994), Weiner *et al.* (1997) and Dornier *et al.* (1998). In our judgment, the research in environmental dynamism which matches very well with the discussions around the TLC is that of Jaworski and Kohli (1993). It therefore makes little sense at this point to further discuss all the developments which the authors have provided. We therefore give only an outline of the three different components of environmental dynamism developed by Jaworski and Kohli (1993): market dynamism, technological dynamism and competitive dynamism. In addition to these three components, we wish to identify the actors in supply networks to measure their changing characteristics over the TLC. A good overview has been presented by Verduijn (2004), with which we finish this section.

Market dynamism

The first component is market dynamism. To formulate and execute successful strategies, firms must understand the nature of the markets in which they compete (Besanko *et al.* 2003). Porter (1981, p. 609) writes: *"The essence of this paradigm is that a firm's performance in the market place depends critically on the characteristics of the industry environment in which it competes"*. In general, dynamic markets can emerge, collide, split, evolve or die quickly. In static environments with stable markets, companies have to focus on the right positioning. In dynamic markets, it is vital to know "how to compete" (Stake *et al.* 1992). Fine (1998) addresses this problem by discussing the clock speed. Time is important in any possible context. Highly competitive markets are dynamic, with firms gaining and losing a competitive edge over their rivals, through continuous improvements and changes in their supply chain network and production methods. Shi and Gregory (1998, p. 195) write: *"In general, these new driving forces – global market opportunity, new patters of competition, and reorganizing potential or possibility – require a new generation of networks beyond the classical pipeline of physical transformation"*. Mitchel *et al.* (2003) find that in dynamic markets there is a move from a product-centric value heading toward a person-centric value expressed by passion partnership, solutions assembly, trading agency. The delivery model shifts from an emphasis on product manufacturing to services and solutions.

In summary, this development suggests that value chain partners in so-called high-tech sectors demand organizational flexibility in terms of switching capabilities. Customers demand change quickly and constantly. New customers regularly approach the firm and bring new ideas and requests. This kind of dynamism is driven by customer behavior. This explains why companies in dynamic high-tech markets need to have a strong customer focus. The computer and communication industry represents these markets with high-tech/complex solutions (Accenture, INSEAD, Stanford University Report, 2003).

Competitive dynamism

The second component is competitive dynamism. Strong competitive dynamism is linked to high competitive pressure. In such an environment it is extremely difficult for a company to establish and protect its competitive position. A competitive advantage can be wiped out quickly by the competition. Thus, in a competitive environment, the benefits of a competitive advantage can be short-lived. Competitive dynamism is enhanced due to continuous globalization. According to Yip (1992), in most cases, growing industry globalization intensifies the strength of competitive forces. Globalization can change the strategy needed for managing competitive forces. A firm can use advantages of location and economies of scale to generate competitive advantage. Prahalad and Hamel (1994) identify several forces impacting the nature of competitive environment: deregulation, structural changes, excess capacity, M&A, environmental concerns, less protectionism, changing customer expectations, technical discontinuities, the emergence of trading blocks, and global competition. These forces change the sources of advantage of firms and the economies of industries.

Technological dynamism

The third component refers to technological dynamism which is a more internally driven factor. In a technological, highly dynamic environment, a company's technological advantage may change quickly. A new technology may be disruptive and of a revolutionary character. Enders (2004) finds that competitive dynamism shows only scant relation to technological improvements, whereas market dynamism and technology dynamism are linked and result in fast and considerable technological developments. Strong technological dynamism comes about if there are opportunities in the market where the company is competing in rapid technological changes. New technological developments may even have a revolutionary character. Technological change can also impact production processes. For example, laser molding is a disruptive manufacturing technology to punching, which impacts set-up times, manufacturing flexibility and operational cost (Schenk and Wirth, 2004, p. 3).

Fine (1998) defines four measurements of the clockspeed of an industry and therein its dynamism. Two of these measurements describe technological dynamism: Process Clockspeed and Product Clockspeed. Process Clockspeed measures the capital equipment obsolescence rates, for whole factories with their manufacturing processes and their machinery. Product Clockspeed is defined as the rate of product launches over time. In a high clockspeed industry there is much uncertainty and thus industries tend to generate hedging strategies. They typically have more complex networks, and making money means controlling the network. Here, the role between the supply chain dominator and a component supplier may vary over time. However, all competitive advantage is temporary. An impulse to increase the speed may come from shocks to the business environment, economic shocks, technological shocks, and shocks from competitors' breakthrough products and services or the shock of a new business or supply chain model (e.g., Wal-Mart, Dell). The remaining types of clockspeed variables are Organizational Clockspeed and the Clockspeed of Brand Names and Distribution Channels, neither of which are covered in our discussion.

Actors in supply networks

Verduijn (2004) analyzes dynamism in supply networks and the options available to an actor to switch capabilities in a turbulent business environment. He finds nine forms of dynamism in supply networks: "... *dynamism in the actors that are part of a network; dynamism in the channels formed by actors in the network; at the channel level, there can be dynamism in the type of orders; and dynamism in the total volume of orders of all products that flow through the channel; at the actor level, there can be dynamism in the processes and resources used by an actor; and dynamism in the channels in which the actor participates; at the level of processes, there can be dynamism in the channels to* *which processes contribute; from a type of order perspective, there can be dynamism in the channel that is used for the fulfillment of customer orders and; dynamism in the demand volume of those types of orders*" (Verduijn, 2004, p. 323). He observes six motives for switching: new technology, alternative materials, cost, quality, performance, and switching for capacity availability. He notes that companies now have three strategic options regarding how to respond to environmental changes: they can increase the flexibility of their resources; they can implement a supply chain integration strategy to enhance flexibility and responsiveness of all partners of the supply chain; they can adopt a switching strategy. His findings match with our research goal. We especially value the definitions of the actors to extend the measurement model.

2.2 Capabilities in manufacturing

In the first part of this section, we reviewed the literature which discusses scope, roles and capabilities of factories. Koerber *et al.* (2003) provided us with a detailed description of the independent construct of our conceptual model, the types of factories. In the following part of this section we extend the description by Koerber *et al.* to refine the measurement model. We evaluate the literature on manufacturing and supply chain integration, and focus on those publications which deal with business networking to extend the description of the Low-cost factory and the Cooperative factory. In addition, we review the literature on operational excellence to extend the descriptions of the remaining types of factories. However, both branches have been the focus of a tremendous amount of new research, hence we touch on only those findings with significant weight in this area. At the end of each part of this section we summarize the learning and how we link it to our research.

2.2.1 Types of factories

Factories differ from one another significantly. A factory design is dependent on the environmental context which is the market, the actors in these markets, and the technology of products and processes. Koerber *et al.* (2003) described different types of factories for different industries. We now briefly summarize their explanations. This will become the foundation of our conceptual model and measurement model because their theoretical description matches best with the exploratory case described in Chapter 3.

Koerber *et al.* (2003) divide factories into different types according to their capability pattern. Their description of factory types is based on best-practice sharing, or benchmarking, and focuses on the areas with scientific knowledge. Using this approach, they postulate that the planning certainty for factory planners will be increased if they can assign the factory to be developed to a certain factory type. Management can thus permanently resort to successful examples of solutions. Koerber *et al.* (2003) make the point that the type of factory may change again and again because completely new market conditions can arise continuously due to new product technologies or radically changing market conditions. The development passes through various phases: first as a functional factory, followed by the decentralization phase, the outsourcing phase, the development of partnerships on the same level in the supply chain, until finally a production network (p. 6) is in place.

Our study extends this view and closely examines the connection between market changes and changing factory capabilities. Following Wiendahl (2001), Koerber *et al*. describe factories from three different perspectives: market, company, and processes. Our research relates to the TLC, which, in turn, describes market changes due to technological developments. We therefore focus on the types of factory described from a market perspective – with one exception, the Cooperative factory. They assign this type of factory to the process view. On the market level, factories are oriented to market requirements and adjust to the respective wishes of customers. In the following paragraph, different types of factory are described more closely, following Koerber *et al*. (2003, pp. 9-36). It is not our goal to describe these types down to the last detail; we confine ourselves to the most important characteristics. A summary is shown in Appendix VIII.

The High-tech factory

High-tech factories produce highly innovative products, such as computer chips, and they are frequently found in the electronics industry (Kodama, 1991, p. 124). A major factor for their success is short time-to-market, i.e., the time from the development of the product to its commercialization. This is necessary because product life cycles in these industries are often very short.

High-tech factories appear on the market as technology leaders. In order to maintain this position it is essential to make high investments in research and development. The degree of innovation in these factories is also extremely high. This is defined by the proportion of new developments to the whole portfolio per time unit. Product performance in these factories is being constantly improved. A great deal of time and effort is also invested in quality assurance in order to secure the mostly sensitive application fields of the products and thus their reputation in the market. Furthermore, a high process quality will guarantee a high yield as the manufacturing value is often high due to costly production conditions.

The Low-cost factory

Low-cost factories appear on the market as cost leaders and operate the strategy of minimizing manufacturing costs. Key technologies have already been developed in this field, with the result that investments in product R&D are lower and the rate of change in product technology is therefore slower than, for example, in the High-tech factory. The fundamental criterion for success is lower product costs (Kodama 1991, p. 124). The market price determines the production budget, which may, in turn, partly impair quality or delivery reliability. It is of central importance for Low-cost factories to optimize all production factors regarding production costs to keep costs low.

The whole supply chain has to be considered in terms of total cost of operations. The degree of automation is increased and more and more low-skilled workers are employed. Another characteristic is that material costs make up a large part of the manufacturing costs. We find Low-cost factories particularly when high manufacturing volumes are involved. In order to cut costs even further and to secure the profitability of the products, innovations take place more on the process level (Utterback, 1994, p. 30).

The Flexible factory
This type of factory is relevant in highly competitive markets which demand high-quality, customized products. The goal of the Flexible factory is to produce a high diversity of variants at low prime costs. The crucial criterion for success is the capability of Flexible factories to produce a high mixture of variants. This is facilitated by modularization of processes and components and by a push/pull construct on the supply chain level. By modularization and platform strategies, late customer individualization in the manufacturing process can be achieved (Corsten and Gabriel, 2004, p. 250), thus enabling Flexible factories to respond quickly to the most diverse requirements.

The Breathing factory (Atmende Fabrik)
These factories make sense when market demand fluctuates because of the nature of the product (e.g., perishable goods), the customized character of the product, or for cost reasons (e.g., high inventory or capital cost). Breathing factories can meet fluctuating market demands as their manufacturing processes are highly adaptable. The crucial factor for success is the employee himself: through flexible work and remuneration models or concepts such as “fractal manufacturing”, adaptation of the employees to the order volume can be realized. To deal with order peaks, machines and systems can be used to maximum capacity. All processes are aligned to maximum capacity.

The Velocity factory
These factories are suitable for customized products which have to be available in the short term. Velocity factories are characterized by very short throughput times as the crucial criterion for success is the ability to deliver in the short term. This is guaranteed by very fast and flexible manufacturing, characterized by tight and, in part, parallel one-piece-flow processes and is aligned to the throughput time. These factories work on the pull principle, which means that there are hardly any stocks in manufacturing. Furthermore, the elimination of waste in all areas is rigorously pursued. Transport delays, for example, can be removed by optimizing the manufacturing layout. In this way, potential waiting times are skipped, which further reduces the throughput time. Logistics also play a major role in Velocity factories. Information and material procurement, as well as distribution logistics, must be tightly linked up with the operative processes so as not to jeopardize short-time deliverability. The use of EDI and electronic marketplaces in information procurement, multi-vendor sourcing and the sourcing of standardized component platforms in material procurement or handling unit management (HUM) in distribution logistics are examples of such concepts.

The Cooperative factory
The Cooperative factory is used particularly when products are manufactured to specific customer requirements and so display high variance – while at the same time very fast deliveries are important and the markets are volatile. This means that, above all, production capacities are switched and aligned. According to Kreikebaum (1998, p. 131) components, products, people or information may also be switched. It is possible to distinguish between internal cooperation within a company and cooperation spanning different companies. In the case of internal cooperation, for example, market fluctuations can be compensated for at different locations. In the case of multi-company cooperation,

demand fluctuations can also be compensated for, or a combination of the capabilities of the different partners is used. Optimum use of the respective capabilities can at the same time reduce manufacturing costs. Selection of partners means ensuring that a comparable company culture, a complementary product portfolio and geographical proximity prevail. Production planning is closely coordinated and joint research is sometimes carried out. The processes often work in a pull mode, where Kanban or JIT methodologies are applied. The collaboration between many different partners involves a high level of coordination. The goal is to make maximum use of synergies without jeopardizing the particular competitive advantages of the partners.

2.2.2 Operational excellence

The following discussion enhances the descriptions of the types of factory as discussed above. Operations management has been studied in many different areas. Four key manufacturing performance drivers are identified by DuBoies (1993): efficiency and cost, quality, dependability, and flexibility. These are linked with the key variables: market orientation, experience and product characteristics. In particular, questions are raised about the drivers and inhibitors of operational performance and needed capabilities. DuBoies (1993) finds operational flexibility, i.e., flexibility of capabilities/competences and capacity, important. Larger studies regarding turbulence in operations management were carried out by Hendricks and Singhal (2003), who found that the majority of reasons for disturbances of the supply chain flow stemmed from component shortages, followed, in descending order, by customer order changes, production issues, new product introduction and product wind-down problems, then quality problems and engineering changes.

The following findings support the descriptions of the Low-cost factory and the Velocity factory in particular. The characteristics regarding flexibility, in addition, support the description of the Solution factory.

Flexibility can be seen as a “meta-control” aiming for an increase in variety, speed and velocity of responses as a reaction to uncertainty (Kickert, 1985, p. 24). It has to do with changes in customer requirements, technology, markets and the environment (Fine, 1998). Value chain flexibility, product development flexibility and manufacturing flexibility are of the utmost importance.

Value chain flexibility is about customers’ needs, which enables quick deliveries of a variety of high-quality, low-cost products. Value chain flexibility covers product development manufacturing and logistics (Day, 1994; Zhang, 2001). A value chain was first mentioned by Porter (1985), and can be described as a chain of value-add activities to a product provided by a network of different partners in operation and service.

Product development flexibility enables firms to respond quickly with product modifications. It offers a flexible design which can, in turn, increase manufacturability by simplifying product structures and the use of standardized components or modules (e.g., Clark and Fujimoto, 1991). It enables firms to introduce new products faster and support rapid product customization. On the one hand, costs can be reduced for customization; on the other, manufacturing lead times are shortened and products are delivered in a timely manner. It also enables companies to improve supplier performance, lowering inventory levels. Day (1994) suggests that this requires integration, coordination, and communication across the value chain. Thus value chain flexibility focuses more on customer orders than on improving the efficiency and effectiveness of equipment and processes. Accordingly, manufacturing firms need to develop cross-functional and cross-company efforts, which eliminate bottlenecks, increase responsiveness, and create a level of performance to be competitive (Blackburn, 1991).

Manufacturing flexibility is the ability of the firm to manage production resources and uncertainty to meet customer requests (e.g., D'Souza and Williams, 2000). Zhang *et al.* (2003) stress the importance of manufacturing flexibility, and provide a review of how operational flexibility and an enabling structure are impacting customer satisfaction. Their research focuses on the relationship between competence and capability. They split manufacturing flexibility into flexible competences and flexible capabilities. Flexible manufacturing competence refers to machine, labor, material handling and routing flexibility. Flexible capacity is a combination of volume and mix flexibility, which has a strong impact on customer satisfaction. The breadth and the intensity of flexibility need to cope with changing customer requirements which cannot be provided by only one department or function. It must be a company-wide and supply chain-wide effort to increase responsiveness and eliminate bottlenecks across the value chain (Blackburn, 1991). Thus, manufacturing flexibility is the ability of a company to manage production resources and uncertainty to meet various customer requests. Manufacturing flexibility enables firms to produce the needed quantity of high-quality products quickly and efficiently through set-up time reduction, cellular manufacturing layouts, preventive maintenance, quality improvement efforts, and dependable suppliers. Zhang *et al.* (2003) cite the following more detailed definition of manufacturing flexibility: Machine flexibility is the ability of equipment to perform different operations economically and effectively (Chen *et al.*, 1992). It can be measuredI as the number of operations a machine could perform and the related speed. Labor flexibility allows the workforce to perform a great variety of manufacturing tasks economically and effectively (Upton, 1994). It can be measured as the number of tasks a worker could perform and the related speed of execution and the ability to learn. Material handling flexibility and routing flexibility is the capability of a company to transport different material over multiple paths and routs at the lowest cost. Material handling equipment offers a broad range, mobility and uniformity attributes (Hutchinson, 1991). Routing flexibility enables a logistic system to quickly find alternatives in cases of breakdowns of overflow (Sethi and Sethi, 1990). Measurement of mobility can be the time and cost expended to make a change. Uniformity can be measured by differences in processing time and quality when alternative routs are used. Volume flexibility could be expressed as the ability to operate at various batch sizes economically and effectively. It can be measured as the range of different production volumes where cost differences are little (Sethi and Sethi, 1990). Finally, mix flexibility is the ability of a company to produce different combinations of products economically and effectively at a certain capacity. It can be measured as the number of different sets of products manufactured, and the time and cost incurred for changing the product mix (Sethi and Sethi, 1990).

Link to our research:

Zhang *et al.* (2002) provide a review of how operational flexibility impacts customer satisfaction and give a definition of flexible operations and enabling structures. We specifically use their definition of manufacturing flexibility which comprises machine, labor, material handling and routing flexibility. Flexible capacity is defined as volume and mix flexibility. This extends the definitions of the Velocity factory and the Solution factory.

2.2.3 Integration and business networks

Much research has been done in the area of supply chain and manufacturing integration. The following findings support the Solution factory and the Cooperative factory in particular.

Ferdows (1989) realized a rapid change from a factory focus toward a corporate international factory network. Frohlich and Westbrook (2001) amplified this work and studied the business performance improvements based on the arcs of integration with suppliers and customers. More research followed proving that the degree of integration of a supply chain improves firms' performance (e.g., Stevens, 1989; Lee *et al.*, 1997; Narasimhan and Jayaram, 1998; Hines *et al.*, 1998). For example, Birou *et al.* (1998) and Lee and Billington (1992) posit that process integration across functional boundaries become a major differentiator for competitive success. This would suggest a growing consensus in the literature to see supply chain integration between factories and vendors as well as customers as a differentiator of better performance.

Integration of partners within a supply chain and its impact on business performance

Frohlich and Westbrook (2001) is a key reference among international studies of supply chain strategies and their impact on business performance. They evaluated the integration of partners within a supply chain and more specifically the level of integration of manufacturers with both suppliers and customers. They stress the importance of linking with suppliers and customers and measuring the direction and the degree of supply chain integration activity and its impact on performance. Both supplier and customer interaction were measured, so they tested the direction and the degree of integration activities and grouped them into five different strategies. First, inward facing: if only poor integration was measured in both directions. Second, periphery facing: if either a more intense collaboration was measured with suppliers or with customers – but not with both. Third, supplier facing: intense cooperation was measured with suppliers and a poor collaboration with customers. Fourth, customer facing: if an intense cooperation was measured with customers and a poor collaboration with suppliers. Finally, outward facing: if an intense cooperation was measured with both customers and suppliers. The result clearly indicated that the wider the degree of integration is in both directions, the stronger the positive impact on operational performance. The research of Frohlich and Westbrook (2001) extends the work of Voss (1988) who divides success in manufacturing into three levels: marketplace competitive advantage, which supports longer term success and results in greater profitability and increased market share; productivity increases in manufacturing through a greater throughput at less operational cost; and non-productivity benefits supporting customer satisfaction through better quality and increased service levels in operations like order lead time.

Frohlich and Westbrook define the following independent variables: Access to planning system, sharing production plans, joint EDI networks, knowledge of inventory mix and levels, packing customization, delivery frequencies, common logistics equipment and the common use of third-party logistics. The dependent variables are based on the work of Voss (1988) and defined as manufacturing success. He defines manufacturing success in terms of a company achieving marketplace competitive advantage through manufacturing. This can be achieved through productivity increases which, in turn, can be achieved through decreasing costs and increasing output and non-productive benefits like quality and lead time.

Impact of manufacturing capabilities on supply chain integration and business performance

Rosenzweig *et al.* (2003) extended the research of Frohlich and Westbrook (2001) and proved that supply chains with more integrated players perform better than those which collaborate in a more loosely organized network. Subsequently, they evaluated and proved the impact of manufacturing capabilities on supply chain integration and business performance and confirmed that increased information visibility and operational knowledge improves the responsiveness to demand fluctuations. They emphasized the importance of the procedures of coordination of all internal and external groups and the knowledge transfer to better synchronize the demand management (Rosenzweig *et al.*, 2003, p. 440). In addition, those more integrated supply chains are more cost efficient. In an extreme competitive environment, highly integrated organizations can reduce transition costs toward the development of new capabilities in three areas: Manufacturers with tight linkages to suppliers can correct transaction discrepancies faster; comprehensive information-sharing reduces information irregularities; and self-enforcing protection systems – which are not contractually linked – lower maintenance costs in highly integrated organizations.

Effects of vertical and horizontal integration on customer service and financial performance

Shawnee *et al.* (2003, pp. 523-539) also researched supply chain integration, considering upstream and downstream integration on the one hand, and horizontal integration within the company on the other hand. They define the integrated supply chain strategy as an arrangement of an integrative IT system in combination with supply chain integration, and they test both the value of supply chain integration and the value of technical systems. Many scholars in this area support this and find that technology eases the stream of information between companies and reduces both the coordination costs and the transaction risk of the cooperation (e.g., Holland *et al.* (1992); Frohlich and Westbrook (2001); Lee *et al.* (1997); Narasimhan and Jayaram, (1998); Hines *et al.* (1998)). Shawnee *et al.* (2003) discuss the effects of an integrative supply chain strategy on customer service and financial performance. Their work is an analysis of direct vs. indirect relationships and an examination of the integrated supply chain strategies on customer service performance followed by a firm's performance. Supply chain integration is defined by level of integration of IT and partner integration. An integrated supply chain can synchronize the requirements of the customer with the flow of information in combination with the flow of material to reach a balance between cost and customer service. Partner integration is supplier partnering, a close customer relationship and cross-functional teams, all of which support customer service thinking which, in turn, is defined as pre-sales, product support, responsiveness to customers, delivery dependability and delivery speed. The results of our research extend our descriptions of the Low-cost, Velocity and Solution factories.

Effects of internal versus external integration on time-based and business performance

The effects of internal vs. external integration practices on time-based performance and on overall firm performance have been proven by Droge *et al.* (2004). External integration is considered as strategic design integration and is measured as supplier partnership and supplier development, and closeness of customer relationship. This includes active feedback on supplier performance, site visits, clear goal-setting regarding performance expectations, as well as training. Supplier partnering goes further as it treats the participating suppliers as strategic partners and includes them in the company. Clearly, they also better utilize their technological capability (see also Narasimhan and Das, 1998). Closer customer relationship is also a partnership development which enables the firm to proactively determine customer requirements. This again improves timely responsiveness to customers and increases the difficulties for competitors to interfere (Stank *et al.*, 1999). Internal integration, also called design process integration, is about the match between design requirements and process capabilities and enables a seamless transition from R&D to the shop-floor. This is supported by several methodologies and technologies: concurrent engineering, design for manufacturing, standardization and the use of CAD as a tool for interactive engineering. Concurrent engineering (CE) overlaps product and process design to achieve a simultaneous development process. According to Swink, (1998) and others, CE includes product design, testing and production, focusing on manufacturability and also competitive uses and product life-cycle considerations. Design for manufacturing (DFM) enables fast new product introduction into the manufacturing process (Droge *et al.*, 2004). Standardization includes the use of standard procedures, materials and processes. Much research has been done in this area (e.g., Millson *et al.*, 1992, Clark and Fujimoto, 1991; Cooper and Kleinschmidt, 1995), and researchers consider the following attributes to speed up the innovation process: The use of CAD, supplier involvement, overlapping product development stages (e.g., CE), and multifunctional teams and supplier involvement.

Strategically managed buyer-supplier relationships and their impact on business performance

Supply chain management and supplier relationships management has been analyzed by Carr and Pearson (1999). They found several success criteria: The existence of a strategic purchasing organization, a supplier evaluation and development system, an actively managed buyer-supplier relationship, loyal and value-based cooperation, frequent face-to-face meetings, and high corporate level communication with direct EDI links. The supplier evaluation system is composed of a formal supplier certification program linked with a formal system to track the performance, and a formal evaluation and recognition of suppliers. Carr and Pearson define strategic purchasing as a process of planning, procurement strategy implementation, evaluation and controlling. Particularly for supplier management, this includes identifying, qualifying, selecting, evaluating, developing and certifying suppliers (see also Watts and Hahn, 1993). Carr and Pearson (1999) define strategic purchasing as having a formally written long-range plan which is regularly reviewed and adjusted considering various types of supplier relationships.

Dynamics in supply chain partnering

Another empirical study of the "dynamics" in supply chain partnering has been done by Boddy *et al.* (2000) in which they define partnering and define seven business processes for partnering and how human interaction can positively or negatively impact a successful partnership. In their research they consider both the collaboration with suppliers and with customers and they look at the process of cooperation and the needed skills. Elements of partnering are: technology, which includes the type and location of fixed assets like buildings, machinery, and the information systems used by all partners; resources, which cover mainly the financial resources which are available; how to deliver the goods and services – internally and externally; the people and their related knowledge, skills, attitudes and goals; the culture; the power of the people participating in a collaboration (see also 2.2.1).

Smart business networks

This topic was discussed by Vervest *et al.* (2005) who defined a smart business network as a group of participating businesses, organizational entities or "actors" that form the node. Important capabilities in smart business networks include the establishment of a common understanding and common ethics, having compatible goals and a mechanism to share risks and rewards. They can select the best capabilities of the actors in the network. These actors, playing in unison, can be quickly connected and disconnected. Each participant perceives increased value so that these networks are sustainable over time. A competitive capability is the ability to construct and manage such a supply chain. Van Nunen *et al.* (2005) concluded that collaboration with customers and suppliers enhances the performance in supply chains and makes them more sustainable. However, there is a need for enabling technologies to support data exchange, automated control mechanisms and integrated planning. Wolters *et al.* (2005) stressed the fact that networks with modular processes, products and networks achieve better profits and greater customer satisfaction – but only if customers participate and the organization is technologically capable of managing the increased information (and collaboration) complexity. Koppius and van Heck (2005) discussed adaptation and adaptability of networks and found that there are two types of configurations which demand their own business logic and rules: the supply-driven and the demand-driven network.

Manufacturing networks

Manufacturing network management and the network structure of manufacturing systems is another important cornerstone of our research, and a great amount of theory has been developed around this topic in recent years. Ferdows (1989) found that each factory in a manufacturing network plays a different role: off-shore, source, serve, contributor, outpost and lead. He focuses on the relation between network and its factories. Flaherty (1986) discovered that international factory networks are driven through their geographical structure and a shared common infrastructure. De Meyer and Vereecke (1994) determined two types of manufacturing network architecture with either a process focus or a product focus, where each has great impact on the roles and responsibilities of the factories. They found that a process-focused company typically operates less autonomously than the factory in a product-focused company.

Links to our research
Collaboration takes place in different types of factories. This is especially true for the Cooperative factory, the Low-cost factory and the Velocity factory. The literature discussed in this section serves to extend the description of our measurement model and the interview questions. The parameters which we use are summarized as follows:

We integrate Frohlich and Westbrook's (2001) measure regarding the direction and the degree of supply chain integration in our research measurement model.
Rosenzweig *et al.* (2003) extended the measure of Frohlich and Westbrook (2001). They evaluated the competitive capabilities provided by manufacturing to enable internal and external (raw material suppliers, distributors, customers) supply chain integration. The key capabilities they found are: increased information visibility combined with comprehensive information sharing; operational knowledge sharing; having procedures for the coordination of all internal and external groups; and knowledge transfer to better synchronize the demand management.
Shawnee *et al.* (2003) discovered that an integrated supply network is specified by an integrative IT and supply chain integration, supplier partnering, a closer customer relationship, and cross-functional teams. This supports customer service thinking which comprises pre-sales, product support, responsiveness to customers, delivery dependability and delivery speed.
Droge *et al.* (2004) evaluated the importance of external (supplier and customer) and internal (design and concurrent engineering) integration. They found the following to be important: Supplier partnership and development, close customer relationship, concurrent engineering, design for manufacturing, standardization, and the use of CAD as a tool for interactive engineering.
Carr and Person (1999) researched the significance of buyer/supplier relationships and found the following to be important: The existence of a strategic purchasing organization; supplier evaluation; an actively managed buyer-supplier relationship; a loyal and value-based cooperation; frequent face-to-face meetings; high corporate level communication; and direct EDI links.
Boddy *et al.* (2000) evaluated supply chain partnering in a dynamic environment. They defined the following elements of partnering: common business processes; technology, which includes the type and location of fixed assets like buildings, machinery, and the information systems used by all partners; understanding how to deliver the goods and services – internally and externally; the people and their related knowledge, skills, attitudes and goals; the culture; and the power of the people participating in a collaboration. The conclusions regarding smart business networks provide us with the definition of the actors and the characteristics of business networks. Ferdows (1989) and De Meyer and Vereecke's (1994) findings facilitate our research regarding the definition of the type of manufacturing network. Ferdows (1989) found that each factory in such a network plays a different role.

Vervest *et al.* (2005) found that in smart business networks, a common understanding and common ethics are important. They have compatible goals and a mechanism to share risks and rewards, where actors, play in unison. Wolters *et al.* (2005) found modular processes, products and networks important.

2.2.4 Local and global manufacturing (geographical organization)

These topics are relevant because they address the question of local versus global manufacturing and the role of the local factory. In addition, they provide further explanation concerning the Cooperative factory. This is further analyzed in Section 8.5.

Hirst and Zeitlin (1991) found two different views of local industries. First, a geographically-localized network of small firms that sub-contract within the network and share services to extend the capacity or capability of a firm. Second, a split of firms into decentralized autonomous productive units, which continue to benefit from the research, marketing and finance of other divisions of the parent company. Our research focuses on the second view. Nassimbeni (2002) picked up the discussion about local manufacturing systems and the global economy to see if they were compatible. He confirmed the correlation of firms' competitiveness on the international markets and their territorial roots. Some researchers found that globalization exposed the limits of local manufacturing systems since they may be under-sized and therefore have difficulty accessing adequate technology and financial support (see also Gottardi, 1996; Grabher, 1993). However, smaller firms often have to work in a cluster, which has several advantages and disadvantages. An example of the latter is the greater complexity required to align strategies. Nowadays, local enterprises must go beyond borders and collaborate over an extended geographical area. This requires the modification of values and rules of these local manufacturing systems. Nassimbeni (2002) summarized the main features of the local industrial district (local manufacturing) as follows: "*High proportion of small and very small firms; clustering of firms in a geographical location; firms engaged at various stages of production – intense specialization; dense networks of a social and economic nature; blend of competition and cooperation between firms; rapid and mainly informal diffusion of information and new ideas; adaptability and flexibility*". According to Piore and Sable (1984), a strong inter-firm distribution of labor among clusters of small firms, linked by horizontal and vertical relationships, can lead to greater collective efficiency than that of a larger-scaled "Fordist" enterprise. Best (1990) found that local firms can continuously adjust and improve their economic performance through quasi-spontaneous coordination mechanisms when entrepreneurial attitudes facilitate innovation. Porter (1990, 1998) discovered that a geographical concentration of manufacturers can increase productivity because the access to knowledge and other factors involved in production becomes easier. In general, this demonstrates the greater dynamism of small firms and their related manufacturing systems. Also, within the content of globalization, local firms and their manufacturing systems can reward differences, variety, and specificity (May, 1990). He argued that a firm's competitive advantage is rooted in its territorial environment, where knowledge, relations and interactions regarding the production processes can be exchanged. Nassimbeni (2003) concluded that a global economy will favor a greater geographical split of labor and additional specialization. On the other hand, it also offers opportunities for the development of local systems using territorial specific resources and competencies. Nevertheless, local firms must change to compete in a global environment. From a manufacturing viewpoint, Nassimbeni (2003) argued that in a global environment leading firms usually locate the local part of their value-add into the local district, defining how the work should be distributed and selecting the external partners. Thus, he characterizes the following combination of tasks for the local factory. First, manufacturing tasks, which include system flexibility and flexible specialization. D'Souza and Williams (2000) describe manufacturing flexibility as the ability of the manufacturing function to make the necessary modifications as a reaction to environmental changes, without significant impact on performance. Flexibility in this context refers to volume, variety, process and material handling flexibility. At least three of these dimensions were very well performed by local firms (Nassimbeni, 2003). This is due to the often higher flexibility of the workforce (time, skills) of the local manufacturing firm and a wider mix of specialist capabilities. Nassimbeni (2003, pp. 154-155) concluded that "*the units of a local system are legally and economically independent; therefore, their entrepreneurial attitude, motivation and levels of control are better than those of production departments in a large- size integrated enterprise. They can often have significant fiscal advantages too. Thanks to these characteristics, flexibility in local systems is achieved at relatively low cost.*" Second, he discovered manufacturing choices which represent the strategies which can be chosen for the manufacturing system. According to the literature, several views and dimensions can be considered, for example, the complexity of manufacturing technology, the maturity of the processes and the sophistication of the product and the production method. Nassimbeni concluded that there are two views: the level of vertical integration and the geographical manufacturing scope. The vertical integration describes the manufacturing depth and thus the number of internally managed processes. The geographical manufacturing scope of local manufacturing is typically limited to a local, and therefore limited, distribution. Nassimbeni argued, therefore, that a combined effect of specialization and localization is advantageous, thus justifying the development of a local manufacturing system. Local manufacturing has a more specialized and therefore focused workforce which has a positive effect on economy of scale and experience. Local sourcing has a positive effect because of the proximity to partners that offer specific services, specialized labor, support infrastructures, lower transport cost, simpler interaction and common cultural identities, etc. Prasad and Babbar (2000) argue, on the other hand, that global set-ups with their facilities in low-labor countries can often offer better flexibility/cost ratio with fewer legal environmental restrictions, lower site cost, lower salaries and access to certain resources like other suppliers or natural resources. The local system may have limited financial sources and need longer time-to-market since a network of partners must be aligned.

We assume that the right configuration of the supply network depends on the characteristics of the industry, and is a very important decision for competitiveness in the later stages of the TLC.

2.3 Summary

In this section, we present a summary of the two streams of literature discussed above. The links to our research have already been discussed at the end of each part in Sections 2.1 and 2.2.

2.3.1 Summary – TLC theory

The literature discussed in Section 2.1 provides us with a description of the phases of the TLC. It illustrates how the environment changes if a product technology matures. In addition, it suggests different strategies. Some researchers advise high-tech companies on how to adapt the core competencies that make it possible for established firms to bridge the gap caused by technological change – from a marketing perspective as well as from a process perspective. We have seen that some researchers propose that the high-tech company should adapt its marketing strategy, while others discuss an operational management approach. The later approaches are presented in
Figure 6.

The literature on TLC research discussed in Section 2.1 can be split according to two different views. The first approach adopts the S-curve research with the relationship indicating the change in market share over time. The classic research is Rogers' theory. He divides the different phases along the TLC into five main marketing segments – innovators, early adopters, early majority, later majority and laggards. These five phases and their descriptions will set the basis for the contextual framework of our research (see Chapter 4). The second approach adopts the S-curve research regarding the relationship between the product performance and investment and efforts over time. This kind of TLC description differentiates the phases according to new technology development processes. These phases are: stage of state-of-the-art, advanced, mainstream, maturity and the stage of decline.

The main findings can be summarized as follows. Most of the high-tech companies follow a similar pattern – the TLC. When the core technology of a company moves towards maturity while investors demand new growth, management in the high-tech company tries hard to develop good strategies. In most cases, a more complicated technology is created. Thus, many companies fail to create the required growth fast enough because of their ignorance of the marketing change along the TLC and their inability to reengineer the business. Moore suggests that Rogers' classic model of the TLC is an ideal situation. Actually, there are several gaps between every two market segments. It is dangerous for a high-tech company not to recognize these transition points. Moore's discussion extends our description of the TLC phases as defined by Rogers. Utterback presents the model of product innovation and process innovation, which is very important for a high-tech company's further development when the technology and products mature. The model provides a framework forf how to process the product and production development as the technology goes into the late stages of the TLC. Utterback's findings provide a description regarding the changing process- and product-focus along the TLC phases of a company. Christensen's theory enforces the notion that a firm should pay more attention to developing disruptive technology and that a focus on low-cost manufacturing is not sufficient at the end of the TLC because it is not advantageous for a company if the long-term development is based on obsolete technology at low cost. Christensen's findings regarding the switching of capabilities provide us with further descriptions of the phases of the TLC. Norman's advice to high-tech companies is similar to that of Moore. He suggests a "3-leg chair" model, pointing out that a company must set the same value on technological development, marketing and user experience. A company should make the transition from technology-oriented to customer-oriented company. His findings regarding the two major types of customers provide a description of the customer characteristics. A summary is presented in Appendix IX.

2.3.2 Summary – Operations management

The most x-rayed area within the field of OM literature is operational excellence. To understand the drivers of change in this area, all possible turbulence in the supply chain and its impact on operational performance and business have been researched. The majority of issues come from inside the company, rather than from customers and suppliers. This challenge can be controlled by using a number of management tools to realize potential supply chain and operational issues earlier and resolve them more quickly. Operational flexibility overall is seen as one of the most important assets an operation can have. Flexibility supports customer – and shareholder – value since it aims for an increase in variety, speed of delivery and of response time to customer wishes and changes, and from a more strategic view, reduces time-to-market. Value chain flexibility focuses more on customer requirements than on improving operational efficiency and effectiveness.

Porter (1980 1985) set the theoretical foundation of supply chain integration. Frohlich and Westbrook (2001) extended his work and started to evaluate the value of integration. Much research followed and confirmed that tighter cooperation and data sharing and a more integrated supply chain strategy have a positive impact on companies' cost and service competitiveness, time-based performance, and ultimately business performance. Many researchers state that the use of technical applications supports supply chain management and tighter collaboration between the supply chain partners. Others evaluate different supply chain methodologies – such as concurrent engineering, design for manufacturing, etc. – and acknowledge the value of these approaches for the overall performance of firms.

The management of supply and manufacturing networks is the consequence of the supply chain integration trend which, in turn, is triggered by the changed driving market forces like global market opportunity, new patterns of competition, and reorganization of potentials. Several structural and infrastructural capabilities of the operations must be managed to control the manufacturing network. Overall, strategic capabilities and the capacity to recognize and react rapidly to a change in the environment are now very important. Manufacturing competitiveness nowadays heavily depends upon network construction rather than separate factory nodes. Other lower level capabilities of such an international manufacturing network have to be established in order to serve as a presence in the marketplace, to increase efficiency through networking and to gain manufacturing mobility, and learning ability. A fundamental question is the geographical organization of the supply and manufacturing network and the horizontal and vertical split of roles and responsibilities. A focus on both processes and products is needed. Thus, the way these networks collaborate is becoming essential to business success. The center of all thinking must be customer service or customer value, linked with an intense relationship in partnership through cross-functional teams. Herein, an important asset is the ability to understand customer needs, which can be achieved through tight linkages with customers – also on the supply chain level. It is also important to be able to quickly link/unlink with supply chain partners who have complementary skills, as a result of a change in market or customer requirements. The process of partnering is also an important aspect. This is very much dependent on the history of a company, the industry and local/geographical proximity.

In the area of geographical organization of manufacturing, there are two streams of literature. Some researchers argue for a local/global structure of smaller manufacturing set-ups, while others see a trend toward global/off-shore set-ups. However, they all agree that this decision is of great importance and depends on the industry, the markets and the products.

For the purposes of our research we deduct variables from all these areas to build the conceptual model as discussed in the parts "Links to our research" in the sections above. The changing capabilities of the local factory over the TLC are measured according to how the factory handles operational excellence, how it changes its collaboration focus (internal vs. supply chain oriented), and how the shifting dynamics and glitches change the way it operates. A summary is shown in Appendix VIII.

2.3.3 Extending the existing literature

Gap in the literature

Current studies on the TLC are scarce and can be classified as fragmented. This applies in particular to those that focus on the link between the market view and the operational view. Most research on the TLC considers the market/technology relationship and offers suggestions for a whole company strategy. However, researchers do not explicitly refer to the impact of the TLC on manufacturing. Utterback underlines this view since he discusses product and process innovation. Fine discusses the clockspeed of a whole industry and deducts the "double helix" model which explains the supply chain structure of industries over time. More of that will be discussed in our research conclusion. Furthermore, there is no accepted measurement model which helps to identify the particular TLC phase a manufacturing operation is facing. This has to do with the fact that it is extremely difficult to identify clear criteria for distinguishing the phases of the life cycle (McGahan *et al.*, 2004, p. 16).

On the other hand, there are numerous studies about manufacturing excellence. Many researchers have focused on the basic operational excellence variables: quality, dependability, flexibility and cost. Recent research has focused on integration strategies within the factory or for the whole supply chain. Also, dynamism forces causing turbulence in supply chains have been discussed intensively in the literature.

Nevertheless, we have come across no theories linking manufacturing capabilities with the market characteristic changes triggered by the technological evolution of a product. That is why we structure our thesis as two interlinked parts. First, we address the problem of technological forecasting and the measurement of the TLC phases. Second, we look at capability management in manufacturing and how this is interfered with by the TLC. We focus in particular on the impact of the technology evolution on the manufacturing capability needs, and when and in what sequence they are needed, this being a gap that our study seeks to fill. We develop a system to measure the impact of technological evolution on the capabilities of a factory, something which has been overlooked in the literature so far.

3 EXPLORATORY CASE STUDY – HEWLETT PACKARD

In this chapter we present the case of Hewlett Packard (HP), a global player in the computer hardware and peripherals business. HP develops, produces and sells computer products – from handheld devices to large enterprise-wide computer solutions. The HP example serves as an exploratory case upon which we deduce the research propositions and our conceptual model. It therefore also contributes to the development of the standard research interview procedure used for the two validation cases.

In Section 3.1, we give an overview of the business, followed by the supply chain structure, the factory structure and strategies. We continue the discussion with the contextual perspective on capability switching along the technological evolution of the products produced. Based on the feedback from HP management, we have divided the evolution into four phases. Phase 1 describes the situation before the 1990s; Phase 2 describes the era between 1990 and 1998; Phase 3 covers the phase from 1998 to 2002, and Phase 4 the situation from 2003 to 2005. For each time phase, we develop the contextual frame for both dimensions of our conceptual model. First, for the contextual framework – the TLC – we give a general overview of the market characteristics and describe how prices and margins have evolved. We continue by discussing the evolution of customer requirements and the changing importance of the competition. In addition, we put forward the evolution of product technology as a possible driving factor of market evolution. Second, for the manufacturing capability development we present different perspectives regarding technology, cost, flexibility and speed, and then solutions and networking. For simplicity, we will call the factory and its respective business units “HP”. The description of all the cases follows the same chapter structure and uses the same key words. These key words are marked in bold to ease the pattern matching process during data analysis.

In Section 3.2, we present the interpretation and conclusions of the HP case. For each time phase measured (noted in Arabic figures 1, 2, 3, etc.), we evaluate at what point HP experienced which phase of the TLC as described by the literature (noted in Roman numerals I, II, III, etc.) and how HP switched its factory capabilities accordingly for best-in-class manufacturing. In Section 3.2.1, we give an overview of an HP definition of a TLC model to better explain HP’s decision on a worldwide supply chain level. The phases described there correspond with the phases discussed regarding HP’s factory case description. In Section 3.2.2, we study each of these time phases in detail. We start by presenting two different tables resulting from a pattern matching analysis. From a research process perspective, there is no need to further analyze an exploratory case with tools like a pattern matching analysis. However, we applied our measurement instrument, as developed in Chapter 4, to the HP case at a later stage of the research process. Our motivation was to post-validate our newly developed instrument, to better explain the findings by using this tool, and to exemplify at this point the way that the validation results are presented later in this research. These HP validation results are shown in Table 2 regarding the types of factory and Table 3 regarding the TCL phases, and in more detail in Appendix V.

Section 3.3 is most important. Based on the results of Section 3.2, we deduce in this section the research propositions and the conceptual model of our research.

3.1 HP case description

3.1.1 Data gathering

Data are based on intense discussions with different managers over a period of several months in 2005. A large amount of company information was available, including details of supply chain strategies, factory strategies and processes, the company financial statements, company documents and published articles. This extensive data collection was completed by gathering company reports and documents and HP's public web pages.

The following managers were our main contacts during the discussions: Tom Viola, the worldwide manufacturing manager {Worldwide Supply Chain Manager}; Heinz Schmid, the European procurement manager {Procurement Manager}; Conny Gauss, the European marketing manager {Marketing Manager}; and the author of this research, the European Operations Manager. Many discussions, face-to-face and on the phone, and many written notes provided deep insights into the decision processes and the strategies behind the worldwide decisions impacting the local factory.

3.1.2 Company introduction

Industry

In the early 1970s, IBM was the major player in the computer market and was very profitable. The company used an integrated product architecture with which competitors' products were not compatible. Customers were not able to combine products of different computer vendors. In the late 1970s, Apple computers increased the market pressure and IBM "created" the personal computer (PC). This new product created a very dynamic market environment. The dominant product was no longer the "IBM computer" but the "IBM-compatible computer". The industry rate of change increased and the products became modular. This lowered the hurdle for smaller vendors to enter the market. More and more system modules were now provided by these suppliers. Consequently, the supply chain changed from a vertical to a horizontal structure (Fine, 2003, p. 207).

The computer business is now one of the most dynamic industries; in recent years few industries have received as much attention as IT. A major reason for this is the speed of technological development. The so-called 'computer revolution' began approximately 25 years ago with the invention of the PC. It is thus only one generation old (Stiller, 2001). This level of innovation and fast development led to very short product life cycles for computers, accessories and peripherals. Today, the life cycle of a server ranges from six months to two years. Hence, the IT industry can be defined as a fast-changing industry (Fine, 1998) where companies have only a short timeframe to pay off the costs of development. Within the low-end and mid-range sector, margins have become so small that costs can only be amortized by additional supply chain services, after-sales support and consulting. This trend has certainly been impacted by the TLC of this industry. While the industry is dominated by large and global companies, small firms have been able to enter the market, some of them with innovative technologies. Demand fluctuates greatly from month to month, quarterly and seasonally. During winter months, for example, it may be up to four times greater than in the summer. This high volatility makes planning extremely difficult. Consequently, computer manufacturers utilize weekly but also long-term forecasting in collaboration with suppliers and customers to cope with this dynamic environment (Johnston *et al.* 2004; Kulp *et al.* 2004). Not only manufacturers but also suppliers and distributors have to find an adequate response to be flexible enough to deliver value to the final customer. The integration level in this industry is high – all the companies involved are jointly responsible for the delivered product or service.

With respect to the firm's driving forces, price is one sales criterion. Computer manufacturers emphasize quality but with strict cost targets. Feedback is formally gathered and evaluated, and daily contact with major customers is maintained. Communication links are essential to allow customized cooperation as well as efficient data gathering and regular face-to-face meetings and EDI links are established between many vendors and customers. Services and solutions selling has become a major differentiator, and much of this effort comes from the supply chain operations (Craig and Douglas, 1996b and 1996c; Johnston *et al.* 2004; Kulp *et al.* 2004). To achieve these strong price targets, outsourcing and subsequently off-shoring play a major role in computer manufacturing in the later stages of the TLC. Thus, strategic purchasing has become an essential part of strategic planning for computer companies. In recent years, most companies have undergone some changes in their purchasing department, which has often been integrated into supply chain planning and logistics, thereby improving information sharing and company profitability. Strategic purchasing also seems to have earned the support of top management (Chen *et al.*, 2004). Product technology is also continuously changing. Only five years ago, technology changes occurred about every one to 1.5 years. Today, product life cycles are as short as three months, and some components alter in as little as six weeks. As technology cycles become shorter, innovation gains in importance. Therefore, manufacturers and their partners have to continuously work together to share knowledge and information (Dyer and Hatch, 2004; Kulp *et al.*, 2004).

HP Company profile

HP was founded by Bill Hewlett and Dave Packard in Palo Alto, California, in 1939. In 1959, HP established its first manufacturing plant outside the USA, in Böblingen, Germany. In 1999, HP switched its worldwide business strategy and decided to focus solely on the computer business. From its original core business, HP pulled out $8 billion in revenues and about 30,000 employees to create Agilent Technologies. Agilent Technologies business covered manufacturing scientific instruments, semiconductors, optical networking devices, and test equipment for telecom and wireless R&D. In 2002, HP merged with Compaq Computer Corporation, thereby becoming the world's largest manufacturer of personal computers.

In 2004, HP was organized into four business segments: Imaging and Printing Group, HP Services, Personal Systems Group and the Enterprise Systems Group (ESG). The ESG produced servers, mass storage devices, network solutions, software and other business solutions. The Computing Systems segment was worth $15.2 billion in sales revenue. The

ESG had distribution centers located all around the world, including three in the United States, two in Europe, two in the Middle East, two in Africa (EMEA), one in Tokyo and one in Singapore. Two factories located in Scotland and Germany/Herrenberg near Stuttgart served the European market. For EMEA, 90% of the shipments were delivered to Central Europe, 3% to Eastern Europe, 3% to South Africa and 4% to the Middle East.

Back in 1939 HP's first product was invented in a garage in Palo Alto, California. It was a sound oscillator, an electronic testing instrument used by sound engineers. One of the first HP customers was Walt Disney Productions, who bought eight "Model 200B" oscillators. HP earned global tributes for a variety of innovations, especially in the field of calculators. HP introduced the world's first handheld scientific electronic calculator in 1972, the first handheld programmable calculator in 1974, the first alphanumeric, programmable, expandable calculator in 1979 and the first symbolic and graphing calculator, the HP-28s. Just like the scientific and business calculators – the oscilloscopes, logic analyzers and other measuring instruments, had the same reputation for sturdiness and usability. HP's idea of design at that time was "to design for the guy at the next bench" (Packard, 1995). The first ink jet and laser printers for desktop computers were introduced by HP in 1984. Along with its scanner product line, these were later developed into successful multi-function products.

Factory overview

The case describes the HP factory in Herrenberg, Germany. The factory produces workstations that provide UNIX, Windows and Linux based systems. The UNIX server offerings range from low-end servers to high-end scalable systems, capable of handling large-scale applications and databases used in online transaction processing and cooperative product development.

In all, the Herrenberg plant produces 2,000 different products with more than 10,000 options and offers 19 languages. The plant produces 80,000 boxes per month (18,000 different orders) and generates annual revenues of nearly $2.5 billion. Much of what the Herrenberg plant produces consists of high-end, complex IT infrastructure solutions for mission-critical projects. The key customer product requirements are high performance, reliability, scalability and security. Fulfillment of these requirements necessitates interactions with channel partners and customers, and integration of their design needs. Product demand can vary from anything between $0.5 million (equivalent to a single high-end system or 100 workstations) to $16 million (32 high-end systems or up to 1,000 workstations) a day. Coping with this kind of volatility requires immense flexibility at the shop-floor level in order to avoid incurring inventory carrying and obsolescence costs, on the one hand, and lost sales or dissatisfied customers, on the other hand. The HP factory in Herrenberg has won several awards.

In the following sections we describe five time phases regarding the changing market conditions, at HP and how the supply chain and the HP factory in Germany adapted. Keywords as used in our measurement system (Chapter 4) are marked bold.

3.1.3 Phase 1: Before the 1990s

3.1.3.1 The end-market and customer evolution

Before and during the 1980s, the company had a reputation for consistently making products on the leading-edge of technology and of the highest quality. As a result, it could charge a significant premium over its competitors. Investment in R&D was maintained between 10% and 15% of revenue, and to meet the innovative designs for new products it was necessary for manufacturing to develop new processes and capabilities because the product specifications could not be met by commercially available components. HP declared **product technology,** product performance and product quality to be the most competitive elements. The computer products had not been designed for operational simplicity and planning efficiency. Design for manufacturing was not considered during the product design. Customer and country options were hardwired with the processor board. Different technological options, language options as well as localization options, created different Stock Keeping Units (SKU) resulting in 3,500 different products. The sheer number of SKUs in the factory portfolio made planning and forecasting very complex, and there was enormous uncertainty about results.

From a **market** perspective, this phase was characterized by constantly changing product and process technologies and significant volume growth. On the other hand, **customers** accepted an order cycle-time of more than three months, which compensated for this uncertainty to some extent. The factory faced a revenue and unit growth of 35%-40% per year. The **competitive situation** was still manageable because the overall market growth and market differentiation was based on product technology only. **Prices and margins** were so high that tight budget control did not play a major role.

3.1.3.2 Supply chain evolution

The company at this time had many facilities dedicated to several different manufacturing capabilities: wafer fabrication centers producing memory chips, transistors and integrated circuits, and even “tool and die shops” for special metal components and screws. In addition, HP had printed circuit board fabrications (PCB), sheet metal and finishing facilities, plastic molding facilities, printed circuit assembly and test operations (PCA), and final assembly and distribution (FA).

From a procurement perspective, all material components were treated more or less “opportunistically” because a materials management strategy was missing. However, a lot of emphasis was put on the process technology progression within manufacturing. The **supply chain process technology** was poorly developed and, overall, the arcs of integration were low in this phase. Vertical integration in manufacturing was high and little importance was placed on working partnerships with suppliers. Vendors had no access to planning systems. The major suppliers got a monthly rolling forecast for their products via e-mail; other suppliers got no forecasts or production plans. Inventory mix and inventory levels were only known by the internal planning organization. Collaboration with customers and channel partners did not take place.

From an **inbound** perspective, in many cases the local factory received components as raw material from other internal HP divisions to produce parts according to the customer order in a pull mode. HP produced processors and monitors centrally in the US, and memory and graphic boards were built in Puerto Rico because of the tax advantage there. PCB and PCA

took place in specifically designed buildings in southern Germany, where final assembly was made in a multi-purpose office building which provided a sub-optimal environment for computer mounting. However, the geographical closeness of these main production steps simplified collaboration and increased flexibility. Material supply came from seven warehouses scattered across southern Germany.
For **outbound** distribution, several distribution hubs had been installed where all components belonging to an order were consolidated to make complete shipments to customers possible. The main distribution hub was close to Frankfurt Airport, while other hubs were located across Europe.

3.1.3.3 Factory evolution

This description focuses mainly on the final assembly process. Printed circuit production and assembly are treated secondarily because they were outsourced in a later phase of the HP factory.

Manufacturing **process technology** development was crucial to building the fast-evolving computer technology. Shop-floor planning was complicated since manufacturing depth was complex. The manufacturing bandwidth ranged from sheet metal molding to power supply wrapping, memory mounting, disk storage assembly, printed circuit board production and assembly for graphic boards and the motherboards up to the final assembly of the computer with some customization, testing, packaging and documentation.
Since older low-running products, as well as newer or high-runner products, were treated the same way in the factory, a product portfolio management function had not yet been implemented. The factory was still not very automated since the processes were complicated. Standard components were not used a lot and product innovation speed was exceptionally high. The process flow of most production steps within the factory was sequential – step by step. Printed circuit board assembly was part of the final assembly process, for which operators needed to memorize the sequence of the assembly processes. There was no support by a system until 1989 when the shop-floor system was changed and the so-called ‘half-automated’ tables started to support the operators. The system opened a specific push loading drawer on the assembly table to provide the right electronic component and then flashed the spots on the board where this electronic component had to be placed. This happened step by step. ESD (Electro Static Sensitive Device) safety was implemented simultaneously. Final assembly was supported by a manual control panel showing which computer was waiting or was being processed and where. Production plans were scheduled in production just before start of assembly.
The types of machines in operation were quite different. Heavy machinery was needed in sheet metal production, printed circuit board production and printed circuit board assembly. Other, lighter machines were used for power supply multiple-turn coiling. Pre-assembly of kits, final assembly and testing, kitting, packaging and customizing were manual, with only a little system support.
Capacity planning was not a critical element since customers did not expect short and precise delivery. Production capacity planning was a manual process, all material plans were based on forecasts, and available to promise (ATP) checks did not exist. This resulted in an on-time delivery against the first customer acknowledgement of roughly 64% and very long order cycle times of up to 80 days per order. The labor workforce was 100% HP-

owned with some contractual flexibility to shift work time according to the order book situation. Order volume fluctuations could therefore not really be considered at that time since all contracts were based on "standard" work times requiring eight hours per day in two shifts. The workforce was fixed and a long-term adoption was only possible with a small flexible pool of students. On the other hand, the required staff skills level changed over time and a transition from a direct labor focus to an engineering content was realized, driven by the complexity of the products.
The IT systems were still proprietary and not very integrated. HP used a self-developed materials planning system (MRP) and a separate – also self-developed – shop-floor system. Order management received the orders through the sales system, and checked manually whether orders were realizable and if material and capacity were available. Some IT systems were linked by batch oriented processes.
Material planning treated all components with the same priority. From a general operational process perspective, all products followed the same processes – from order management to final packaging in production. Product technology, product value and size were not yet considered to be drivers of a differentiated process design. Processes had not yet been integrated and were split into segments as a consequence of a distinctive "silo thinking", a functional hierarchical organizational set-up and batch process oriented IT systems. The main challenges had been seen in material availability and material quality, test capabilities and management of the manufacturing depth. The focus was on the operational effectiveness of these high-tech products but not operational efficiency since capital budget and manufacturing overheads were not at the center of management attention. The focal point was to get the product and production technology under control and build products of high quality.
Delivery speed or **cost** reductions were not important since the market simply did not ask for anything but technology. "*Cost was never an issue we discussed. We were used to getting the budget we asked for and this budget grew year by year,*" {Procurement Manager}.
The same was true for manufacturing **flexibility and speed.** These capabilities had not been developed yet, although manufacturing was constantly seen as the bottleneck within the business. Marketing and sales often exceeded their monthly stretch goals and shipments of 120% of plan were not unusual. This can be explained by the fact that salespersons were paid according to order entry and not yet according to shipment performance. Consequently, there was no pressure on manufacturing regarding speed and flexibility – neither from sales nor from the customer, as mentioned above. Nobody even thought about special **fulfillment services** or even **customer solutions** since there was neither the market need nor any manufacturing process technologies available or planned exceeding mere hardware manufacturing. In addition, not many suppliers were capable of supplying these leading-edge components so that make or single sourcing, with all their well-known constraints, were the only two sourcing alternatives. **Business networks** with vendors or channel partners had not been developed.

Summary
Dynamism was faced only from a technology perspective. Customers and market behavior were not impacting dynamics. Thus supply chain structures focused on managing the technology. Technical adaptability turned out to be important, together with engineering.

Hence, the factory developed internal manufacturing capabilities to be able to build the constantly changing and evolving new products of high quality. The focus was upon product quality yield and manufacturability. Cycle time, lowest cost and precision were not within the management focus area since they were not considered to be market differentiators. The focal point was to get control over the product and production innovation speed. Few suppliers supported HP's business and so most manufacturing was done internally at HP or even at the local factory. Most emphasis was put on engineering for all kinds of processes, and process research and development were considered important. In addition, the market demand was increasing steadily and the capacity needed to adapt constantly.

3.1.4 Phase 2: From about 1990 to 1995

As described in the previous section, the factory developed internal manufacturing capabilities in order to build the constantly changing and evolving new products, with the focus on quality and manufacturability. Operational cost, speed and precision were not really managed since they were not considered to be market differentiators. The focal point was on getting control over the product and production innovation speed, a perspective that changed significantly in the early 1990s.

3.1.4.1 Market and customer evolution

This phase was affected by a major **product technology** change. The move from proprietary operating systems and processors to standard UNIX systems was a major transition which pushed down **prices and margins** for the first time in this industry. New **competitors** like Dell showed up in the computer sector, and the participation of other competitors like Silicon Graphics, Sun, IBM, and Siemens, increased the pressure on cost and operational excellence. This also changed the customers' position and the market switched from a vendor to a customer **market**. The **customers** now had the choice between several computer manufacturers. The switch from high-tech manufacturing toward low-cost manufacturing was a paradigm shift for HP management and employees to maintain the large parts portfolio described in Phase 1. An example will **illustrate this issue: "***In workstations during Phase 1, we talked about how many 'seats' a customer like Ford had for Graphics Workstations. For example, an automotive OEM, with 2,000 engineers working on new car designs, and each one needed a graphic engineering workstation. Therefore, in this example, Ford had 2,000 seats. As the technology transitioned, the OEMs realized they could save significant money by segmenting the design process such that not all engineers needed the "hottest" graphic workstation. By segmenting the design process they were able to buy the lower performing workstations from Dell, thus reducing the number of 'seats' available to HP*" {Worldwide Supply Chain Manager}.

3.1.4.2 Supply chain evolution

Supply chain process technology and supply chain focus changed in response to the product technology change mentioned above. The R&D divisions in the US provided new product introduction support for the different regional factories. The US factory, which was located close to the R&D division, played an important role in the introduction of new products. This factory received the technical specifications from R&D engineers and developed test processes. These test processes, which were rigorously regulated, were then implemented worldwide to ensure HP quality standards. On the other hand, the manufacturing process development responsibilities were within the local factories. Thus each HP factory looked a little different since it adapted to the local needs, and with this a healthy competitive spirit among the factories also developed.

The common need for a competitive and responsive infrastructure initiated the vision of a regional manufacturing strategy and a single site per region such as Europe. In addition, HP came up with a design that would consistently optimize future manufacturing. The manufacturing process was divided into a generic build-to-forecast segment and a customer-specific build-to-order segment to allow postponement and late differentiation (see Figure 7). A decision had to be made about when, in the manufacturing process, the generic processes would switch over to custom processes – at the so-called 'decoupling point'. The decoupling point between the push process from vendors and the pull process from the factory was actually the raw material warehouse at the factory. The positioning of this boundary called for a trade-off between manufacturing technology, landed production costs, order cycle time targets and product complexity. In fact, HP decided to allow configuration at the product level consisting of a chassis, to which mechanical components, memory and disk storage, input and output devices, processors, and software were added. The customer order could have potentially been introduced at the time of any one of these assembly elements, but was shifted upstream to the most generic sub-assembly to permit mass customization. This generic sub-assembly was called the lowest common denominator box (LCD) and was defined per product family. This represented the main component upon which all potential product configurations could be built. The LCD box could then be produced to plan in a push mode in one of HP facilities in Singapore. They were ordered centrally, based on global demand, and were part of HP's worldwide inventory replenishment process. This approach reduced costs for HP in three areas. First, inventory reduction, since these generic components could be used worldwide and thus enabled forecast aggregation with its positive effect on planning accuracy. HP tried to aggregate demand uncertainty across multiple operations or across multiple regions, to reduce forecast errors and thus minimize inventory required. Fast-moving worldwide refill processes two to three days from Puerto Rico and ten days from Singapore were the basis for taking advantage of the centralized inventory pool. Second, the lower labor costs in Singapore. Third and even more importantly, the opportunity to benefit from Singapore's tax system which significantly reduced the tax payments of HP on the corporate level. These generic boxes could be sent into all HP final assembly factories worldwide according to the actual demand since they were neither customized nor localized. The local stock levels of these components were between two and three weeks, depending on market fluctuations and the inbound cycle time from Singapore and Puerto Rico for the specific product.

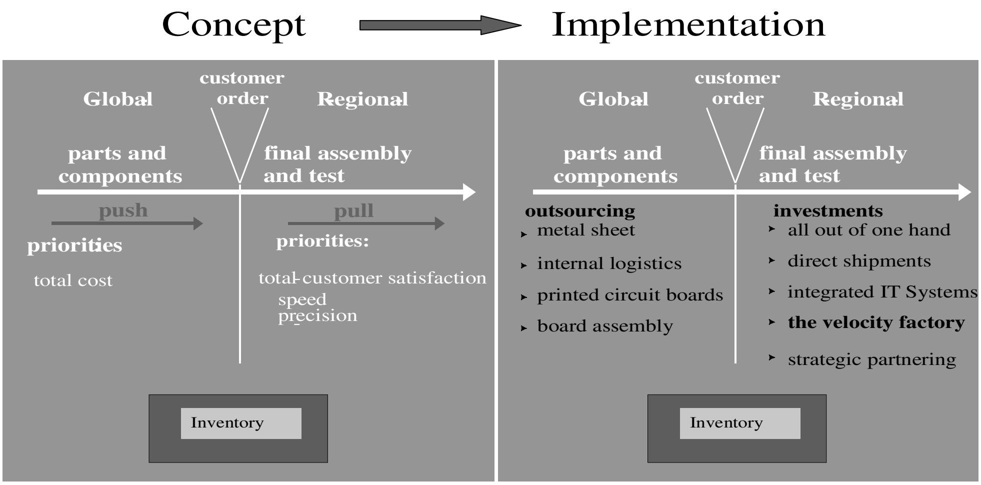


Figure 7: The new push/pull interface driving the strategy (Source: HP, 1994)

Inbound partners

In this phase, HP started to outsource manufacturing with the purchasing of more and more components from outside companies as their capabilities started to meet the technical needs of HP's new products. The first facilities to feel the impact were the sheet metal, plastic molding and the tool and die shops. The logical question to ask at this stage was why HP did not maintain internal manufacturing to control quality, time-to-market and responsiveness? "*Let's examine this question in some detail. The first interesting change that occurred in the marketplace that started to undermine HP's model for success was the simple fact that the quality of competitors' products started to meet the needs of the majority of the customers. As a result, the customers were no longer willing to pay HP a premium for something they now expected from all suppliers*" {Worldwide Supply Chain Manager}. Once this happened, HP could no longer be competitive for the following reasons. External suppliers for the components mentioned above had much higher volumes to spread their fixed costs, and in many cases, they also paid lower wages. Return on assets became a critical metric within the company and in financial circles. To expand its capacity to meet growing demand it now became necessary not only to construct new facilities and purchase very expensive equipment, but also to hire additional employees.

For many years, R&D refused to purchase these components externally until it became obvious that they could receive the same responsiveness and quality at a lower cost. Once this occurred, R&D engineers would by-pass the internal shops and work directly with external suppliers. When this happened, the internal facilities were doomed and manufacturing moved external.

In reality, this same dynamic continued as the capabilities of external suppliers in other disciplines improved. One by one, each internal facility closed. Year after year, the pressure to purchase all components externally increased. "*Why build memory chips when*

a whole industry developed in Japan around this component? Why fabricate components such as diodes and transistors when IT could provide what we needed? Why invest in printed circuit manufacturing when the industry could meet all our demands?" {Worldwide Supply Chain Manager}.
It become obvious to HP executives that manufacturing was capital intensive and labor intensive, and that a significant proportion of the labor costs was associated with low-skill positions.

The best way to illustrate these dynamics is to review the experience of the supply chain team:
"*At that time, the electronics industry was going through the transition from through-hole assembly for printed circuit boards to surface mount. It was recognized by the company that HP needed to change how they managed assembly due to the cost of this new technology. As a result, a Manufacturing Council was formed to manage this situation and to look for leverage opportunities in materials purchasing and other areas. Every division (approximately 50) in HP had its own through-hole assembly operation, and it was obvious that this couldn't be allowed as we transitioned to surface mount. The council decided we would approve only five sites, and you can imagine the amount of infighting this created among divisions. Ultimately, we ended up with ten sites with three of them in the computer group: Roseville, Fort Collins and Germany. Eventually, the Roseville SMT (surface mounting technology) center was consolidated into Fort Collins.*" {Worldwide Supply Chain Manager}.

Prior to SMT, the subcontract business was very small, and really started to grow as companies wanted to outsource their older through-hole business so they could expand into SMT. As the outsource industry business grew, these companies also expanded into SMT and it rapidly became clear that they had a lower cost structure than internal manufactures. Most companies resisted moving SMT outside because time-to-market, cycle times and responsiveness to the needs of R&D were considered critical to new products. "*In Fort Collins, the HP Division ultimately had five SMT lines, and to install the third line HP needed to construct a new building. To get a new building approved took almost an act of God; you had to get the Executive Council's approval. You also had to go to the same council to get a new SMT line approved. At the same time, the company was putting pressure on headcount, so we started to use 'temporary labor' rather than hire full-time employees. In reality, it cost more in wages to hire a temp worker, but the company didn't have the long-term liability of health care and retirement costs. We did everything possible to reduce our costs per placement, but we could never get as low as the external subcontractors since they had higher volumes.*" {Worldwide Supply Chain Manager}.
Up to this phase, all manufacturing was still done in the local countries, but as HP continued to put more and more pressure on the external suppliers to reduce costs, they were forced to move a significant amount of manufacturing to low-cost countries with low wages and little or no long-term costs, i.e., healthcare or retirement benefits. Over time, the subcontractors adopted the same strategy as HP, and ramped up new products in the US and then transferred the production volumes overseas.

Consequences for the local factory
For the local factory in Germany, the described supply chain strategy resulted in a large outsourcing program where vendors and contract manufacturers started to play a dominant role. The outsourcing concept was twofold. First, outsourcing of processes which could work in a push mode based on forecasts and plans. Second, this resulted in:

i. Simple components which could be sourced from external vendors, like keyboards, monitors, disks. The responsibility for these components moved from production to procurement and was handled there using the normal procurement processes.
ii. Complex manufacturing processes, where full process engineering responsibility was taken away and the link to final assembly was not too tight. They were outsourced to contract manufacturers. They owned all process responsibility and all production took place in their manufacturing environment. Examples were: metal sheet production going to a local company called BVS, printed circuit board production which was outsourced to a global player called Multek, as well as Printed Circuit Board assembly (PCA) which was outsourced to another global player called Solectron.
iii. At a later stage, the whole pre-assembly of the servers and workstations was moved off-shore to an HP internal factory in Singapore. These pre-assembled computers, known as Lowest Common Denominator (LCD) boxes, offered HP significant savings in tax payments and thus allowed the company to keep the most critical processes – the server and workstation assembly – within HP. These processes were tightly aligned with the pull production system of the local factory.
iv. In-house outsourcing. Warehousing, internal logistics and six of the nine production lines were given to contract manufacturers which were forced keep these operations under their operational responsibility within the new HP factory using HP’s IT systems. The goal here was to keep a maximum of control over these processes and to link them with the pull system of the factory. This so-called “all under one roof concept” was a major step toward simplifying collaboration and reducing material movements. These partners had only limited engineering responsibility.

The major benefit of all such outsourcing was the switch to variable operational cost and the avoidance of heavy investments – especially in PCA and PCB equipment. Furthermore, operational costs could be reduced, especially in PCA. Overall this outsourcing impacted more than 1,000 jobs at HP Germany and the manufacturing depth was significantly reduced.
Extensive outsourcing by the plant shifted the business environment from an internally integrated supply chain to a complex network of contract manufacturers, third party logistics providers and suppliers. Managing such a network involved more than transactional interaction; it involved bi-directional information, material and financial flows and the way of collaborating. The role of HP in the supply chain was becoming that of an orchestrator.

The cost of transportation was high (~2% of revenues) since all computer systems were shipped directly to the customer. These **outbound logistic** costs were reduced by the implementation of hubs and later cross-docking hubs. These were later consolidated into one-hub-per-country and a multi-vendor hub system was installed to further increase the probability of full truck loads. The concept of bulk-packaging reduced the long-distance transportation cost from the LCD factory in Singapore. These products were bulk-packed and repacked with the final customer packaging at the local factories. Consequently, about 18 products could be put on a pallet instead of about six when using the end customer packaging.

3.1.4.3 Factory evolution

HP's strategic goal changed direction: total **cost** reduction within the factory and the whole supply chain now became a key issue. There were two major factors facilitating this change. On the one hand, the HP employees had to adjust their way of thinking. While cost efficiency had never really been critical in the past, it now became a major focus. The measurement system was changed from quality control to quality and cost control. Staff were trained in the areas of cost of non-quality, inventory-driven cost, and operational cost of inbound and outbound manufacturing. The factory was renamed "The HP-Distribution Center" to reflect the new thinking and to move from a high-tech toward a low cost way of thinking. On the other hand, new opportunities were appearing on the worldwide markets with the birth of the contract manufacturing industry; suppliers were expanding their skills and developing entire system modules instead of components. For example, disks, monitors and keyboards were now offered by several vendors. All in all, the restructuring of the supply chain became apparent and outsourcing of non-core competences became possible. These strategies are explained in more detail below.

Manufacturing process technology – the HP concept of efficient manufacturing

Efficient manufacturing at the HP factory involved the following workforce management and space management, as discussed in the previous section:

i. Consolidating final assembly, originally practiced at a "multi-usage office building" in southern Germany with seven warehouses scattered all over the region, into a real production building.
ii. Efficient operation: High automation of test, software load and transportation processes helped to cut down direct labor costs and so compensate for Germany's unfavorable cost structure.
iii. Efficient production overheads: A "fractal factory" with self- organized teams at the shop-floor was implemented.
iv. Efficient production through built-in quality: All routings through the factory could be controlled via a special shop-floor control system in combination with bar code scanner systems.

As discussed previously, the **business networks** evolved very much toward the inbound site of the supply chain due to the heavy outsourcing in this decade. **Flexibility and speed** were still not the major concerns in this phase. Flexibility was used to cut down costs. In particular, the flexibility of the direct workforce and the adaptive equipment capacity helped to adjust to the market order volume fluctuations and thus helped to reduce safety capacity costs. In addition, **fulfillment services and customer solutions** had not yet been developed.

Summary
The major goal of HP manufacturing was to react to the changed market needs. Competition increased significantly and customers were no longer willing to pay whatever computer companies asked. In addition, a new industry evolved: the contract manufacturing industry, a concept that HP heavily utilized, offering opportunities to gain economies of scale for their customers. It refocused all planning from a product view to a supply chain view. Under this concept more supply chain management skills and fewer production skills were needed. Collaboration with internal and external partners as well as supply chain process and product design were re-evaluated so as to be able to work in such a fragmented process world. New capabilities in complex supply network management were evolved and therefore new skills to enable collaboration with external contract manufacturers were needed. These included the management of the relationship, the ability to evaluate make-or-buy decisions and to find the right partners. Outsourcing was totally new and employees had to be prepared to become more flexible in terms of the structure of the company for which they worked. Many HP employees lost their jobs and moved to the contract manufacturer. Both cost reduction and making cost variable were achieved. Within the German factory about 65% of the costs were now variable. Cost reduction mainly happened in PCA and PCB production. In addition, HP was able to avoid large investment in expensive PCA and PCB manufacturing machines, which became obsolescent every two years or so, thus requiring high volumes to recoup these investments. Logistics costs were cut by 20%, mainly due to the lower overheads, infrastructure and operational cost of the service provider.

3.1.5 Phase 3: From about 1995 to 1998

3.1.5.1 Market and customer evolution
In the mid-1990s, **product technology** evolution slowed down, but a new product complexity emerged. First, product diversity increased and the production bandwidth became even larger – spanning over 2,000 different computer products with more than 10,000 options and 19 languages. This was triggered by the marketing department in its efforts to better cover all possible market niches. Second, customers ordered more or less unique products where similar configurations occurred rarely. Third, the increasing price erosion among electronic components required that these components be put to immediate use to avoid high inventory write-offs (see competitiveness).

The overall market continued to switch toward a buyer market, bringing with it further price pressure and volume volatility. This volume volatility was also amplified by the HP sales model where a salesperson's pay was based on his or her monthly order quota achievements. Thus, salespeople started "quota gambling" , entering most orders either at month or quarter ends or the beginning of the following month, whichever would maximize their salaries. Usually, 50% of the monthly orders came in during the last week of the month whereas all orders needed to be delivered to the customer within the same cycle time and quality – regardless of when and under what kind of volume conditions they were entered in the order management system. A daily order volume fluctuation of +/–150% was not unusual due to changing market conditions and because of the HP sales model. Thus, flexibility of the operation turned out to be even more business critical. Figure 8 shows an example.

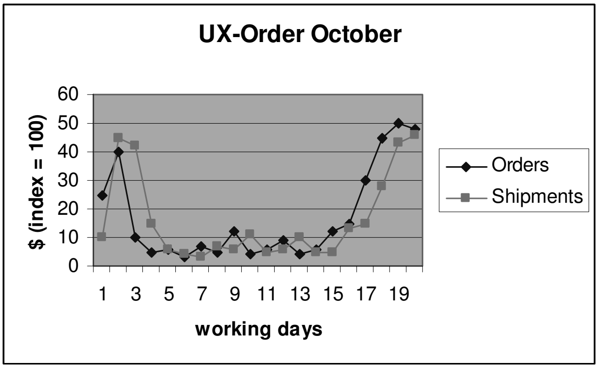


Figure 8: Order volume fluctuations (Source: HP, 2000)

Customers started to demand short delivery cycle times which triggered a need to increase operational service levels. An order cycle time of 15 or more days for a mid-range hardware system was, according to HP marketing, no longer acceptable. HP's factory management noticed that in the low-end area, companies like Dell offered 5-day cycle times from purchasing to power on at the customer site, and Sun offered about 10-12 days. Especially in the high-end sector, most product shipments were part of bigger infrastructure enhancement projects at customer sites and required accurate deliveries according to detailed specifications. Thus speed and precision became an important factor from a customer service perspective. In addition, the fulfillment in this business segment required precise high-quality deliveries and was dependent on collaboration with sales partners or end customers, and the integration of their design requirements. Consequently, **competitiveness** was about speed of delivery, high availability, and all that at lowest **prices.** The latter was driven by the modularization of the components, which again triggered further cost reductions. During Phase 2, cost improvements were only achieved through outsourcing. Now controllers criticized too much inventory in work-in-process due to long supply chain and manufacturing cycle times. High price attrition of components over time and the unpredictability in demand required strict inventory management. Many components were unique and could become obsolete at once if the product was not used in production. In addition, the common components underwent steep value erosion due to the rapid clockspeed character of the business. The price of memory lost value at a rate of up to 80% per year, processors and hard disks lost value at about 40%-50% per year, and motherboards and monitors declined by about 10-20% per annum, thus making the cost of holding excess inventory prohibitive. Cost competitiveness therefore needed to be further improved by shorter factory cycle time with its positive impact on inventory and productivity. In Phase 2, the supply chain and factory processes were not really assessed and improved, and the need for a total re-engineering of all these processes became apparent.

3.1.5.2 Supply chain evolution

So far, the **supply chain processes** had clearly been developed on the inbound side of the SC. The backbone of the European outbound supply chain was the factory and six distributors (channel partners) who were supplying Small and Medium Businesses (SMB) with low-complexity solutions. Both the factory direct shipments to enterprise partners and the indirect shipments via sales and distribution partners accounted for about 50% of the business.

On the **outbound** side, a major change started to evolve. In phase II, the operational performance of the factories was not meeting market expectations in terms of speed and precision. HP sales partners built their so-called integration centers around the HP factories to buy material from HP for stock. They could guarantee 24-hour delivery to their main customer base in central Europe. With the increased velocity of the HP factory, this model became more and more obsolete and many discussions started on the importance and the role of these channel partners (especially the distributors). The channel partners' focus was on instant availability and simple customized software (SW) and hardware (HW) integration. In this phase, different supply chain processes were implemented based on the product sales characteristics.

On **the inbound side**, more and more service providers were ready to really support HP's business strategy. They continued to develop upstream capabilities – like simple manufacturing and logistics. The integration of suppliers was thus an important factor. Point-of-sales data were distributed to the major suppliers (mainly internal suppliers) and orders were sent automatically based on ERP calculations. Some external suppliers were linked via fax and e-mail to meet order-fulfillment's locally defined target dates. A monthly, and later weekly, forecast update was transmitted to the entire supply chain to ensure that all partners worked from the same demand pattern. A Vendor Managed Inventory (VMI) concept was introduced for those suppliers where conditions seemed to be feasible.

3.1.5.3 Factory evolution

For HP it became clear that a highly innovative manufacturing operation was needed that focused on speed and attempts to eliminate delays in bringing computer products to the sales partners and end customers. In Phase 2, HP's factory management transformed the local supply chain from geographical dispersion to one central location, concentrating final assembly and related logistics under one roof. This concept continued to be developed, but now **speed** (see results in Figure 9) **and flexibility** were set as major goals to be achieved with the new factory concept. Velocity in fulfillment supported cost reduction and customer satisfaction, but velocity in fulfillment in this volatile environment required much flexibility in the supply chain and the factories. HP's idea was to increase process speed and efficiency based on a combination of flexible processes, flexible labor, space on demand and best-in-class IT systems. Thus, the **process technology** evolution focused mainly on adaptable and flexible capacity management. The velocity and speed concept again impacted processes, labor and space.

Velocity and flexibility of product introduction
For years, the German operation had introduced products one to two months after the US – because of the distance and to allow the division in Fort Collins to work out any manufacturing issues. As this was unacceptable to Marketing, they began working on simultaneous introductions. To accomplish this, HP developed the processes necessary to ramp up new products in a remote location away from the R&D center to improve time-to-market. Once this proved to be effective, the next logical step was to ramp up new products directly with external subcontractors.

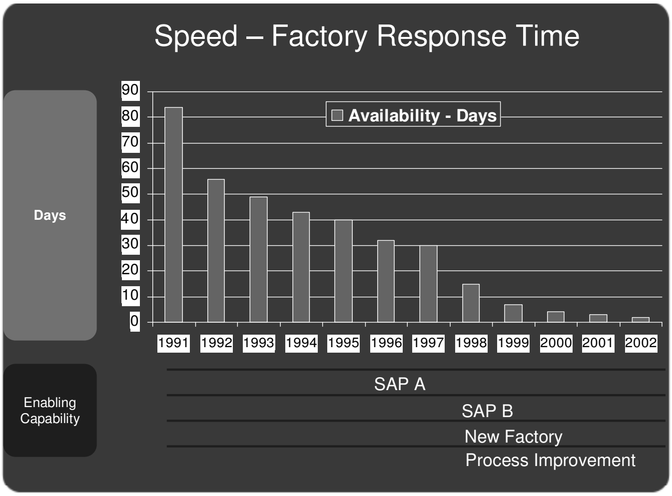


Figure 9: Order cycle time reduction over time (Source: HP, 2002)

Velocity and flexibility of processes and equipment
A build-to-order pull manufacturing system was inherent to manage the broad variety of products efficiently. HP put great care into creating the lowest possible asset load when designing the new factory. Simplification, focus on standards and multi-usage of their physical processes was essential. Thus, it was possible to easily adjust the material flow, the equipment for assembly and test, and the factory layout for the daily capacity required. The food and grocery industry was the best practice model. High-tech manufacturing was compared to grocery logistics where deterioration drives the need for speed. Several HP concepts were applied to achieve process flexibility and velocity:

i. The design of increasing process capacity along the factory process steps to be able to better manage the internal bull-whip effect.
ii. Processes were simplified and designed as standard process modules. Furthermore, routing flexibility and a one-piece-flow concept of parallel processes were realized with the internally developed production planning system.

iii. Process automation: High automation of test, software load and of some transportation processes was realized to cut direct labor costs and so compensate for Germany's unfavorable cost structure.

Velocity and flexibility of labor
The demand volatility natural to the industry was a unique challenge in terms of labor management and the highest possible productivity was needed to compensate for the German labor cost disadvantage. On a macro level, the workforce needed to adapt during a quarter or a month to manage the order volume volatility described. In addition, employee capacity had to be adapted on a daily level based on the daily order entry – since manufacturing was triggered by customer orders and there was no production planning horizon. Due to the higher labor costs in Germany, an extremely flexible workforce model was implemented to deal with variations in demand patterns, enabling productivity levels to rise above 85%. In low workload phases under declining orders, as well as during times of exploding demand, equal process effectiveness was necessary to keep costs down and to hold the published customer order cycle time. Long term it could be adjusted by reducing or increasing the workforce based on the order trend. The flexible workforce model had three distinct components:

i. The flexible workforce structure included four elements. The first element consisted of HP permanent workers known as "solution experts". The second element consisted of "HP temporary staff", who provided monthly flexibility. The third element consisted of "external temporary staff", who provided weekly flexibility. The remaining workforce came from contract manufacturers located in HP's manufacturing facility.
ii. The underlying component was the work-time model, which provided daily and hourly flexibility, and also for partners and service providers. Workers had an individual "flex account" which kept track of the number of hours worked. The entire workday was split into four blocks with maximum possible work time of 10 hours per block. At short notice, the workers had to show up at any time within the pre-assigned block and they could be asked to stop work at any time and go home. HP used outsourcing of its processes extensively where the strategic partners had to be located in the HP factory, working on HP's IT infrastructure and ERP system. Extensive outsourcing at Herrenberg had shifted the business environment from an internally integrated supply chain to a complex network of contract manufacturers, and third-party logistics providers and suppliers. The role of HP in the supply chain was becoming that of an orchestrator.
iii. In order to further increase this flexibility, each worker was trained in an average of five different types of jobs.

Velocity and flexibility of space
Since the cost of space in Germany is expensive, the management team developed the so-called "Space on Demand" model. HP management decided not to own the new building but to lease it from an investor to reduce fixed costs and improve return on assets. The investor from whom HP leased the manufacturing and warehouse building charged HP according to the actual space consumption. Variability was within a window of two

months. The building was simple and standardized, and provided as much flexibility as possible to adjust processes easily.
If more space was needed, other buildings owned by the investor could be used. They were located close to the velocity factory and equipped with all IT and other infrastructure facilities, and were handled like a remote stock section of the normal warehouse. The only difference was the longer lead time from warehouse to production which had to be recorded in the warehouse management system.
Fulfillment services were limited to fast delivery of products. **Business networks** were still inbound focused.

Summary
From a shareholder perspective, costs were lowered because of lower inventories, leaner processes and tight collaboration with suppliers. From a customer perspective, delivery performance increased while lead times were reduced. The approach allowed a much faster response to demand fluctuations and customer requirement changes. Timing was everything. Since velocity was the goal, the working mode from batch and serial-based push processes to parallel pull processes became essential. Linking all processes and systems holistically increased speed and reduced costs. Each and every transactional material and information flow between people or between people and systems was synchronized. The system needed to run like clockwork and total synchronization was now achievable to facilitate a seamless flow of material and information. By doing it right the first time, quality, prevention of expensive rework, and velocity were assured. On the supply chain level, the information and material flows were synchronized as well, and the diverse points at which information was created and transferred were aligned. For example, a reduction of the bull-whip effect was achieved by reducing uncertainty with information (the integrated ERP system and strategic partnerships like the VMI models with vendors), by reduced variability with the portfolio management and by lead time reduction in all areas. This model later became the master concept for the remaining factories in the US and Asia.

Resulting business benefits (see
Figure 10)
The process and building design of the velocity factory had a measurable performance impact in the timeframe starting in 1997.
From a customer perspective, the following achievements could be made. Factory cycle time, which was measured from customer order entry to customer receipt, was reduced from 15 days in 1993 to five days in 1998 because the process now worked without a backlog – and therefore there was no longer a planning horizon. This was an 80% performance improvement. The on-time delivery performance improved from 64% to 98% within the same timeframe. Customer complaints came down to below 0.8%.
From a shareholder perspective, there were significant benefits from the redesign and the following were achieved. Inventory levels were cut to approximately 30%. For servers, it even came down from \$60 million to \$18 million. The internal operations costs were also cut by 30%. Here, the main portion came from increased speed. Another important driver for increased efficiency was the work time model, resulting in 17% savings in labor costs compared to traditional worker deployment methods and allowing a production capacity

flexibility of 0-150% within 24 hours. The distribution cost shrank by 70%. On a supply chain level, the new tax model was the main driver of cost competitiveness on a company level.
These results were achieved by focusing on customers (1995), distribution (1995 to 1996), a new manufacturing site, the implementation of a new ERP system (SAP R/3) and a shop-floor system.
Asset intensive processes like warehousing were outsourced to service providers. Process costs were cut by using standardized process modules which could be combined individually as exchangeability and modularization were the key factors. All main operative processes were kept within one building to keep processes lean. A rigorous pull "one-piece-flow" concept was applied to reduce process inefficiencies. Parallel "late start" oriented processes increased speed while lowering cash-to-cash cost. Inventory costs were reduced because the main vendors were integrated into the planning process and vendor managed inventory (VMI) approaches were implemented. The use of standardized multi-usage components was important to aggregate inventory planning. Process speed and the one-piece-flow concept reduced work-in-process. Transportation cost reduction was achieved through bulk-packaging and cross-docking at the velocity factory.

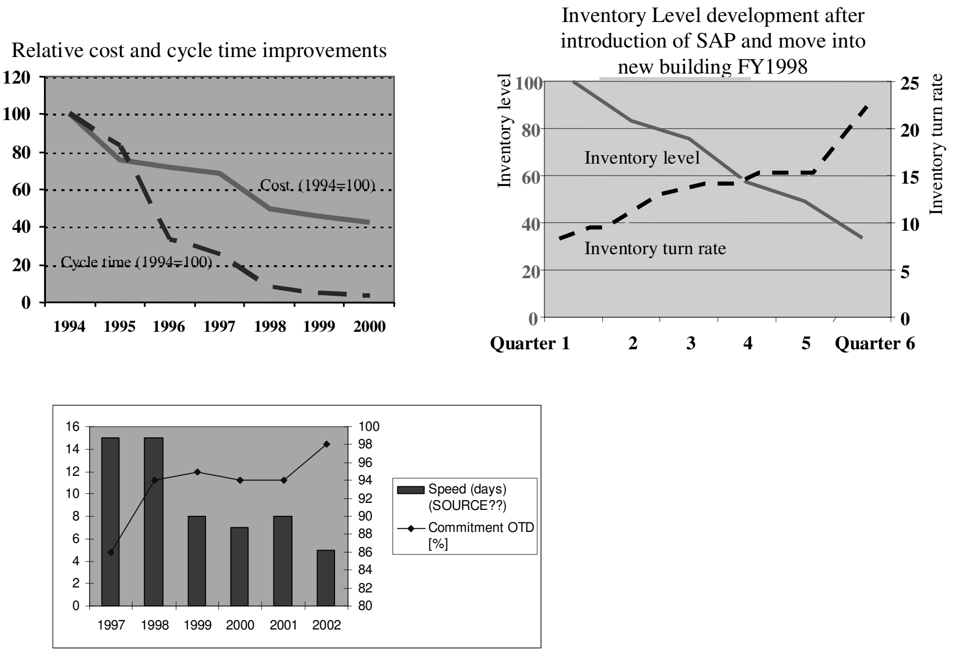


Figure 10: Performance of the velocity factory (Source: HP, 2002)

3.1.6 Phase 4: From about 1998 to 2003

Competitive operational excellence and manufacturing cost reduction were achieved during phase III. Nevertheless, a lack of opportunities to really differentiate with product technology put significant pressure on margins in this industry. So far in phase III, supply chain integration had been developed extensively on the inbound side. The general questions now were: Can the supply chain provide more benefits to the company than just cost efficiency and operational excellence in deliveries? And what about the integration of customers and partners?

3.1.6.1 Market and customer evolution

The rate of standardization finally shifted from technology to industry standards. Thus **product hardware technology** no longer played a major role since there was enough performance to satisfy nearly all customer expectations. The new paradigm was to look at solutions technology – a combination of HP hardware, software and third-party products.

From a **market** perspective, a continuous drive toward lower **prices and** lower **margins** in hardware in combination with shorter time-to-market and shorter life cycles for new products, driven by Microsoft and Intel Roadmaps, was recognized and made it difficult for HP to differentiate on hardware alone. Thus HP evolved toward a software and service company. The **competitive situation** was described by the worldwide manufacturing manager as follows: "*The company who owns the customer experience will have the power, since the technology power is good enough.*" (WW Supply Chain Manager, 2001). The HP factory strategy was to offer supply chain services and thus position HP in this business between IBM – with its focus on consulting and overall services – and Dell with its focus on build-to-order low-end servers and PCs. The management team was convinced that they could offer something unique since Dell did not yet have the capabilities to do complex systems integration, and IBM no longer owned factories and therefore could offer only standard fulfillment services.

Regarding **customers**, HP realized that there were different types of customer demand:

i. The demand for making complex solutions simple to install: Enterprise customers typically ordered complex data centers, large servers or complete computer solutions. These solutions could consist of HP products and components and non-HP products. Since the "HP open system architecture" strategy allowed the customers to "plug and play" with other vendors' products and components, mixed solutions were ordered from time to time (HP – Cambashi report, 2004).
ii. The demand for "Customer Specific Product Portfolios": Large customers like OEMs demanded easy ordering to improve cost efficiency and very fast deliveries.
iii. The demand for "Ready-to-go Products": All kinds of customers could order "simple product solutions", which were offered with some additional services to increase ease of installation at the customer site. Typically, the operating system was loaded and configured according to detailed customer specifications.
iv. The demand for "Standardized Cost Optimized Products": All kinds of customers could order standardized products to achieve lowest possible procurement prices and ongoing maintenance costs.

3.1.6.2 Supply chain evolution

In this phase the supply chain structure changed significantly on the outbound side. The **supply chain processes** were enhanced toward supply chain services capabilities (see Figure 11). In addition, a team at the HP factory provided supply chain consulting to large **outbound partners and customers** (channel partners; OEMs). The factory supply chain services team was trained thoroughly in supply chain management, using HP's extended and company-wide experience. They searched for channel partners and OEMs who were interested in such a model and together developed a state-of-the-art supply chain including partner vendors, the HP factory, the partners themselves and their customers. This important service enabled HP to link its own supply chain with that of the partners to make both supply chains more efficient. Partners were allied long-term with HP due to the infrastructural characteristics of this service, which was difficult for competitors to copy. Consequently, a consignment inventory concept was offered where HP would buy material on behalf of the partner. The main challenge was who would take the inventory and the handling risk at the warehouse. This then became a part of the contractual discussions.
On top of all this, a closed-loop supply chain needed to be offered to the market. HP already had a separate "Remarketing" organization. This organization was now linked with the Solution factory which so far had only been producing new products. This concept had two considerable advantages: Engineers, processes for assembly and test, and infrastructure could be leveraged to cut costs. Second, and more importantly, HP could now offer servers where new and used components could be mixed. This lowered the material cost for HP and therefore could be used by sales to lower prices for customers in competitive situations. In addition, HP used this for internal server orders to cut inventory of used material.

On the **inbound** side of the supply chain there were no major additional changes installed compared to earlier phases.

Service Categories

Startup	Supply chain	Catalog solutions	Complex solutions
Startup configured products	**Supply chain services for repetitive business**	**Build of customer specified solutions**	**Highly customized complex solution**
combination of products built and configured to customer specification, including rack positioning, cabling, disk mirroring, ip addressing, etc.	customer engagement service level agreements manage demand & supply deployment services product life cycle management	procurement of all solution components solution built and configured to customer specification. delivery service to customers specification	procurement of all solution components solution landscape setup in the factory, built and configured to customer specification. function tested, documentation creation. delivery coordination

Figure 11: The HP Solution factory service categories (Source: HP, 2001)

3.1.6.3 Factory evolution

Fulfillment services and customer solutions

All this forced HP to go beyond its current build-to-customer-order model with its volume manufacturing processes (mass customization). One of the factory managers asked the following strategic questions: "*Can the supply chain provide more benefits to the company than just cost efficiency? Can the HP factory be cost efficient* <u>*and*</u> *enable revenue generation through services and partnering*?" HP had to build up a portfolio of services that would allow it to provide all kinds of diverse solutions and be able to fulfill these straight out of the factory directly to end users. To offer all this at the lowest **cost**, many activities were transferred into the factory that had hitherto been carried out by HP customer support and channel partners. Several significant changes needed to be implemented (
Figure 11).

i. **Services capabilities and business networks** – to increase the value-add of the factory and to allow revenue generation through these services and customer interaction. In addition to the supply chain services described, three extra service blocks were offered.
First, the so-called "start-up services": These included integration and installation of the operating system (custom software) as well as testing and shipping of the entire solution as one shipment to a customer site. These solutions arrived almost ready to operate, requiring minimum start-up time. HP also provided documentation for rapid deployment. An HP solution factory partner then

installed the system at the customer site, trained the system administrator and performed any on-site software and network integration if required.

Second, so-called “catalogue solutions” for original equipment manufacturers (OEMs) and independent software vendors (ISVs): HP provided a variety of ready-to-go solutions under this umbrella including services such as project coordination, procurement of third-party components, customer-specific application loading, product life cycle (PLC) management, which was particularly important for OEMs with long-life products, customized labeling and boxing plus relationship management. HP had developed a matrix of relationships with a number of ISVs to provide the services mentioned above to its end customers. The ISV then provided the know-how around the physical integration to the factory.

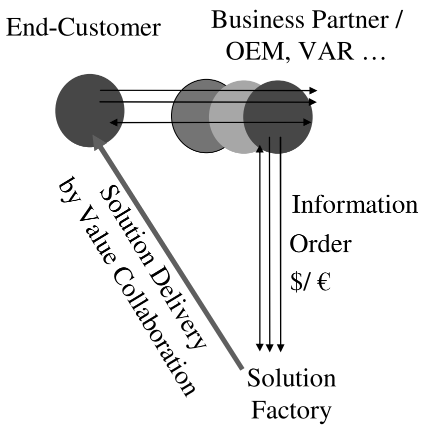
Third, “complex solutions”: These were whole ERP systems which were completely pre-integrated and installed at the factory.

ii. The supporting **manufacturing processes** were as follows: The existing infrastructure was redesigned and the concept of mass customization, developed in phase III, was enhanced in this phase. This was necessary since the complexity of the solutions requirements increased dramatically and an answer had to be found to the question of how to keep this complexity under control. Highly skilled and autonomous workers were needed to work with adaptive, self-configuring processes modules. These capabilities also needed to be applied to the most important partners in the supply chain.

iii. **New supply chain and fulfillment models** – to offer customer-specific outbound supply chain services. The Solution factory concepts considered the different needs of these different partners and then built up a specific mechanism for each type of customer. The biggest potential was with the distributors but also with the OEMs. In both cases, HP had a high volume of repeate business. HP did not change the business model but the supply chain model. The partners still owned the order and the customer, but fulfillment was carried out by the HP Solution factory on behalf of these partners. This concept had several benefits which can be seen in Figure 12.

iv. **Integration with sales** – to become part of the sales process through customer collaboration, solutions **integration,** and the offering of best-practice events with customers and partners in the factory. This was considered to be the most important part of the strategy. The factory used the opportunity to directly collaborate with sales, channel partners and customers and to extend the relationship to these partners. The new thinking could be expressed as follows: The factory opened its portals and started to network and collaborate with the outbound world. This was not limited to end customers but also to channel partners.

v. **Operational excellence** – to keep operational excellence at the center of concern. The goal here was to maintain the level which had been achieved in earlier phases despite the increasing complexity due to the solutions business, and to extend the “all-under-one-roof” concept.



- "end to end" solution delivery
  order fulfillment coordination delegated to the factory
- proven quality
  solution pre-testing before shipment.
- speed
  through direct end customer shipment
- efficiency
  eliminate duplicated efforts
- on-site installation time to operation
  reduced through pre-integration
- relation ship model
  for long term customer relationship

Figure 12: "Direct" shipment of "indirect" orders (Source: HP, 2002)

From the transactional life cycle to the solutions fulfillment cycle

Far-reaching change management was needed to move the factory staff into a new business world with completely new challenges and the different skills that these required.

Engineers needed to develop communication skills to represent HP to the customers and to collaborate with new and often changing partners. The major differences were the uncertainty of the solutions business compared to the product business, which followed predefined processes. In the new world with its consultative life cycle (see Figure 13), all workers in manufacturing, planning, procurement and order management were confronted with an "unlimited" product and services portfolio for solutions.

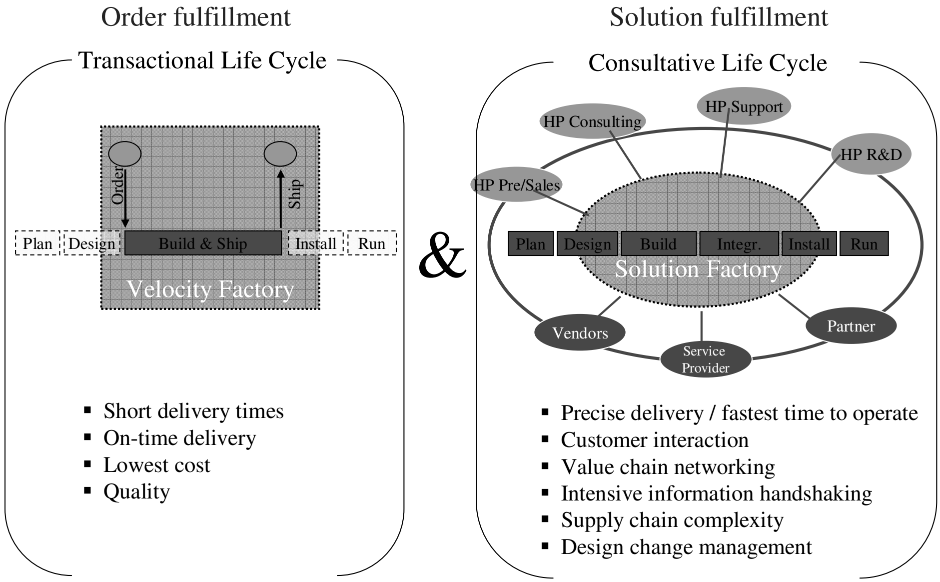


Figure 13: Transactional order life cycle and solutions fulfillment life cycle (Source: HP, 2001)

Thus predefined and well organized NPI processes were no longer possible. Whenever orders came in, the employees needed to find the most efficient way themselves or in conjunction with several other HP organizations and external partners.

Summary

The Solution factory concept was primarily not a question of developing new capabilities but much more a question of how people engage with the supply chain and how supply chain managers handle the end-to-end experience. The major change was in bundling the capabilities of different partners remotely and the ability to open the doors and communicate with customers and partners directly. In addition, portfolio management was extended and played a significant role in reducing complexity.

In comparison, the Velocity factory was about manufacturing products according to customer specifications, focusing on everything until the product left the factory gates. The Solution factory started to integrate the whole supply chain, increase the value-add of the factory, shift activities to lowest cost in the supply chain and utilize the available operational excellence to build individual solutions. The factory was able to use its assets and started to integrate systems by integrating all partners in the value chain. Highest return on assets could now be achieved by utilizing HP's Solution factory infrastructure and inventory pooling with proven excellence of execution. The ultimate goal was to revolutionize the role of the factory in the supply chain and make it part of the sales process while using this as a significant competitive advantage to gain revenues.

Resulting business benefits

From a shareholder and total supply chain view, the overall costs were reduced. Most savings came from the fact that the partners who used the Solution factory removed one physical node from the supply chain. This saved transportation costs and infrastructure costs. Inventory costs were reduced due to higher speed of fulfillment and increased transparency. Another cost advantage was achieved by the factory with its high volume and standardized processes accepting integration which had so far been executed by channel partners in their job shop environment or on site at the customer location by HP-Services.

In general, **customers** started to ask for more than fast delivery of good quality; they wanted minimum hassle and a minimized total cost of ownership. Customers now received a pre-integrated system solution in fewer than four packages, which would previously have come in 12-15 packages. This reduced the complexity of the system installation at the customer location and lowered the installation time on site from days to hours, resulting in minimum disruption. The customer no longer had to order hardware and software applications separately. Shorter order lead times for pre-tested solutions and increased flexibility improved customer satisfaction. Customer collaboration and direct interaction in combination with supply chain services linked customers with HP long term. Other benefits for the customer were that the Solution factory became a single point of contact for direct communication and the coordination of services and order fulfillment. Duplicated efforts, inconsistency of delivery and quality risk were reduced significantly; the on-site installation time was reduced and performed in a smooth way.

From a sales perspective, the Solution factory moved into a new role as it worked very closely with the sales teams. As part of this program, HP opened up its factory to customers, allowing them to visit the factory to see how their solutions were being built, to share some best practices and to provide training for their engineers. This also improved customers' confidence in HP's ability to meet their requirements after visiting the factory.

Conclusions

The major shift was from manufacturing expertise and knowing the products toward knowing the regional customers (EMEA) and the management of complex supply and distribution networks – which now included the customers and partners. HP could now decide to become either a lowest cost manufacturer focusing on high volume or a computer solutions vendor, providing products with the greatest perceived differentiated values, or both. The local factory clearly supported the latter option and operated with the customers who wanted to buy benefits and, where possible, to differentiate through supply chain "services" and "performance". Based on HP's customer value idea, the local factory tried to increase the perceived value to the customer of the entire relationship with the company, from pre-sales to project management, manufacturing and solutions integration. It was very important to understand why customers chose HP's products, what the customers preferred and needed, and how to satisfy these needs. Investment in supply chain services and solutions integration was expensive, so it became important to understand which customers were profitable and had potential for revenue growth. The closer connection between customers and the Solution factory by developing individual relationships was essential.

3.1.7 Phase 5: From about 2003 to 2005

3.1.7.1 Market and customer evolution

The challenge posed by **product technology** was twofold: the unending trend of product standardization and commoditization with the resulting cost pressure on the one hand, and on the other, HP's observation that **customers** wanted a customized solution – on time and fast at the **price** levels of the commodity business, and that shareholders expected the cost structures of the mass consumer market. Intensifying **market** pressure forced the company to develop new supply chain models. At HP, the indirect fulfillment model was questioned since competitors like Dell were more successful with direct fulfillment. However, these channel partners were an important part of the overall business model with their direct contacts to small and medium businesses. The **competitive situation** intensified: New, rising competitors pushed to the limit the growing over-capacity of the market. This resulted in enormous pressure on the supply chain and meant that excellence in physical distribution was no longer sufficient to compete. At the same time, increasing contract manufacturers' capabilities and new global supply opportunities opened up new innovative ways for HP to construct the enterprise SC.

3.1.7.2 Supply chain evolution

Although the indirect business model with the **outbound channel partners** was cumbersome from a cost and an overall supply chain efficiency perspective, the channel partners still played an important role. They were still important for business generation but no longer for logistics services. Their integration center locations were too close to the HP factories and did not provide geographical advantages (see Figure 14). Furthermore, overcapacity and duplications of infrastructures increased the total supply chain cost. In addition, partners' solutions integration capabilities were limited regarding their capabilities and less efficient regarding the automation of processes. Considerable investments in infrastructure and engineers would have been essential to increase competitiveness in this tight market.

To combine the advantages of the indirect and the direct model, a new approach, the HP Partner Park, was considered. From a supply network structure perspective, the model is as presented (Figure 14) and is described in Section 3.1.7.3.

From an **inbound partners** perspective, there were no further changes compared to phase IV.

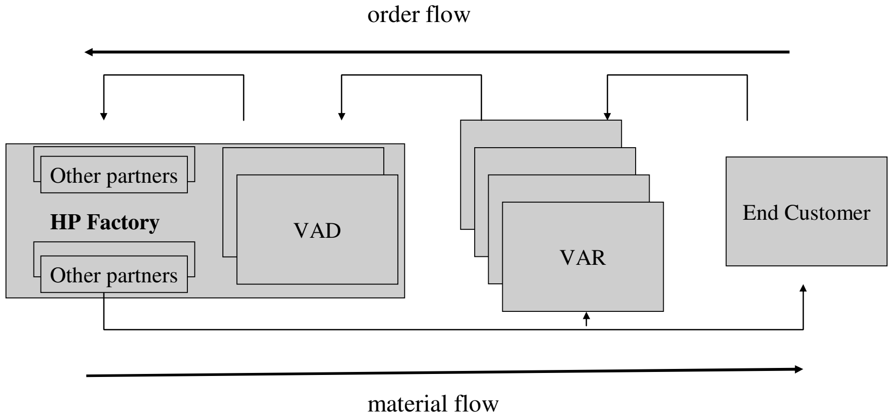


Figure 14: The HP Partner Park supply chain structure

3.1.7.3 Factory evolution

HP's Partner Park was described as a new **business network** concept of the HP factory. Partner Park was viewed as a new cooperation approach in the computer industry focusing on the integration with upstream suppliers and downstream sales and logistics partners. Thus, it was a cooperation model of companies along HP's enterprise value chain facilitating new strategies and supply chain models.

It built on two existing cooperation models from very different industries: The grocery industry, with its cooperative planning forecasting and replenishment (CPFR), and the automotive industry, with its supplier co-location model. The CPFR idea advocated the forming of common plans and forecasts. The automotive supplier co-location model triggered the idea of co-locating outbound partners.

The idea was to develop an end-to-end delivery model physically located at the factory, which would enable HP and its business partners to act as "one" virtual delivery and value chain. Furthermore, competences and capabilities of HP partners could be increased to sell and deliver a broader set of HP solutions and IT infrastructures, to gain corporate growth while infrastructure cost could be shared and thus lowered.

The goal was to increase end customer benefits by offering a broader set of completely pre-integrated **solutions** with an even shorter delivery time of less than 2.5 days. For the operation, the objective was to allow faster, undisturbed on-site installation, to leverage infrastructure and the procurement power of the larger partner, to lower inventory through elimination of safety stock, process steps and process buffers, to remove a transportation step from HP to the distributor, and to reduce risk of damage through the elimination of process steps. The ambition to facilitate business generation through supply chain services, and particularly through joint marketing, selling and delivery, was unusual to say the least. First, HP wanted to demonstrate a strong commitment to the channel partners. Second, combining the expertise and capabilities of all cooperation business partners made doing business simple. It could now be achieved by one-stop shopping for stand-alone products, HP solutions and multi-vendor solutions with one order, one shipment and one invoice.

Manufacturing process technology

Moving from the HP Solution factory to the HP Partner Park required making three important changes to the existing set-up. First, HP needed to convince the selected channel partners to collaborate and to bring into the HP factory the integration and stocking activities traditionally carried out by them. These supply chain partners then let HP conduct the entire physical assembly of the solution and the complete solution was directly shipped from HP's site to the end customer without any further intervention from channel partners. The channel partners used HP's infrastructure at the HP factory or through remote access to carry out some modifications or customizations on a product (in case HP did not have the know-how, and they did) before HP delivered them to the end customer. They were also able to work with HP engineers on joint problem-solving teams. Each partner within the value collaboration network focused on what it did best. A service portfolio was defined listing all possible collaboration activities and their corresponding prices.

Consequently, anything to do with the physical product and order fulfillment was done at the Solution factory, to gain leverage and efficiency in the supply chain. Doing all the integration work in one single place eliminated a lot of duplication. It was also faster and guaranteed quality.

This approach facilitated the greatest **flexibility of capability** management and the fastest delivery **speed** of complete **solutions**, while the leverage of the HP factory infrastructure lowered **costs** for all partners. The integration of the independent channel partners reduced the number of inventory points and thus the supply chain inventory level. The combination of resources enlarged the competences of the whole supply chain and enhanced the solutions bandwidth for the customer with the same resources.

Summary

The strategic goal of the concept was to extend the business portfolio to facilitate more sales; to increase agility and speed-to-customer; to lower the infrastructure and resource cost through leverage; to lower operational cost through the procurement power of the larger partners; to lower inventory levels by combining warehouses and forecasting plans; to let partners participate in HP's operational flexibility capability (e.g., the workforce model), and last but not least to offer future outsourcing models to relieve HP or the channel partner from operational fixed costs.

The objective of HP's Partner Park is to allow HP partners to achieve a direct-like agility with increased integration and delivery capability at a significantly lower cost. This program provided a comprehensive range of logistics and engineering services that included complete hardware/software integration, configuration and testing, as well as logistics services such as receiving, warehousing, picking, packing, and transportation activities.

Investments were low and limited to linking some IT systems to be able to transfer orders and financials. Within only six months it was possible to demonstrate both operational effectiveness and efficiency. The fulfillment cost dropped by 15% for the distribution partners and the overall revenues increased by 25% because distributors could now offer services delivered by the network that they could never have offered before. Needless to say, the number of new customers increased. In addition, HP was able to leverage

inventory which increased availability while lowering the inventory level. Data and information sharing was not only limited to formal communication processes. The employees of these different companies met each day informally and exchanged valuable information. Marketing campaigns were communicated early and forecasts were made together.
End customers were served with complete solutions, much faster and more efficiently than ever before. Different nodes in the outbound supply chain were eliminated and consolidated under the roof of the Solution factory. Partner Park became a real “One-Stop-Shop”, delivering computer hardware, services and complex IT infrastructure solutions.

3.2 Analysis of the HP manufacturing concept evolution

We now present the results regarding the exploratory case of our research. The interpretation of the results, in combination with the findings to emerge from our case description, will lead us to initial conclusions based on which we define the research propositions. This analysis was done in cooperation with HP management, who supported the research team with explanations and additional examples.

3.2.1 Overview of the HP TLC evolution

Figure 15 was developed during a discussion with HP management. It is designed to explain HP’s experience of market changes, as triggered by the evolution of its product technology. It shows how customers changed their requirements over time and how new competitors or partners impacted the HP worldwide manufacturing strategy. The figure shows the product performance of the available technology over time. The dotted line is the Customer Product Performance Expectation Curve, which indicates how HP perceived its customer expectations from a technology performance perspective. The solid line is the Industry Performance Curve, which explains the product performance available at a given time. The intersection of both curves is called the “commodity intersection point”, which was seen to be important at HP. The graph also shows different phases. The arrows indicate the speed of change which is not measured in the research. As long as the Industry Performance Curve is below the Customer Product Performance Expectation Curve, there is a strong demand for new technology. At the beginning of this life cycle customers seek product performance. In this section, the manufacturing scope at HP was local according to the criteria “closeness to the main customer base”. If the commodity intersection point is passed, customers either look for design, services and solutions or for price vs. performance.

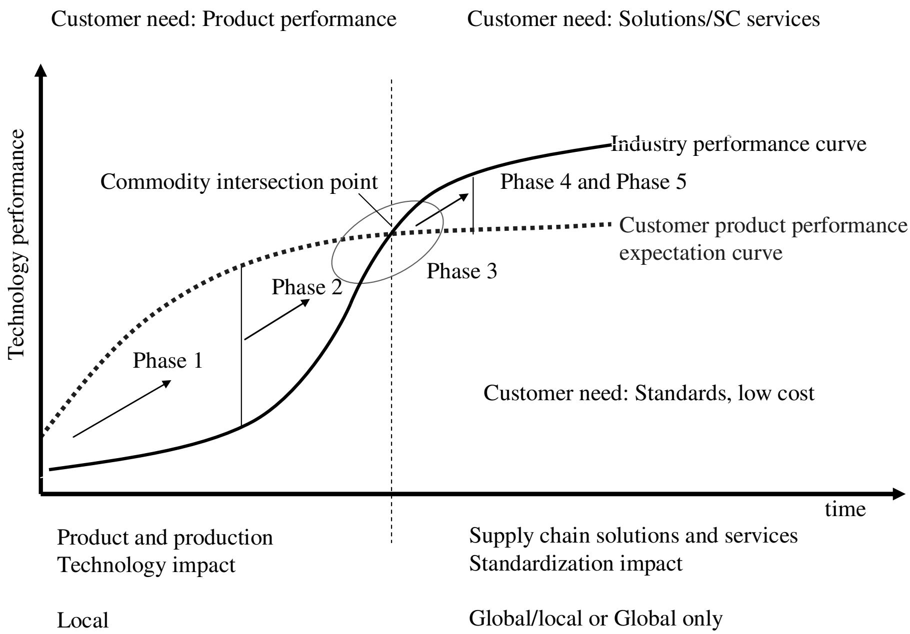


Figure 15: The TLC from an HP view

We seek to infer that these phases correlate with the phases described regarding the HP factory.

3.2.2 Detailed analysis of the HP Phases 1 to 5

Although that the measurement system is define later in Chapter 4, we already present at this point the HP pattern matching validation results, as explained in the introduction of this chapter. Table 2 shows the time phases and when each type of factory was developed at HP. The variables change according to the type of factory and can take a value of 0 (a specific theoretical type of factory has not been developed at the timeframe measured), 1 (has been developed to some extent) or 2 (has largely been developed). The median or so-called “mid-value” shows the result per time phase measured. Table 3 shows which phase of the theoretical descriptions of the TLC occurred at what time phase as measured at HP. The same scoring logic is applied. Here, the center of gravity value shows the result.

Index: H = High-tech factory; C = Low-cost factory; V = Velocity factory; S = Solution factory; N = Cooperative factory (network).

OM- EVALUATION
Possible values of variables:
2 = Situation of the case largely matches the theory
1 = Situation of the case matches the theory to some extent
0 = Situation of the case does not match the theory
- = non-existent

	Time-Phase 1					Time-Phase 2					Time-Phase 3					Time-Phase 4					Time-Phase 5				
Type of Factory	H	C	V	S	N	H	C	V	S	N	H	C	V	S	N	H	C	V	S	N	H	C	V	S	N
Sub Variables																									
Customer requirement and products - Requirements - Product portfolio characteristics	2	0	0	0	0	2	2	0	0	0	2	2	2	1	0	1	2	2	2	2	1	2	2	2	2
Competitive Strategy of the factory - Leadership through - Goal - Strategy	2	0	0	0	0	1	2	0	0	0	0	2	2	0	1	0	1	1	2	2	0	1	1	2	2
Process Strategy - Focus	2	0	0	0	0	1	2	0	0	1	0	2	2	2	1	0	1	1	2	1	0	0	0	2	2
Total Value	6	0	0	0	0	4	6	0	0	1	2	6	6	3	2	1	4	4	6	5	1	3	3	6	6
# of variables	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
Mid Value (median)	2.0	0.0	0.0	0.0	0.0	1.3	2.0	0.0	0.0	0.3	0.7	2.0	2.0	1.0	0.7	0.3	1.3	1.3	2.0	1.7	0.3	1.0	1.0	2.0	2.0

Table 2: The HP Types of factory (Summary)

TLC- EVALUATION
Possible values of variables:
2 = Situation of the case largely matches the theory
1 = Situation of the case matches the theory to some extent
0 = Situation of the case does not match the theory
- = non-existent

	Time Phase 1					Time Phase 2					Time Phase 3					Time Phase 4					Time Phase 5				
Theoretical TLC Phases	I	II	III	IV	V	I	II	III	IV	V	I	II	III	IV	V	I	II	III	IV	V	I	II	III	IV	V
Grand Total Value	24	13	0	0	0	2	15	11	2	0	0	5	17	10	1	0	0	1	22	9	0	0	0	17	9
Grand # of variables	12	12	12	12	12	10	10	10	10	10	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12
Grand - Mid Value (median)	2.0	1.1	0.0	0.0	0.0	0.2	1.5	1.1	0.2	0.0	0.0	0.4	1.4	0.8	0.1	0.0	0.0	0.1	1.8	0.8	0.0	0.0	0.0	1.4	0.8
Grand - Center of gravity		1.35					2.43					3.21					4.25					4.35			

Table 3: The HP TLC (Summary)

Phase 1: Before the 1990s

Phase 1 matches with TLC Phase I. The evaluation table (Table 3) shows a total center of gravity value of 1.35. Table 2 shows the factory is a high-tech type of factory with a match of 2.0/0.0/0.0/ 0.0/0.0/.

Products are at the beginning of the TLC. For customers, functionality and performance are essential and the industry offering is below customer need. This means that few customers buy these products and accept to pay a high margin. This conclusion can be explained by another example coming from HP's workstation business. During Phase 1, all graphic chip designs are internal or 100% internally sourced, and the technology is considered confidential and a core competency. Product R&D is important and only a few manufacturers might have the product technology and the process technology to produce the product. Revenues increase, R&D investments increase, and new products are introduced with higher performance over time. Product and process, so far, is internal since no capabilities are available on the market and it is a market differentiator.

Impact on the factory in Germany: The factory focuses on the development of internal manufacturing capabilities to be able to build the constantly changing and evolving new products. Product quality yield and manufacturability is key to controlling the product and production innovation speed. Only very few suppliers can support HP's business, which explains why most manufacturing is done internally at the local factory.

[Summary 1]: This time phase correlates with the description of the first TLC-phase with its growing markets and increasing customer needs, and of the High-tech factory with an overall focus on building new product technology and satisfying the market demand for new and better performance.

Conclusion 1
In Phase I of the TLC, HP developed a High-tech factory.

Phase 2: From 1990 to 1995
Phase 2 matches with TLC Phase II. The evaluation table (Table 3) shows a total center of gravity value of 2.4. The factory is a Low-cost factory and still a High-tech factory with a match of 1.3/2.0/0.0/0.0/0.3, as shown in Table 2.

At the beginning of Phase 2, revenues still increase, R&D investments increase and new products are introduced with higher performance. In a later stage of Phase 2, competition increases in the area of pricing because of two factors: First, customers still need growing technology but some low-end customers are demanding less. Thus, some products are becoming commodities since customers are increasingly demanding standard products. Consequently, cost pressure is pushing harder for standardized processes. Second, skilled people with their own companies start to push into that market to satisfy low-end customers (for example, ex-employees of HP, Sun or SGI). In our example, these start-up companies enter the graphics chip design and fabrication business. These new companies release some products and start to meet the needs of the small percentage of customers at the bottom of the customer base. In our example, Dell entered the workstation business. In this stage of development, a company like Dell realized that the only real difference between a PC and an engineering workstation is graphics performance and that those customers were willing to pay four to five times PC prices for a workstation. Dell incorporated these "off-the-shelf" graphics chips. It probably bought high-end chips to be able to enter the workstation business without ever having to invest in R&D. It charged only twice the PC price, steadily increased market share and made significant profits. By the end of this phase, customers are increasingly demanding standard products to achieve lower prices and maintenance costs. More and more suppliers now have the capabilities to offer component technology on the market. The new market participants, particularly, are now buying commodity components from global suppliers. Consequently, internal manufacturing becomes less important and supply chain management starts to evolve. Starting a business in a later phase of the TLC has a significant impact on processes and company culture. HP was, and still is, a product R&D-oriented company. Dell was and is a supply chain-oriented company, where much emphasis is put into process R&D.

The impact on the factory in Germany:
Until then, all manufacturing was still done in the local countries, but as companies continue to exert more pressure on external suppliers to reduce costs, they are forced to

move a significant amount of manufacturing to low-cost countries with low wages and little or no long-term costs. Over time, the subcontractors adopt the same strategy. Return on assets is now a major financial driver, and companies try to minimize investment in plants and equipment. Cost of labor is prompting companies to minimize the number of employees, especially low-skilled labor.

[Summary 2]: This phase correlates with the descriptions of TLC Phase II and the Low-cost factory. In Phase 2, a new category of players comes into play (like Dell) with a focus on SCM on the one hand, but low product R&D spending on the other hand. The competition increases and prices become more important because some customers start to look at the second best technology to save money and new types of market entrants launch products in the low-end area. However, some suppliers become capable and now offer components to OEMs at costs lower than their internal manufacturing costs. Thus the focus switches from high-technology to supply chain management for reasons of cost optimization.

Conclusion 2

In Phase II of the TLC, HP developed, in addition, capabilities of a Low-cost factory.

Phase 3: From 1995 to 1998

Phase 3 matches with the TLC Phase III with a center of gravity value of 3.2. The factory becomes a Velocity factory with a match of 0.7/ 2.0/ 2.0/1.0/ 0.7. This is shown in Table 2. Still, High-tech factory and Low-cost factory capabilities are there, and some capabilities evolve into the area of Solution factory.

Next to cost, the customer experience cycle time is now impacting the value chain at most. During Phases 1 and 2, customers look at a very limited number of factors, mainly product performance and later cost. This tendency changes after the commodity intersection point. Now, enough product performance is available and products become cheaper because of their maturity in production, the additional competition, and because suppliers offer lower-cost alternatives (see Phase 1 and 2 details). Now, customers are looking for more factors (variables) than just product performance and cost. In this stage, velocity comes into play. From a customer perspective, delivery performance has to be improved and lead times have to be reduced. Some customers start to ask for more customized configurations, delivered within the same timeframe as standard computers. On the other hand, a dominant design and industry standards start to evolve. Market differentiation by product technology becomes more difficult and customers are no longer bound, in their purchasing decision, to a specific vendor, unlike in Phases 1 and 2. Thus stock availability and short order cycle times turn out to be vital factors to compete in this market. This new velocity approach allows a much faster response to demand fluctuations and changes in customer requirements.

The impact on the factory in Germany:
Since velocity is the major goal, the working mode from batch and serial-based push processes to parallel pull processes becomes necessary. Information management, linking and synchronizing of all processes and systems increases speed and reduces costs. Quality assurance, prevention of expensive rework, and velocity now need to be guaranteed. From a shareholder perspective, costs have to be cut, inventories lowered, and processes made leaner.

[Summary 3]: This phase correlates with the descriptions of the third TLC phase and the Velocity factory. Manufacturing technology matures and internal capability is no longer needed to the same extent as in Phases 1 and 2. Velocity becomes important from two perspectives. First, customers expect lower order cycle times. Second, velocity reduces pipeline inventory and safety inventory, and thus supports low cost – which is still important. Velocity in fulfillment supports cost reduction and customer satisfaction but velocity in fulfillment in this volatile environment requires much flexibility in the supply chain and the factories. In this section, HP's objective is to increase process speed and efficiency based on a combination of flexible processes, flexible labor, space on demand and best-in-class IT systems.

Conclusion 3
In Phase III of the TLC, HP developed extra capabilities of a Velocity factory.

Phase 4: From 1998 to 2003
Phase 4 measured matches with the TLC Phase IV with a center of gravity value of 4.25. The factory type is shown in Table 2 and becomes a Solution factory with a match of 0.3/ 1.3/ 1.3/ 2.0/ 1.7. Low cost and velocity still play an important role but capabilities now evolve into the area Solution factory and to some extent the Cooperative factory. The Cooperative factory value is 1.7 and therewith is already strong.

This can be explained by the fact that inbound integration was extremely high and some outbound integration starts to become more intense. From the commodity intersection point on, we see two kinds of customers: The price- and commodity-oriented customer buying standards, and the solutions- and services-oriented customer buying complex products. For these customers, design variances, customized solutions, and industry-mix solutions trigger their buying decision. Low cost products in combination with solutions and supply chain services evolve. In other words, in this phase customer needs are split into standard products for lowest prices and operating cost and complex solutions for complex customized applications. Many competitors are now competing mainly within the low and mid range. There the only differentiator is price. Alternatively, other customers ask for highly complex and customized products with combined supply chain services.

[Summary 4]: The measured time segment Phase 4 correlates with the descriptions of Phase IV of the TLC and a Solution factory evolves. According to the market demand HP presents two types of supply chains: A global low-cost supply chain with

standardized products, and a solution- and service-oriented global/ local supply chain. The focus of the local factory slides into solutions and services.

Conclusion 4
In Phase IV of the TLC, HP developed extra capabilities of a Solution factory.

Phase 5: From 2003 to 2005
Time Phase 5 measured also matches with the TLC Phase IV with a center of gravity value of 4.35. However, the factory becomes a Cooperative Factory with a match of 0.3/ 1.0/ 1.0/ 2.0/ 2.0, as shown in Table 2.

The market and with that the TLC characteristics do not change much anymore except that customers now expect customized solutions and supply chain services for lowest cost and fast. In addition, shareholders want the solutions business to be more profitable which can only be achieved by intense outbound partnerships with value-added resellers, distributors and integrated system vendors. Thus capabilities now evolve into the area Solution factory and Cooperative factory.

[Summary 5]: Phase 5 measured also correlates with the descriptions of Phase IV of the TLC and can be characterized as process capability adaptation to adjust to the tighter expectations of customers and shareholders in the area of solutions and services. Thus a more efficient network of partners in close geographical proximity was developed.

Conclusion 5
Later in Phase IV of the TLC, HP developed extra capabilities of a Cooperative factory to increase the efficiency of the Solution factory and to supply customers with solutions faster and at lower cost.

3.3 Deducing research propositions and conceptual model

Bacharach (1989, p. 500) defined theory as follows: Theory "*can define a statement of relationships between units observed or approximated in the empirical world*". Bacharach continues by saying that propositions are not yet tangible and watertight and that they describe the relationships between constructs. Hypotheses are derived from propositions and specify the relationship between variables.

Based on the HP experience and Conclusions 1 to 5, we deduce the following the propositions and the conceptual model regarding successful manufacturing within the electronics high-tech value business. Within these propositions we use three terms. Necessary refers to a necessary condition and is defined as follows: B exists only if A exists or if there is B there is A or A is needed for B or A is a necessary condition for B if A is always present when B occurs (Dull and Hak, 2007, p. 91). The types of factory are defined in Section 4.2. The definition of "best-in-class" is defined below in this section.

From Conclusions 1, we constitute the following proposition:

Proposition P1
In Phase I of the TLC, a High-tech factory is necessary for best-in-class manufacturing.

In other words: A High-tech factory is necessary to be able to produce a new high-tech invention.

From Conclusion 2, we constitute the following proposition:

Proposition P2
In Phase II of the TLC, it is necessary for the High-tech factory to evolve and a Low-cost factory to become dominant for best-in-class manufacturing.

This implies that the capabilities of the High-tech factory continue to exist and that these capabilities will be partly adapted toward low cost or become obsolete because of new product technologies.

From Conclusion 3, we constitute the following proposition:

Proposition P3
In Phase III of the TLC, it is necessary for the Low-cost factory to evolve and a Velocity factory to become dominant for best-in-class manufacturing.

This again implies that the capabilities of the earlier types of factories continue to exist but will be tuned toward velocity or that they become obsolete due to new technologies.

The following proposition is drawn from Conclusion 4 and also Conclusion 5. This is based on the fact that both conclusions are about TLC Phase IV, where HP developed two types of factories.

Proposition P4
In Phase IV of the TLC, it is necessary for the Velocity factory to evolve and a Solution factory and later a Cooperative factory to become dominant for best-in-class manufacturing.

This again implies that the capabilities of the earlier types of factories continue to exist in a way to support solutions offerings and services, or that they become obsolete due to new technologies.

Remarks

We want to state, that the High-tech factory, the Low-cost factory, the Velocity factory and the Solution factory are types of factories which support certain market conditions. However, the Cooperative factory is only a process related extension of the Solution factory.

As said, there will be no further proposition regarding the value of "local" manufacturing since this is not validated but can be concluded from the results of the propositions.

Our findings and the link between the contextual framework of the TLC and the independent constructs, the types of factories, can best be illustrated by looking at Figure 16. This figure is a combination of Figure 1: Factory evolution, and Figure 15: The TLC from an HP view. Figure 1: Factory evolution shows how the successful HP factory adapted the capabilities along the TLC phases in a certain sequence. Figure 15: The TLC from an HP view is HP's description of the TLC and is close to the descriptions of the TLC literature. However, it explains how the market changes via the industry performance curve and the customer product performance expectation curve.

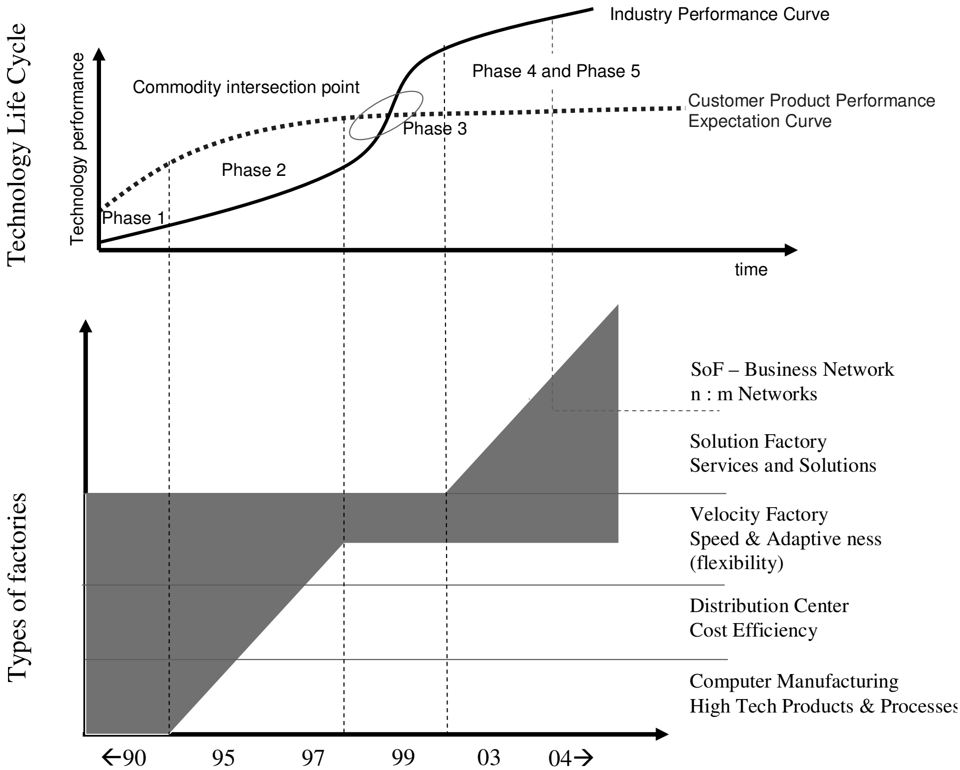


Figure 16: Linking HP TLC and types of factory

Conceptual model
The construct of this proposition is shown in our conceptual model in Figure 17. We validate whether the switching of factory capabilities in accordance with the sequence of TLC phases, as specified by TLC literature, is necessary for being best-in-class. The

contextual framework comes from the TLC literature which classifies the transition of a market in several phases, driven by the product technological evolution. Within each phase the characteristics of the customers, competitors and the technology change.

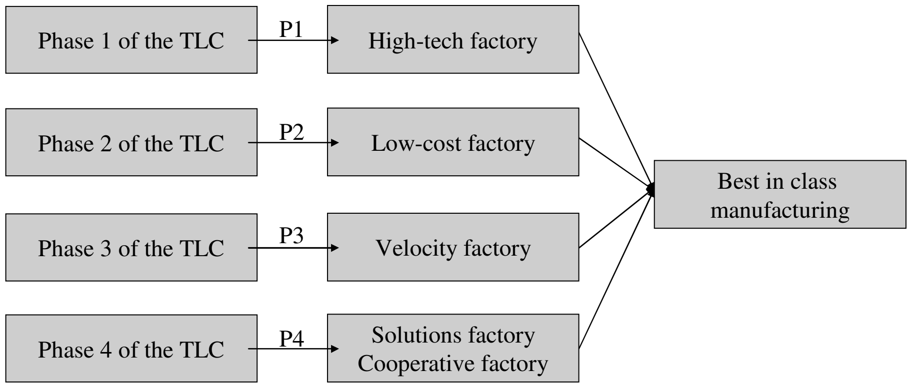


Figure 17: Conceptual model

Definition of the dependent construct – best-in-class manufacturing

Best-in-class manufacturing may be viewed from a quantitative or from a qualitative standpoint.

i. Quantitative performance measurement on company level: Many researchers define quantitative performance as financial performance such as return on investment (RoI), return on assets (Droge *et al.*, 2004), or profit as a percentage of sales (Carr and Pearson, 1999). Other looked at the market and sales related performance such as market share (Droge *et al.*, 2004), sales growth, cost of sales (Rosenzweig *et al.*, 2002), return on investment, or return on sales (Shawnee *et al.*, 2003). Some researcher selected time-based performance metrics such as time-to-market (product development time; product introduction), time to product (procurement lead time or manufacturing lead time), or time to response (product support, pre-sales services) (Droge *et al.*, 2004).

ii. Quantitative performance measurement on manufacturing level: For example DuBoies (1993) defines four key manufacturing performance drivers, which are efficiency (cost), quality, dependability, and flexibility.

iii. Qualitative performance measurement: Frohlich and Westbrook (2001) or Voss (1988) define success in manufacturing as marketplace competitive advantage, productivity increases in manufacturing, and non-productivity benefits supporting customer satisfaction. Marketplace competitive advantage is supporting companies' success and resulting in greater profitability and increased market share and thus driving a market place competitive advantage. Productivity increases in manufacturing can be achieved by a greater throughput at less operational cost by a decrease in cost and an increase in output. Non-productivity benefits are supporting customer satisfaction by better quality and increased service levels in operations like order lead time.

We deduce the definition of best-in-class manufacturing as follows:
Quantitative performance measurements would not be practical for our research. Despite the manufacturing system undoubtedly impacting a company's success, there are many other factors driving its financial performance. Thus, the financial performance of a company or a manufacturing operation cannot be used as a measurement system. The quantitative performance measurement on a manufacturing level as well as the qualitative performance metrics could be applied to our research. However, to limit the scope and complexity of our research, we define best-in-class based on the following criteria:

Best-in-class manufacturing
We consider a factory to be best-in-class if it has won industrial awards in accordance with soundly defined criteria issued by researchers or university institutions.
Alternatively, best-in-class manufacturing may be defined if the plant has applied state-of-the-art industrialized technologies in terms of manufacturing skills and equipment which are rarely available worldwide and are considered a competitive differentiator for the company.

These criteria can typically only be achieved if the quantitative metrics for manufacturing and qualitative metrics listed are met. Subsequently, best-in-class manufacturing is achieved if a plant has demonstrated that it survived in a highly competitive environment. This additional criterion allows us to widen the potential cases.

In the following chapter we present the development of the research measurement system to validate the propositions defined. In Chapter 5 we define the selection criteria of our population, of which best-in-class manufacturing is a central criterion.

4 INSTRUMENT DEVELOPMENT

In the current literature we could not find an appropriate measurement system to validate the relationship as expressed in our conceptual model. Consequently, we develop the research measurement instrument in this chapter which is to be used for data collection and data analysis to validate the propositions. Our research measurement instrument consists of constructs and variables and sub-variables. Kaplan (1964, p., 55) defines constructs as *"terms which, though not observational either directly or indirectly, may be applied or even defined on the basis of the observables"*. Bacharach concludes that a construct may be viewed as a broad mental configuration of a given phenomenon. Schwab (1980) defines variables as an observable entity which is capable of assuming two or more values. Bacharach concludes that a variable may be viewed as an operational configuration derived from a construct.

In our research, we evaluate a relationship among the TLC and necessary manufacturing capabilities (types of factories) for best-in-class manufacturing. As a result, there are two constructs: First, the TLC, which defines the contextual framework of our research. It describes the changing environment of markets which may trigger a realignment of company strategies on manufacturing. This is developed in Section 4.1 by linking the existing TLC literature as discussed in Section 2.1. The manufacturing capabilities form in concert the types of factories, defined as our second independent construct. This is developed in Section 4.2 and is founded on OM literature as discussed in Section 2.2. Furthermore, each of these constructs will be characterized by variables which alter along the different phases of the TLC and the respective types of factories. Consequently, based on the literature, a sound description of the criteria of the research measurement instrument will enable us to form the research measurement instrument in Chapter 4.

Figure 18 shows the contextual framework and the independent construct of our research measurement instrument.

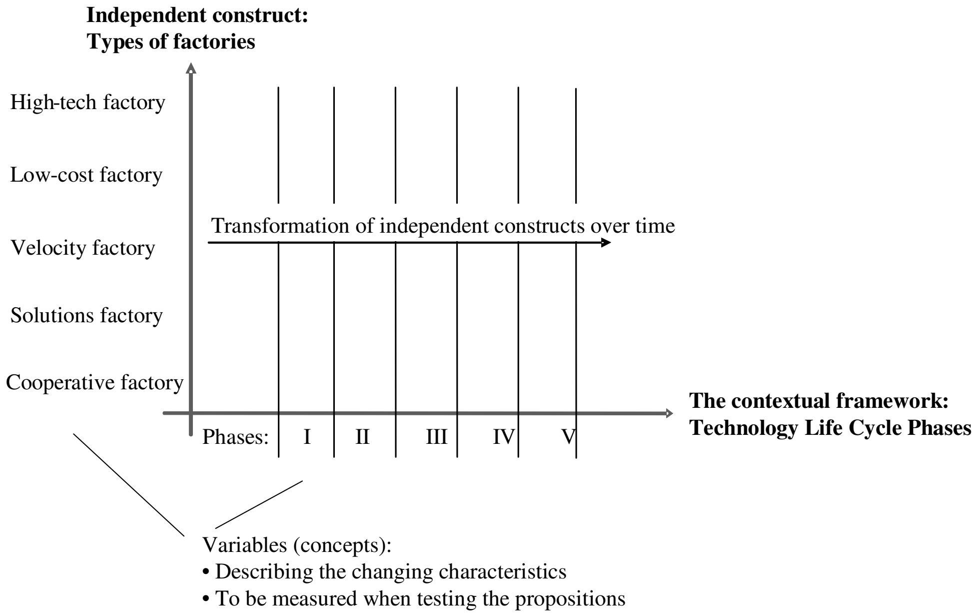


Figure 18: The research measurement instrument

4.1 Setting constructs and variables of the contextual framework

The contextual framework is developed in two steps. We first define the phases of the contextual framework. These phases are noted in Roman numerals. We assessed the most renowned literature and especially the findings by Moore (2002), Christensen (1997), and Norman (1998). In a second step, we define the variables and sub-variables. Literature in environmental dynamism provided the variables regarding the contextual framework. The sub-variables enhanced the descriptions of the variables.

Step 1: Definition of the phases of the TLC

We follow the constructs used by most of the investigators in TLC research and split the TLC into five phases.

i. In **Phase I** of the TLC the technology is unreliable since product performance increases rapidly. Products are technology-driven and feature-laden. There is no consensus about appropriate applications of the product. Price and production costs are high, and there is therefore only a slow growth in profit. The market is a specialist market where technical performance and functional characteristics outweigh unreliability and high cost. For customers, performance is more important than cost. In manufacturing there is typically no focus, and it can be characterized as expensive and inefficient.

ii. In **Phase II** of the TLC the market begins to grow since customer requirements become better understood. The product designs are determined by the needs of special groups of customers which improve product acceptance by the market. Thus margins begin to grow. On the other hand, more competitors appear who still compete on the basis of the functional product performance. Only a few suppliers are available, so manufacturing depth is still high. Product and process innovation are still interdependent.
iii. In **Phase III** of the TLC the technology performance is still growing but less rapidly than in Phase 1. The product starts to become customer-friendly and more reliable. Price and production costs decrease and customers get a better price/performance ratio. Market segmentation occurs since companies offer products for specific customers and market growth evolves. In manufacturing, the first changes from technology push to market pull can be seen.
iv. In **Phase IV** of the TLC a technology maturity is reached. Product functionality and reliability are provided and thus cost, prestige, appearance and convenience, become important differentiators. Market growth declines since the market has become saturated. Customers can be characterized as late adopters and more pragmatic, taking basic performance for granted. The overall business is now much more cost-oriented and thus margins decrease. The technology-driven company must change and learn to make products for its new customers to customer convenience. In manufacturing, there is more focus on cost control and efficiency.
v. **Phase V** is characterized by no significant technological improvements. The market peak has been reached and starts to fade. Sometimes, companies start to apply the existing technology to new products or adopt a new technology.

Step 2: Definition of the variables (concept) of the phases of the TLC
To be able to take the long view and track the changing roles and responsibilities of the local factory during the TLC, it is important to understand the environmental dynamics in the high-tech market and how they impact the supply chain and the local factory. Thus, the environmental dynamics literature provide us with the variables of the contextual framework. As groundwork, we have used the classification of environmental dynamics identified by Jaworski and Kohli (1993) (see also Slater and Narver 1994; Enders, 2004). The authors distinguish between market and competitive and technological dynamism. We will use these three definitions and deduce the following six variables:

i. **Market dynamism**: In dynamic markets, new customers regularly approach the firm and bring new ideas and requests. "Static" markets are defined as having only slight changes in customer preferences (Enders, 2006). Companies that experience a high degree of market dynamism need to have a strong customer focus in order to fulfill changing customer requests quickly and constantly. Market dynamism is driven by customer behavior. In their definition, market dynamism includes customer behavior and customer requirements which we will break up into separate variables. Thus, the first variable is **customer** behavior. According to Fine, the required process capabilities are driven by the change in customer requirements, markets (market characteristics), technology and environment. Thus, we extend the market view of Utterback and define market characteristics as a second variable that has to be measured. **Market dynamism** has impact on the company's profit situation which can be deduced from the customer's position and behavior. So, we extend this second variable including the company's **profit** situation with the technology sold. This is supported by Peterson *et al*. (2002), who defined Customer Actions as a measurement of environmental dynamism.

ii. **Competitive dynamism**: Strong competitive dynamism can be defined as high competitive pressure. In a highly competitive environment it is extremely difficult for a company to establish and protect a strong competitive position, since competitive advantages are quickly eroded and can thereby only result in a short-term benefit (Enders, 2006; Fine, 1998; Utterback, 1996). In his discussion of dynamism in supply networks, Verduijn (2004) named, among other factors, "actors in supply networks". He found actors in the network, channels to which an actor contributes, and processes used by an actor. With the definitions discussed above, we have already covered the actors: "customers, competitors and the factory". To cover all actors of a supply network, we also include "supply chain actors/supply chain (SC) partners" as an additional variable, who are sales and logistics partners and suppliers and contract manufacturers. Consequently, the third variable is **competitors** and how they behave. The fourth variable is **supply chain partners**, which are actors in supply networks like vendors, contract manufacturers or sales partners. This variable will track their changing capabilities in fulfillment over time. This is supported by Peterson *et al*. (2002), who defined competitor actions and supplier actions as a measurement of environmental dynamism.

iii. **Technological dynamism**: In contrast to the first factor, which is more customer – and therefore externally – driven, technological dynamism looks at the internal side. Thus, technological dynamism is the opposite side of the coin, with market dynamism on the one side and technological dynamism on the other (Enders, 2006). Utterback (1996), in his research – as part of the TLC theory – combines the market aspects with those from the supply chain and manufacturing theory, and therefore has the strongest link to our research. The variables used in his model are process technology, product technology, manufacturing, competitors and markets. Both process technology (including manufacturing process technology) and product technology correspond to Jaworski and Kohli's definition of technological dynamism as well as Fine's definition of process and product clockspeed. Thus, we find the fifth and sixth variables, which are process technology and product technology.

These six variables can be summarized as follows:

Six variables of the contextual framework
Market-characteristics including Profit situation; Customers; Competition and Partners (equals supply chain actors); Process technology and Product technology

Table 4 shows the researchers cited and how their findings link to the variables used for our model.

		Markets dynamism		Competitive dynamism		Technological dynamism	
		Markets characteristics	Customer	Competitors	SC - Partners	Process technology	Product technology
Jaworski and Kohli	Market Dynamics	X	X				
	Competitive dynamics			X			
Enders	Technology dynamics					X	X
Utterback	Process technology					**X**	
	Product technology						**X**
	Manufacturing					**X**	
	Competitors			**X**			
	Markets	**X**					
Fine	Process speed					X	
	Product speed						X
	Organizational speed						
Verduijn	Actors in the network				X		
	Channels in the network				X		
	Channels to which an actor contributes					X	
	Processes used by an actor					X	
	Channels to which processes contribute					X	
	Flow of orders running through a channel					X	
	Type of orders flowing through the channels					X	
	Use of channels					X	

Table 4: Selection of the variables of the indirect construct

Table 5 presents this first part of our measurement, the contextual framework, with its constructs (phases), variables and sub-variables. The sub-variables were developed based on the theoretical descriptions of the TLC. We first arranged these theoretical descriptions according to the six variables defined above. Then, we again clustered each of the descriptions of the variables to define the sub-variables. These were then validated and refined in several circles by applying them to the cases.

Variables	Sub-variables	Phases I	II	III	IV	V
Market Evolution Profit situation	Marketing evolution and characteristics Marketing strategies Evolution of margins					
Customers	Characteristics of customers Relevant to customers					
Competitors	Strength of competition Competitive strategies					
SC In- / outbound partners	Strength of suppliers Role of suppliers/ CMs / partners					
Process Technology	Process technology and technical evolution (importance of process technology) Characteristics of manufacturing (How do companies control processes?)					
Product Technology	Product technology evolution Product characteristics and design					

Table 5: The TLC – variables of the research measurement instrument

4.2 Setting constructs and variables of the types of factories

Step 1: Definition of the types of factories and its variables

The OM literature will serve the independent constructs and its variables to measure the capability switching of the factory over a period of time. We appraised a range of literature in OM. However, only a very limited number of research projects evaluated whole types of factories with specific associated capabilities. According to Wiendahl (2001), types of factories can be divided into different perspectives: the market perspective, the organizational perspective, and the process perspective. A “type of factory” is defined as a factory owning a cluster of specific manufacturing or supply chain capabilities to efficiently compete in a certain market environment. Taking Wiendahl’s definitions, we focus on the market perspective since we trace the operational link to the TLC which, in turn, describes the changing market characteristics over a period of time. This choice is also in line with Corbett and Van Wassenhove (1993), who state that a firm’s competitiveness in any particular market depends on its ability to meet that market’s desires, so any measure of competitiveness must be market- or customer- oriented. Koerber *et al*. (2003) described these different types of factories from a market perspective. They claim that certain types of factories are needed in certain industries. They called it “Typologisierung von Fabriken” (types of factories). However, based on the exploratory case, we will prove that these types of factories will be developed by each local factory in the high-tech electronics industry along the TLC. Therefore, we have developed our measurement model based on the different types of factories defined by Koerber *et al.* They named them as follows: The High-tech factory (die High-Tech Fabrik); the Low-cost factory (die Low-Cost Fabrik); the Velocity factory (die schnelle Fabrik); the Flexible factory (die variantenflexible Fabrik) and the Breathing factory (die atmende Fabrik).

We use Koerber's definition of the following three types of factories: the High-tech factory, the Low-cost factory, and the Velocity factory. However, based on the experience of the pilot case, we have refined some of Koerber's classifications and define as factory type four and five the Solution factory and the Cooperative factory. Regarding the Solution factory, we combined Koerber's Flexible factory with their Breathing factory to form the "Solution" factory. In terms of the Cooperative factory, we use Koerber's definition of a Cooperative factory (die kooperative Fabrik). This is an extension of the Solution factory at a later stage. The major difference to all other factories is the strategic viewpoint from which the needs for new capabilities are defined. The High-tech, the Low-cost, the Velocity factory and the Solution factory are types of factories which are used to adapt to a certain market situation. The Cooperative factory is a type of factory defined from a process and partner perspective (Wiendahl, 2001, p. 9). In our pilot case we found that a natural extension of the Solution factory must be the Cooperative factory to better control the bandwidth of capabilities and to be able to offer solutions fast and at lower cost. The Cooperative factory is therefore a further evolution step closely linked to the Solution factory – in a similar market environment but with different processes to facilitate solution capabilities more efficiently.

Summary of the types of factories:

i. The High-tech factory: Control of the technology and the yield of the processes (technology)
ii. The Low-cost factory: Control of the processes flow and cost and efficiency (cost)
iii. The Velocity factory: Control of the process flow and effectiveness (velocity)
iv. The Solution factory: Control bandwidth of capabilities and of products (solutions)
v. The Cooperative factory: Control of the division of work and the efficiency of the collaboration (networking)

Regarding the findings of Koerber, we refer to Section 2.2.1, where all types of factories are described in detail.

Step 2: Definition of the sub-variables (concept) of the types of factories

To extend and elaborate upon the findings of Koerber *et al.*, we have identified and used more literature to enrich their definitions. The following literature sets the basis of the definition of the sub-variables, which are applied for "special indication". Special indication means that we provide additional descriptions of the characteristics of a factory type to better support the validation process.

Since there is an overwhelming amount of research into manufacturing and supply chain excellence, we have verified the researchers most relevant to the ideas of our conceptual model. A close link between more market-oriented research and OM research was developed by Fine (1998), Nassimbeni (2002) and Verduijn, (2004), who looked at the dynamism of markets and their impact on the supply chain and the operation. Much research has been done in the area of supply chain integration by Frohlich and Westbook (2001), Droge *et al.* (2004), Yongjiang and Gregory (1998), Shawnee *et al.* (2003), Rosenzweig *et al.* (2003), Carr and Person (1999) and Boddy *et al.* (2000) to name but a few. They have all found and defined capabilities in collaboration and integration. Zhang *et al.* (2002), Cooper and Kleinschmidt (1995) and Hendricks and Singhal (2003) have tested more specifically capabilities within a manufacturing operation.

Next, we combine Koerber's findings with explanations from other researchers.

i. According to Koerber *et al.*, the "**High-Tech factory**" supports most innovative products. Loch *et al.* (2003) found that High-tech factories often build expertise in manufacturing for later transfer to low-cost locations. Their task is piloting and testing processes in the local factory to off-shore in a true partnership and for mutually complementary value creation across a network, or targeted off-shoring for low-skilled jobs. This is necessary as long as there are new or disruptive technologies appearing.
ii. According to Koerber *et al.* (2003), at a "**Low-cost factory**" all cost categories are consistently and carefully defined and controlled. Zhang *et al.* (2003) define manufacturing flexibility in detail as follows: machine flexibility, labor flexibility, material handling flexibility and routing flexibility, and volume flexibility. More details are listed as part of the Solution factory. The major difference to solution flexibility is that these kinds of flexibilities are implemented if they lower the overall cost of the operation and not to extend the overall portfolio of fulfillment services.
iii. According to Koerber *et al.* (2003), **the Velocity factory** is where customers demand shortest delivery times. Time refers to all lead-time related factors, such as the order fulfillment time, variability of it, lead-time sensitivity to changes in demand and time to market for new products. Time encompasses the role of dependability, flexibility, and rate of innovation (Corbett and Van Wassenhove, 1993). Cooper and Kleinschmidt (1995) define the following attributes to speed up the process: supplier involvement, overlapping product development stages, multifunctional teams and supplier involvement. Zhang *et al.* (2003) define machine flexibility as the ability of equipment to perform different operations economically and effectively. Measurement is made of the number of operations a machine can perform and the related speed.
iv. According to Koerber *et al.* (2003), the **Flexible factory** – we call it the **Solution factory -** offers specific custom solutions or a broad bandwidth of products and options. Flexibility in this context is important to manage the bandwidth of products and services. Zhang *et al.*'s (2003) definition of manufacturing flexibility can be applied here as well. Flexibility plays a major role but from a different perspective since it is important to offer a broad bandwidth of fulfillment

capabilities at a reasonable cost. In more detail, they define the following flexibility capabilities. Labor flexibility allows the workforce to perform a great variety of manufacturing tasks economically and effectively. Measurement may be made of the number of tasks a worker can perform and the related speed of execution and the ability to learn. Material handling flexibility and routing flexibility are the capability to transport different material over multiple paths and routes at the lowest cost. Hutchinson (1991) states that in a solutions environment, material handling equipment offers a broad range, mobility and uniformity attributes. Routing flexibility enables a logistics system to quickly find alternatives in cases of breakdown or overflow (Sethi and Sethi, 1990). Measurement of mobility can be the time and cost expended to make a change. Uniformity can be measured by differences in processing time and quality when alternative routes are used. Volume flexibility may be expressed as the ability to operate with various batch sizes economically and effectively.

v. **The Cooperative factory**, as an extension of the Solution factory, has a manufacturing depth of often less than 20%. The goal is to reduce complexity and increase flexibility, quality and time-to-market by including system partners in the supply chain. Frohlich and Westbrook (2001) define collaboration as a level where partners have access to planning systems, share production plans, have joint EDI networks, share inventory mix and levels with common logistics equipment and the common use of third-party logistics. Shawnee *et al.* (2003) define collaboration in two directions: First, supplier partnering with a high level of trust combined with joint conflict resolutions and the sharing of information, risks and rewards; second, a tight customer relationship. This corresponds to supplier partnering but looks downstream toward the customers. By seeking information on customer preferences, they have the strategic capability to better understand customers' requirements. Cross-functional teams are implemented in a decentralized way to achieve a balanced construct across the supply chain and a win-win situation. From a customer perspective they provide, first, pre-sales, which is the ability to support customers during their purchasing decision; second, product support is the support given to customers after sales have been made to ensure continuing customer satisfaction; third, responsiveness to customers, measuring how fast customers are informed, how fast their order is confirmed and the speed of response to customer complaints; last, delivery dependability, which refers to on-time deliveries and delivery speed.

In summary, we have set the sub-variables for special indication of a factory type as follows:

Variables	Sub Variables for special indication of a factory type	Type of Factory: High-tech	Low-cost	Velocity	Solution	Collaboration
Customer requirements	"High-tech": Importance of manufacturing process technology	x				
Product portfolio characteristics	"Low-cost": Importance of Supply Chain Management/Outsourcing and Off-Shoring		x			
Competitive strategy of the factory regarding areas of leadership, goals and strategies	"Speed and Flexibility": Importance of Flexibility within the operation and Collaboration with Suppliers			x		
	"Solutions": Importance of Customer Service				x	
Process strategy (focus areas)	"Networking": Importance of Collaboration with suppliers, CMs and partners					x

Table 6: The OM – variables of the research measurement instrument

4.3 Defining the validation procedure

To validate the propositions we have combined, in four steps, the contextual framework and the independent construct to form the research measurement instrument. The requirements discussed above support the underlying principle to determine the driving constructs of our model and their dependencies. Figure 18 shows the two constructs. On the horizontal axis we have set the contextual framework with the five phases defined. Within each phase we then set six variables as defined. On the vertical axis we have placed the independent construct – the five types of factories with the corresponding variables. Linking both dimensions allows us to evaluate the relationship between the type of factory and the TLC phases. More details are shown in Appendix IV.
In the following section, we provide insights into the process of how to validate the propositions. The research propositions are evaluated in three steps:

Validation process

In step 1 we assess the chronological evolution of the TLC. With our measurement instrument we will indicate at what point the factories passed through which phase of the TLC. The defined constructs will be evaluated to measure the intensity of the correlation between the real-life cases over time and the theoretical description of the five phases of the TLC. A certain phase of the TLC occurred at a time measured if the correlation between the description of a specific phase of the TLC and the real case at a certain time is high.

In step 2 we measure which type of factory was installed at what point based on the same principle as defined in step 1. The chronological evolution of developed manufacturing capability – based on the variables defined – will enable us to understand at what point the plants established which type of factory.
In step 3 the two dimensions will be linked to see which type of factory was used at what phase of the TLC. We will then deduce which manufacturing strategy was chosen in what market situation for best-in-class manufacturing.

Result calculation
Regarding the evaluation, each variable and sub-variable could be ranked between “0” and “2” indicating that the theoretical description of the variable within a certain phase of the TLC does not match (0); does match to some extent (1); or does match with the case (2) at a certain timeframe measured. We illustrate that with an example. If, in the 1980s, Agilent developed capabilities which match the description of the High-tech factory but with no other type of factory, we scored the High-tech factory 2 and the other types of factory 0. All these results are discussed in detail in Section 8.2. For each variable, the median (mid-value) was calculated. Within the dimension of the TLC, we calculate a “center-of-gravity value”. This is a decimal number indicating how close a company was at a particular time to one of the five phases defined by the TLC theory. The value may be between 1 and 5. The details are listed in Appendices V-VII.
To calculate the center-of-gravity value, we define the following formula:

Center of gravity value
Center of gravity of a certain timeframe of the case factory = 1 x (mid-value phase 1) + 2 x (mid-value phase 2) + 3 x (mid-value phase 3) + 4 x (mid-value phase 4) + 5 x (mid-value phase 5).

For all types of factories we applied the same approach. The variables could take a value between 0 and 2. A value of 0 means that the observed pattern does not match with the defined pattern of a type of factory as described in theory. If there is a total match we score it 2. If it matches to some extent we scored it 1. The pattern matching tables are shown in Chapters 6 and 7, and in more detail in the Appendixes V to VII.

Summary
We defined the contextual framework by defining five phases based on the TLC literature, describing different market and environmental conditions. Each phase can be characterized by variables and sub-variables which switch their value from phase to phase. Next, we defined the contextual framework by defining five types of factories. Accordingly, each type of factory can be characterized by variables and sub-variables which alter from one type of factory to another. Here, the sub-variables are used to describe certain characteristics of each type of factory, to support the identification of a type of factory during the validation process. If values or sub-values occur at a certain phase of the TLC or a certain type of factory we score it 2. If they occur to some extent the value is 1, and if there is no match the value is 0.
In the next chapter we identify the research process to be used and how we integrate the measurement model developed in this chapter.

5 DEVELOPMENT OF THE THEORETICAL FRAMEWORK

In our research we develop and validate a theory originated from the HP experience. We explain a theoretical relationship of variables in a contextual framework by formulating propositions and then testing them. Eisenhardt (1989, p. 548) cited Pfeffer (1982), who suggested that "*good theory is parsimonious, testable, logical, and coherent and can result in new frame-breaking insight*". The statements above demonstrate that making this explicit is crucial and requires a good research strategy, which is developed in this chapter. In Section 5.1 we start with a discussion about the research methodology selection. We develop the general approach to the empirical inquiry. We demonstrate why empirical research, and even more, a case study research methodology, is appropriate for validating our propositions. We continue by discussing the case study research methodology and explain the research structure in detail. In Section 5.2 we develop the research design for case-based research and explain why we used a multiple case study approach. Then, we present the criteria and sample selection process. In Section 5.3 we discuss different methodologies of how to ensure high-quality research and how we applied them. In section 5.4 we will present these instruments from a process perspective. We present the research plan and show how we link the conceptual model to the interview protocol and to the research database. We end this section with an outline of the data collection and data analysis approach.

5.1 Research methodology

Type of research

According to Ellram (1996), theory can be analysis and description, prediction and prescription, exploration, explanation or design of an action. The selection is driven by the research objective. **Exploration** can be qualitative or quantitative. It is about how and why something is being done. It gives depth and insight into a little-known phenomenon. **Description and prediction** can be both qualitative and quantitative. It covers a broad description of the phenomenon including the nature of it (how much, how many), who is performing or participating in the activity of interest, and where it is being done. **Explanation** is more qualitative, where a phenomenon should be described and explained. Depth and richness are needed, and it is about probing the how and why questions. Gregor (2006) explains that explanatory research is a theory of understanding, enlightening and surprising. It is about the explanation of how and why things happen in the real world, followed by conclusions with theoretical abstractions. It clarifies how and why a phenomenon exists and explains how, when, where and why events occur and things happen. It is based on various views of causality and methods of argumentation. The statements about relationships include causal explanations. Typically, further research follows to provide more detailed analyses. Possible alternative explanations as to what caused a particular outcome should be given for internal validity reasons.

These criteria lead to the conclusion that our research is **explanation.** According to Gregor (2006), we are aiming at an explanatory approach for several reasons. First, we focus on how and why things happen in the real world. Our conclusions explain how factories transformed their capabilities and changed their roles over the TLC. We clarify how the factories adapted and understood why they had to adapt – what the triggers for change were. The cases give explanations of "when, how, where and why events occurred" along the TLC. In more detail, we evaluate a causal relationship between the changing environment along the TLC and the types of capabilities (factories). Possible alternative and rival explanations as to what caused a particular outcome are considered, and why it should be possible to transfer these findings to the high-tech electronics industry. Second, the number of variables and their relationships are likely to exceed the capabilities of quantitative research. Third, it is a real-life event over a long time period, and we cannot define concrete measurements and matrices. Fourth, the phenomenon of how manufacturing companies adapted their local factories over time needs an in-depth description, explanation and richness to be able to deduce a theory for decision making in manufacturing. The outcome should be a high-level strategy with a causal explanation of the local factory evolution.

Quantitative or qualitative research

With empirical research methods, empirical observations or data are collected in order to answer particular research questions. Empirical research uses data from the real world via surveys or case studies. In contrast, modeling research uses hypothetical or real-world data which are manipulated by the model, and often a mathematical description of a system is constructed (Ellram, 1996). Data can be quantitative or qualitative. Quantitative data are defined in numerical, quantifiable terms. Qualitative data is typically expressed verbally to increase understanding or to improve a relationship or complex interactions. Qualitative methods are used to build theory and testable propositions. This theory may later be tested using quantitative methods such as surveys and experiments.

Based on the following facts, we decided to use an **empirical and qualitative** tool. We want to develop a well-grounded theory, and our methods have to reflect the reality of OM. Survey methods originally designed to measure psychometric properties may not be well suited to investigating the complex world of OM. There are too many variables that would have to be captured to make valid comparisons. Moreover, the measures used in OM are not standardized as in finance. In addition, each measure is impacted by many external variables stemming from the type of industry and the market (Stuart *et al.*, 2002). Thus, data which are typically expressed verbally to increase understanding or improve a relationship or complex interactions will be mostly qualitative.

Case study research from the range of empirical tools

Empirical qualitative tools may be case studies, participant observation or ethnography. They are characterized by the limitation of statistical analyses, and are often non-parametric (Yin, 2003).

Case studies are a part of empirical research. Case studies contribute to theory building through observation of phenomena in the OM world that cannot be studied empirically. "*It aims to understand these observable things by discovering some systematic order in them…*" (Stuart *et al.*, 2002, p. 426). They argue that the case methodology is both

appropriate and essential where a theory does not yet exist. These methodologies are applied if the research question is open and covers a new field.
There are several conditions where a case study seems to be an ideal research methodology, for example, if a holistic, in-depth study is required (Feagin *et al.*, 1991). It makes for the retention of the holistic characteristics of a real-life situation – such as life cycles, organizational and managerial processes. Furthermore, a case study is appropriate if it is important to understand why decisions were taken, how they were implemented and with what results. Thus the focus is often on why and how questions. In addition, the case study is often chosen to identify a relationship of effect, not to describe an average effect. The theoretical framework of a case study seeks to explain under what conditions a particular phenomenon is likely to be found as well as under what conditions it is likely not to be found. Finally, a case study is suitable if an assumed causal link of a complex real-life intervention must be explained that is too complex for surveys and experiments or it has no clear set of outcomes. However, to explore these situations, cases are often not aimed at being representative, but rather exemplary. Hence, the major concern of case study analysis is the pattern of results and the degree to which the observed pattern matches the predicted one.

Our decision to use a case study approach is, first, supported by Yin's "three conditions to find the right research tool" (Yin, 2003, p. 5) which are:

i. The type of research questions: In the relationship-building stage, the researcher looks for relationships between activities and events (operational variables and TLC), noting any causal effect pattern as well (Stuart *et al.*, 2002, p. 422; Handfield and Melynk, 1998, pp. 320-339). We intend to find a relationship and consequently we start asking "What is the relationship". The question is about why decisions were made and how they were implemented to see if there is a relationship between the TLC and the types of factories.
ii. The extent of control an investigator has: There is no control since the objective is a real-life phenomenon. It cannot be manipulated because it is about the strategy of a whole organization; it covers the full complexity and dynamism of the manufacturing environment, and therefore cannot be covered by a quantitative research methodology.
iii. The degree of focus on contemporary vs. historical events: The role of the local factory is a contemporary and historical discussion. We look at this phenomenon as a historical observation since we evaluate the changing role of the factories along the TLC which has evolved, in our case, over many decades.

Second, the topic is broad because it covers the whole range of manufacturing and supply chain strategies. The objective is to gain a holistic understanding of the phenomenon in its natural setting. We explain an assumed causal link of a real-life interference that is too complex for surveys and experiments. Third, the case methodology is appropriate for our research because we evaluate cause and effects of the evolution of product technologies and necessary manufacturing strategies. Causes and strategies involve time lags, and a theory does not yet exist (Stuart *et al.*, 2002, p. 423).

In summary:
As we are validating a theory, we have decided to use an explanatory and qualitative case study (empirical) approach to explain a relationship of variables.

5.2 Case study research design

We have now accepted the case study methodology to be an appropriate approach to validate our theory. In this section we derive the case study methodology and decide if we apply a single or a multiple case study approach. As a next step, we start defining the validation case selection criteria so that we can examine if our propositions are supported by other cases within the same domain.

5.2.1 Number and types of cases

The theoretical framework is there to describe under what conditions a particular phenomenon is likely to be found as well as under what conditions it is not likely to be found. The number of cases, case selection, and the definition of the measurement system are important in order to be able to find the facts and conclusions, and thus to develop a pattern.

A single case design carries the risk of not being generalizable. The evidence from multiple – in our research serial cases – is seen as more compelling. According to Ellram (1996), the cases should reproduce a phenomenon to enable the findings to be generalized and to allow the development of a rich theoretical framework. The cases should therefore either replicate similar results or show contrasting results for predictable and explainable reasons.
Our research uses a multiple case study approach, selected serially, for the following reasons: We wish to:

i. Account for the large variety of manufacturing strategies during the mature phase of the product technology produced.
ii. Enrich the theory developed by replication within the same environment, either by replication in different environments or by the opportunity to find contrasting cases (Yin, 2003, p. 53). All of this makes it easier to make generalizations.
iii. Increase the reliability of the outcome (supporting cases and rival cases), especially as there are two possible main strategies to follow: off-shoring versus increasing and adapting the capabilities of the local factory.

We will validate a necessary condition in two single instances within a group of instances. Thus, each case study is, in and of itself, a self-contained experiment, within a unique context.

5.2.2 The sample – case selection criteria and selection process

The goal of our research is to validate a relationship, as expressed in our propositions. According to Dul and Hak (2007, p. 35), "*…the propositions of a theory formulate causal relations between the variable characteristics of the object of study*". These variable characteristics must be represented in the samples, which demand a well-defined case site selection process. However, the biggest risk of case site selection is the issue of the paradox of sampling (Kaplan, 1964). This paradox states that the sample is of no use if it is not truly representative of its population. It is only representative when we know the characteristics of the population. Therefore, OM case researchers must consider the possible impact of industry, the size of the organization, manufacturing processes, and inter-organizational effects (Stuart *et al*., 2002, p. 426). Site selection should be guided by diversity and best-in-class manufacturing performance. According to Yin (2003, p. 47), every case should provide an explicit purpose within the overall scope of the inquiry.

Next, we define characteristics of the subset of instances of the domain. We refer mainly to Stuart *et al*. (2002), Yin (2003) and Dul and Hak (2007).

High-tech
This requirement comes from the unit of analysis: The cases must represent manufacturing within the high-tech electronics industry.
Characteristics: According to Stuart *et al*. (2002), a sample must be representative of its population. The internal characteristics of the population were defined as follows: High-tech products are leading-edge and individualized products. They are not mass products at high volume. The high-tech industry contributes significantly to science and industrial evolution (see also Chapter 2). By the high-tech electronics industry we mean the computer and communications, electronics and instrumentation, and medical instruments and devices industry. The related Standard Industrial Classification (SIC) codes are: SIC 357: Electronic Computers; SIC 36: Electrical Machinery (366 Communication equipment; 367 Electronic components and accessories); SIC 38: Instruments (382 laboratory apparatus and analytical optical measuring & controlling instruments; 384 Surgical, Medical, & Dental Instruments & Supplies); SIC 737: Software and Data Processing Services.
Conclusion for case selection: The factories selected must produce electronic products and be part of the classes listed; the factory's production system should be a "one-piece flow pull" production system because this indicates the production of more complex and individualized products at lower volume.

Local manufacturing
This requirement comes from the unit of analysis: The research validates the changing role and contribution of the "local" factory.
Characteristics: We define "local manufacturing" as manufacturing with close geographical proximity to the main customer base. To eliminate manipulation due to external factors – such as the political system, the legal system or economic conditions – the factories should be located in countries with very similar external environmental factors.
Conclusion for the case selection: The cases must be located within a central customer market. Within the research, and for reasons of convenience, we focus on Germany.

Best-in-class or state-of-the-art cases

This requirement comes from theory and the conceptual model: The case factories should be recognized as leading edge. Yin (2003) recommends picking best-in-class performers.

Characteristics: We look at competitive and state-of-the-art factories to build the theoretical model.

Conclusion for the case selection: The factory must have continued to exist in a highly competitive market. Cases must comply with one of the following conditions: The factory has won industrial awards conferred by academic institutions (universities), or the factory is shown to have contributed significantly to the company's success and therefore survived in a difficult manufacturing environment, like Germany.

Replication

Cases should be selected so that either a similar result is predicted in a particular area (literal replication) or a contrasting result is predicted, but for foreseeable reasons (theoretical replication).

First, literal replication: The requirements come from theory. Replication means that important findings in a case should also be found in another case. OM case researchers must consider the possible effects of industry, size of organization, manufacturing processes, and inter-organizational effects and products (Stuart *et al.*, 2002, p. 426).

Second, theoretical replication: The requirements come from theory as well. The selection of cases should differ from one another as widely as possible. This will increase external validity. As mentioned, it is useful to look for sites that are as different as possible in important areas to help establish whether the same phenomenon exists at some sites but not at others (Stuart *et al.*, 2002). In case study research, theoretical sampling extends validity, and this is achieved by selecting cases which differ in certain areas as much as possible (Eisenhardt, 1989). These cases may be called "less likely cases" (Dul and Hak, 2007). According to Stuart (2003, p. 426), OM case researchers must consider the possible effects of industry, size of the organization, manufacturing processes, and inter-organizational effects and products.

Consequently, we will consider cases that match all case selection criteria mentioned. However, on the subject of product technology, size of organization, manufacturing processes and inter-organizational effects, we select a validation case which is similar and another which differs with respect to the exploratory case. In fact, to achieve literal replication at least one validation case should serve the same high-tech electronics markets, be of similar organizational size, and should overlap in the way the manufacturing process is structured with regard to the exploratory case. To achieve theoretical replication, one validation case should cover different high-tech electronics markets within the bandwidth defined under high-tech industries (e.g., not only computer, and not only complex test systems). Furthermore, one validation case should have a different size of workforce to validate the influence of size. Concerning the manufacturing processes within the value business, we cover a low-volume manufacturing operation, thereby covering the influence of the manufacturing system. Finally, regarding inter-organizational effects, we cover cases representing different tiers within a supply chain (OEM, suppliers and maybe a distributor) to include the bull-whip effect as a driver of variation.

Other criteria
The factory should have passed most phases of the TLC. This means that solution selling capabilities should have been developed to some extent. In addition, we consider companies with an existing relationship to the research team to ensure good access to people and data. According to Yin (2003), the personal experience of the researcher is also important. Our research team is very familiar with the high-end electronics industry.

Summary case selection Criteria
We defined the following criteria for case selection:

A. High-Tech:
  i. The factories selected must be part of the classes listed.
  ii. The factory's production system should be "one-piece flow and pull".
  iii. The products technology must be leading edge. R&D efforts must be greater than 2% of revenues.

B. Local Manufacturing:
  i. The cases must be located in the EU or North America. We selected Germany for reasons of convenience.

C. State-of-the-art cases/Best-in-class manufacturing
  i. We consider factories to be competitive if they continue to exist in a highly competitive environment in local markets; if they have won industrial awards conferred by academic institutions (universities), or if they have made a significant contribution to the company's success.

D. Literal Replication:
  i. Industry: We select a company based on the classes listed under "high-tech".
  ii. Product technology: At least two cases should serve the same high-tech electronics markets.
  iii. Size of organization: At least two cases should have similar organizational sizes.
  iv. Manufacturing processes: Some cases should use the same manufacturing system.

E. Theoretical Replication:
  i. Product technology: A case should be selected where products vary within the bandwidth defined under high-tech industries.
  ii. Size of organization: We cover a case with very different size of workforce.
  iii. Manufacturing processes: Low-volume products and higher-volume products but not mass production.
  iv. Inter-organizational effects: We want to cover cases representing different tiers.

F. TLC: The factory should have passed most phases of the TLC.

G. Access: We should have good access to high-level managers with several years' experience.

Our multiple case studies start with a case from HP, which we call the 'exploratory case'. Two other case studies were selected for validating our research propositions. Case selection was serial, as we selected the FSC case first, drew conclusions, and then selected a less likely case, the Agilent case. The selected cases are constituted as presented in Table 7.

	HP	**FSC**	**Agilent**
A. High-tech: A1 Products A2 “One-piece flow pull” production system A3 R&D spending	A1: Computer servers and IT solutions A2: Yes A3: In 2006: 3.9% (Server only)	A: Computer server and IT solutions A2: Yes A3 In 2005: 2.1% (Servers and PCs)	A: Optical test equipment A2: Yes A3: In 2005: 15-17%
B. Local manufacturing:	B1 Germany	B1 Germany	B1 Germany
C. State-of-the-art cases	The factory won several awards: Best factory Europe award 2002 (France, Germany) European SC Benchmarking award 2003 (Switzerland)	In 2005, they became Factory of the Year/GEO 2005 award in the “Country Champion” category for its plant in Augsburg, Germany. In 2003, they received the award “Best Factory/ Industrial Excellence” from the management schools INSEAD and WHU as well as the Ken Sharma Award for Excellence from i2 Technologies.	Agilent is the market leader in this market.
D. Supporting Literal Replication (similarities) and theoretical replication (difference) D1 Industry D2 Product technology D3 Size of organization D4 Manufacturing processes: D5: Inter-organizational effects D6: Countries	D1: SIC 357 Computer (similar to FSC) D2: Computer (similar to FSC) D3: Global player; Enterprise division approx. 800 employees in Germany (large) D4: Computer assembly and integration; BtCO D5: OEM D6: Germany	D1: SIC 357 Computer (similar to FSC) D2: Computer (similar to HP) D3: Global player; Enterprise division approx. 600 employees in Germany (large) D4: Computer assembly and integration; BtCO D5: OEM D6: Germany	D: Instruments (382 laboratory apparatus and analytical optical measuring & controlling instruments. (diff. to HP, FSC) D2: Photonic test and measurement systems (different to HP and FSC) D3 Agilent large but PL 3e approx. 250 (small) D4: Pre assembly (push) and final assembly and test in BtCO (pull) D5: Supplier of test systems for OEMs which offer network products for service provider which offer services to end-consumers. D6: Germany
E. TLC:	All phases passed	Phases 1-4 passed. Phase 5 started	Phases 1-5??

Table 7: Cases selection according to the criteria defined

5.3 Ensuring high-quality research

According to Yin (2003), four tests must be applied to ensure high-quality research. Yin also lists different tactics to pass these four tests. In the following section we discuss how we applied Yin's proposal.

Construct validity

Construct validity refers to whether the measurements reflect the phenomena they are supposed to. Finding sources that would be available at all sites makes it easier to demonstrate that the same phenomenon was measured in each situation. This concerns the quality of the measurement system. To acquire construct validity a researcher must take two steps: First, describe clearly the phenomenon to be studied; second, demonstrate that the selected measurement system reflects the change which is to be measured in order to answer the research question. To acquire construct validity, several tactics and tools have been proposed by Yin (2003):

i. Multiple sources of evidence: An important element of construct validity is triangulation. Triangulation is the use of multiple data sources to substantiate evidence. Yin (2003) and Stake (1995) identified at least six sources of evidence in case studies: documents, archival records, interviews, direct observation, participant-observation, and physical artifacts. With interviews, more stable and reliable results are produced by using multiple informants. (Ellram, 1996, p. 101).
ii. Quantitative techniques for gathering data: Namely, observing the number of occurrences, determining the degree or level of occurrences of an activity (to weight the degree to which the case matches the theory for each variable), scale-related questionnaires.
iii. Establishing the chain of evidence: This starts with the case study questions or propositions which are the basis for the protocol design. Then, the interview questions in the case study protocol must be linked via references to the protocol database. We called this the interview database.
iv. Having key information reviews of the case study reports from the informants interviewed.

We achieved construct validity as follows: In the preparation phase we developed a chain of evidence by linking interview questions with an interview protocol. All the questions were linked via references to the criteria database. As for data collection, although we used different sources of evidence (see Section 5.4.1), management interviews were our main data source. We asked multiple questions per area and interviewed two or more persons per function. Data analysis was done by an independent academic person, who applied the measurement system and evaluated the cases. Finally, the main managers interviewed were asked to review the case study report to check correctness and consistency, and they reviewed our interpretations and conclusions. During data analysis we used a measurement system and weights as defined in Chapter 4.

Internal validity

Internal validity refers to the strength of the relationships – finding out whether the assumed relationships actually exist (Stuart, 2002). Internal validity is primarily impacted by data analyses. In a single case it can be shown that the *actual* data patterns match the *proposed* patterns. This makes for good, sound evidence. Confirmation will be stronger if these patterns can be replicated in similar cases (literal replications). If patterns can be shown not to hold for understandable reasons in dissimilar cases (theoretical replication), confirmation will be stronger still. Here, researchers must reinforce their causal claims and their arguments as much as possible, and they must record evidence of other factors that might offer alternative explanations for the observed patterns. As described in Section 5.4.2, we applied the pattern matching approach combined with a cross-case analysis. Explanation building was used to explicate the findings.

In our research, internal validity was achieved through a stringent pattern matching approach and by addressing rival explanations. Based on the TLC theory, we first developed a theoretical pattern of five phases. These patterns are describing the environmental changes of the business as caused by the technology evolution of a company's products. The interview questions were related to this pattern to validate the "TLC-status/time scale" liaison (when was the factory in which phase of the TLC). Based on theory, we developed, in a second step, five patterns of capabilities defining five different types of factories. The liaison "type of factory/time scale (when did the factory have which capabilities) was then tested through a second set of interview questions. Finally, a cross-case analysis ensured reference back to the original research intent and strengthening of our findings. Rival explanations could be addressed based on a less-likely case, the Agilent case.

External validity

External validity tests the generalizability of the findings and whether the results are relevant beyond the boundaries of the research. It is impacted by the research design and the case selection process. In case study research, analytical generalization is essential as the number of tests is too small to apply statistical approaches (Ellram, 1996). The researcher tries to generalize his findings to a broader theory which can be applied to situations beyond the boundaries of the research. A major tool for obtaining external validity is replication of the findings by using a multiple case study approach. Cases should be selected based on a theoretical sampling in which cases that differ as widely as possible from one another are chosen. They should not be based on representative random samples (Eisenhardt, 1989; Stuart *et al.*, 2002). Furthermore, cases must be chosen according to the theory and also to whether a specific outcome can be predicted. Each case should provide data to refine and complement the theoretical framework.

In our research, we use replication logic in multiple case studies within the high-tech electronics industry. Each test is seen as replication and not sampling. A well-defined single case selection process, as described in Section 5.3.2, was used.

Reliability

Reliability refers to the extent to which a study's operation can be repeated with the same results (Yin, 2003), and is impacted by the way data are linked. The researcher should organize the data selection and storage processes in such a way that other researchers can either use them for their own analysis or replicate the research using the same approach to data collection and analysis (Stuart *et al.*, 2002, p. 424). That means that the results of the

research should not be dependent on the researcher himself/herself, thus contributing to objectivity (Kirk and Miller, 1986).
We applied a research plan containing a case study interview protocol with interview questions. The research team evaluated the questionnaire according to logic, flow, clarity and content so that other people could replicate the research. All questions were linked to our case study database, which we call the criteria database (more details are included in Section 5.4). Furthermore, our interview protocol guaranteed that we focused on the main research questions and that the same patterns of topics were discussed. The preparation work of the protocol helped us to organize the visits, made us discuss problems of logic before the interviews were completed, and guaranteed that the trail of evidence was well documented.

5.4 Research plan

In this section we present an overview of how we defined the research plan (also-called the research instrument) as mentioned above. We discuss how we applied the instruments as explained in Section 5.3. (Further details are listed in Appendix I). In Section 5.4.1 we first define the sources of data (cases, interviewees, presentations, etc.) and how we ensure a chain of evidence. We finish with a short description of the outline of the studies. Section 5.4.2 is about data analysis and how we developed the structure to verify the propositions. We discuss several theoretical methodologies for analyzing case studies and explain our selection.

The research plan ensures that data collection and data analysis follow a stringent procedure to construct a chain of evidence and to enable high-quality research. The basis of the plan lies in the variables which must be tested to meet the research goal. These variables are defined in the criteria database (Appendix IV) from where we derived the data collection and data analysis methodologies.

5.4.1 Data collection

To meet construct validity, we used several sources of evidence including interviews, documents, archival records and direct observation. The sources of data are discussed individually for each case in Chapters 3, 6 and 7, and the applied concept of triangulation is discussed in Section 5.3.
The largest part of our data retrieval came from interviews as these seemed to be the best source of case study information. To ground the interview questions and its protocol, a database was developed based on the constructs and variables of the conceptual model and the measurement model. We now present the logic behind the interview protocol including the interview questions (see also Appendix 1).

Interview protocol

Using a case study interview protocol, we were certain to collect the same data from several sources to verify its authenticity. We followed Yin’s (2003) suggestion that the protocol questions should be used barely as a guide for the researcher through the interviews. Consequently, the case study protocol contained not only interview questions but also the rules and procedures to be followed. The interview protocol helped to make sure that all areas were covered by the interviews and that the responses could be linked with the questions in the protocol. In this way, both goals could be reached: First, to facilitate a structured evaluation and second, to leave enough freedom for the interviewees to discuss new and interesting areas. Finally, our key informants were asked to review the case study protocol to check correctness and consistency.

Development of the interview questions

There are several possible forms of interview: Open-ended, focused, structured, and survey. We applied the open-ended interview technique, whereby key managers were asked to comment on certain events to provide insights into other events. This technique made sense because it helped to get sufficient and comprehensive data on a long time period. The criteria database includes all sources of data in a structured approach and with links to the interview questions. The interview questions were drawn from the literature and the experience from the exploratory case, and were split into overview questions and detailed questions. The content overlap between these two types of questions enabled us to ensure the validity of the answers. The questions were developed following a how, what and why structure (Table 8):

Overview Questions TLC:	How would you describe the "contextual framework" over its lifetime? What were the major forces impacting this construct?
Overview Questions OM:	How did the independent variables evolve? What were the focus areas of the local factory over its lifetime? How did something change over time? What were the major inhibitors impacting the decision processes? What was the competitive contribution of the local factory ?
Detailed Questions TLC:	How would you rate and characterize a "contextual framework" during certain time frames?
Detailed Questions OM:	How would you rate and characterize a "dependent variables" during certain time frames? Why was it changed?

Table 8: Types of interview question

Interview process

The interview process was designed as follows: We first started to gather company data from public sources to get detailed information about the companies selected. Next, we met the top management, explaining the research idea and defining interviewees and meeting dates. Then, interview sessions followed, as per the interview protocol. Audio recordings as well as notes were made to make sure that all kinds of information (oral and written/non-verbal or graphs and tables – via notes and printouts) could be captured. Then, the interview data were reworked and rewritten in prose for the case description and linked with the questions in the interview protocol to carry out pattern matching. All notes were reviewed with the top management. The detailed questions are listed in Appendix II. Other data, such as company presentations, were received before the interviews.

Document structure of cases

Of the three different formats – A, B and C – that exist for structuring the case (see Appendix III), we decided to select Approach A for each case. Approach C could not work because we kept the interview open, and sometimes answers did not exactly match the questions asked. In addition, interviewees often extended their responses into other areas of interest when they tried to explain the interrelationship of events and actions.

5.4.2 Data analysis

High-quality research must demonstrate that all the evidence has been considered and that the analytic strategy is comprehensive (Yin, 2003, p. 137). If some evidence is ignored, alternative interpretations become possible. All major rival interpretations must be addressed. If an alternative interpretation has been found, it must be put into "rival mode". Consequently, the strategy for analyzing could be theoretical propositions, rival explanations, or descriptive frameworks. It must focus exactly on the major point of interest and the most significant aspect of the case studies. If possible, the researcher should then apply his own prior expert knowledge.
One of possibly five analytic techniques must be selected. These techniques include pattern matching, explanation building, time series analysis, logic models and/or cross-case synthesis. We discuss these techniques in the following section.

Pattern matching

In pattern matching an empirically based pattern is matched to a predicted pattern or patterns (Yin, 2003, p. 119). Patterns may be related to the contextual framework, the dependent and the independent variables. In descriptive cases studies, pattern matching is relevant as long as a predicted pattern of specific variables is defined prior to data collection. Pattern matching may include replicating patterns or rival patterns, especially for independent variables. According to Stuart (2002, p. 427), a researcher must ask himself: Are patterns obvious? Do the observations point to critical exogenous variables? Is there a conceptual model that helps to explain the patterns of behavior? Do existing theoretical models reasonably explain the pattern of behavior observed in all cases? If not, what construct would we need to add?

Explanation building

This is a more difficult process of pattern matching and works along these lines: To explain a phenomenon, the researcher stipulates a presumed set of causal links. This differs from other approaches in the following way: Explanation building is iterative; a time series is designed, probably a chronology; a trend of data points is compared to a theoretically significant trend specified before the investigation with some explanatory theory – versus some rival trend. If more cases are used, a cross-case synthesis is a relevant technique. The data of each case are displayed in a uniform framework which will then be compared. Thus, the process is as follows (Dul and Hak, 2007, pp. 38-40): It starts with a theoretical framework, followed by an initial theoretical statement or a proposition. Then, the events of an exploratory or pilot case are analyzed against the proposition, which is revised as necessary. A comparison follows to revise the facts and events of the other cases and compare data with the theoretical framework. It closes with a final discussion. The iterative nature here is that the final explanation may not have been fully defined at the beginning of a study, and therefore differs from the pattern matching approach. The researcher's goal not to try to find a matching pattern from the cases which support/reject the pre-defined proposition but to revise it to examine the evidence from a new perspective, step by step. This explanation building is often done in a narrative form (Yin, p. 120).

Time series analysis
With this tool, changes over time are measured if the events have been traced in detail and with precision. The goal is to find a match between the trend of the data points – coming from the cases – to a theoretically significant trend specified before. The researcher should find a match between the "rival" trends of the data points and a theoretically significant trend specified before (Yin, p. 124).

Logic model
A complex chain of evidence over time with cause–effect patterns is described in a visual way. Empirically observed events are matched with the theoretically predicted events. The measurement is: intervention, immediate outcome, and ultimate outcome. Data must support the theoretically developed chain of events (Yin, 2003, p. 126).

Cross-case analysis
If more than one single case is discussed, a cross-case analysis should follow. Each individual case is treated as a separate study. Often, word tables are used according to a uniform framework.

For our research we found that the following three tools matched our requirements:

i. **Pattern matching:** We match the theoretical pattern of the TLC literature with the real-life cases. Then, we match the theoretical pattern of the "types of factories" with the real-life cases. Finally, we match Steps 1 and 2 and evaluate whether there is a relationship regarding the point in time. We address replicating patterns and rival patterns.
ii. **Explanation building** is used because we developed the proposition based on the experience of the exploratory case (HP), which was analyzed in great detail. Based on a theoretical framework and the HP case we developed the proposition. This experience was used to revise the questionnaire and some of the characteristics of the "types of factories". This revised version was evaluated against the validation cases and then compared with the theoretical framework developed.
iii. **A cross-case analysis** was then used to evaluate the results against the propositions.

The research measurement instrument set the basis for the pattern matching and explanation building process and was applied as follows:

In step 1, the characteristics of each phase of the TLC were defined in detail based on the TLC literature. The case text was then noted in two ways: A summary of the case and a description of how each TLC variable evolved over a timeframe (in decades). These case texts were compared with the theoretical characteristics of the TLC phases. An independent academic did the evaluation to strengthen research construct validity. The result showed when the factory passed which phases of the TLC. In step 2, a similar process followed for finding the capability switching. Each type of factory was defined in detail based on the literature. Also a summary of the case and a description of how each variable evolved over a timeframe followed. These case texts were compared with the theoretical characteristics of the types of factories. Again, the evaluation was done by an independent academic to strengthen research construct validity. The results showed which type of factory was developed in the local factory and when this occurred. In step 3, both occurrences were linked to see if there was a relationship – in terms of content and time. A link in terms of content is when there is an explanation of why the capability was developed during a certain TLC phase. A link in terms of time is when there is a clear overlap of the phases and the capability development.

The following two chapters are about the validation cases and how we applied the process described.

6 FIRST VALIDATION CASE – FUJITSU SIEMENS COMPUTERS

In this chapter, we present the study of Fujitsu-Siemens-Computers (FSC), a global player in computer hardware production. The organization surveyed repeatedly changed its name. We refer to it as “FSC” for the sake of convenience. As in the HP case, FSC develop, produce and sell computer products – from handheld devices to large enterprise-class computer solutions. We evaluate the business and their manufacturing site in Augsburg, Germany. In presenting this case, we have adapted a structure similar to the case of HP. We illustrate the case selection process and the matches to the research proposition. Then, an overview follows about the business, the supply chain structure and the factory. The central part of the discussion is again the perspective on capability switching along the TLC. We have split the phases into the 1980s, the 1990s, the 2000s, and present-day because the Fujitsu-Siemens management team thought that this would correspond very well to the actual development. This is followed by an overview of the contextual framework, the company’s characteristics regarding their TLC and the independent construct, and the evolution of the manufacturing capability. In Section 6.2, we point up the results of the pattern matching approach. We present our findings and conclusions and examine the research propositions.

6.1 FSC case description

6.1.1 Data gathering

We start the discussion with the case selection criteria and then outline the interview process and the data selection methodologies used.

Case selection

In Chapter 5, we defined several criteria for how to choose the right cases, and the FSC case has been examined in accordance with these variables.

i. We look at high-tech companies with manufacturing capabilities. We define high-tech companies as firms that produce high-tech products which are defined, in turn, as leading- edge and individualized products. A high-tech company contributes significantly to science and industrial evolution. FSC’s shareholders’ overall expenditure on R&D is $2 billion for Fujitsu and €5 billion for Siemens; 20% of the FSC workforce works in R&D.
ii. We have listed the standard industrial classification codes, SIC. Their products correspond to “SIC 357” electronic computers.
iii. We looked for one-piece flow manufacturing systems. FSC uses two manufacturing processes: a PC volume production and a server mass customization one-piece flow production with a high mix of options. We evaluate the latter.
iv. The unit of analysis, as well as the research propositions, is about local manufacturing. We define “local manufacturing” as manufacturing with close geographical proximity to the main customer base, and a “local factory” as a

manufacturing operation in close geographical proximity to the main customers. The FSC factory in Germany serves European customers, the majority of which are in Germany. Most of its suppliers are in Asia and the US. The manufacturing site thus matches our predefined locations.

v. The choice of best-in-class cases. The FSC factory in Augsburg has won many awards in supply chain management and manufacturing: In 2005, it received the "Factory of the Year/GEO 2005" award in the Country Champion category for its plant in Augsburg, Germany. In 2003, it received the "Best Factory/Industrial Excellence" award from the management schools INSEAD and WHU, as well as the "Ken Sharma Award for Excellence" from i2 Technologies. The juries recognized its balanced approach in "cost vs. customer orientation" as a successful case of local manufacturing in a high labor cost country (Germany). Furthermore, its total supply chain management approach was praised, a fact which has facilitated an increase in productivity of 8% annually over the past five years.

vi. The research team has easy access to the factory and supply chain management to ensure comprehensive data collection.

We have enhanced validity by means of literal and theoretical replication. Both cases, the HP case and the FSC case, concern the computer server industry – which supports literal replication.

Data selection

Data are based on recorded interviews held in Augsburg, Germany, in January 2007; company presentations provided by the factory management; company financial statements; company documentation and published articles. We spent one day at the company interviewing the top management of the Augsburg factory. To complete our own impression of the manufacturing process and the products produced, we inspected the manufacturing operation. This extensive data collection was completed by gathering material from company presentations and documentation and the public FSC web pages.

We spent the whole day with the manufacturing manager, Walter Degle {Manufacturing Manager}, who is in charge of the factory. We spoke to the supply chain manager, Karlheinz Czauderna {Supply Chain Manager} and the marketing and sales manager, Rolf Kleinwächter {Sales Manager}. In addition, we interviewed several staff members who report to these managers. The standard research interview procedure was adapted and used to guide us through the interviews and to make sure that all relevant topics were discussed. The interview questions were arranged according to the functional areas "management, marketing, supply chain and manufacturing" to facilitate a dedicated and efficient interview. Some questions were directed at two or all three managers to evaluate topics from different perspectives. All three are senior managers with more than 15 years' experience at the business unit.

6.1.2 Company introduction

Industry
Both cases selected, HP and FSC, are part of the computer industry which is described in Chapter 3.

FSC Company profile
The German company was founded in 1897 as Siemens & Halske AG. During the 1970s and 1980s, computers were produced by Siemens AG. During the 1990s, the Siemens computer sector – as part of Siemens AG – was expanded by a merger with the German company Nixdorf Computer AG, which was specialized in mini-computers mid-range computers and software development. The company was called Siemens-Nixdorf during this period. Nixdorf products and successor products now became part of the production portfolio of the Augsburg factory. In 1999, FSC was founded as a joint venture of Fujitsu Limited, Tokyo (50%) and Siemens AG, Munich (50%). The headquarters were located in Maarssen, Netherlands Holding BV., NL. The overall goal of this merger was to combine the development, manufacturing, purchasing power, as well as the sales and distribution capabilities of the two companies to achieve efficiency and economies of scale.
In FY 2006, 11,200 employees in 36 countries generated €7 billion in revenues and a profit before tax of €85 million. The research and development staff represents about 20% of the total workforce, mainly at locations in Germany, as well as in the heart of Silicon Valley, USA. The company focuses on the EMEA market while Fujitsu Ltd. concentrates on the customers in the Americas and the Asia/Pacific region. Their markets range from scientific and technical applications for business enterprises, large corporations, small and medium enterprises and private users. Geographically, they are mainly present in all the key markets across Europe, the Middle East and Africa, where it achieves about 85% of its turnover. The channel is split into 50% large enterprise customers who are served through corporate resellers, 25% small and medium enterprise customers who are served through resellers, and 25% consumer customers who are served through retailers.
FSC produce computer products in the consumer and professional area. These include handheld devices, notebooks, desktops and servers, storage solutions and enterprise-class computer solutions. From a market perspective, a special focus lies on high-performance computers for the automotive industry, solutions for government and the telecommunications industry, as well as the financial services sector. From a technological and a market perspective, the products differ significantly from one another, and many of them have already passed several phases of the TLC.
Product innovation is important to the company as it underlines the state-of-the-art character of the company and the factory. They were a ‘first mover’ in notebooks with wireless communications, mobile high-performance workstations for 3D graphics, and all-in-one home entertainment equipment. In the early 1990s, the company was one of the first to qualify for environmental approval of server systems. The low-end products are now mainly commodities; the mid-range servers are customized in manufacturing, containing mainly standard components, and the high-end servers with leading-edge technology and partly specific components.

Supply Chain Structure
The company's manufacturing sites are located in Augsburg, Munich, Paderborn and Sömmerda, (all in Germany) and Milpitas in California. Augsburg, Paderborn and Sömmerda are manufacturing sites which produce more than three million computers per year.
This case discusses the Augsburg plant in Germany where they produce notebooks and servers and the related printed circuits. Today, their supply chain is required to respond flexibly and to ensure a high availability of products. FSC still produces most of its products in Germany, which is very different from those supply chain strategies of most competitors. FSC's core competence, "supply chain management", includes network management, quality control, design, cost management, financial controlling, purchasing and procurement.

Factory overview
FSC seeks "*to deliver best-in-class products using the most advanced production and test equipment, creating good processes and motivating employees to contribute to this success*" {Sales Manager}. The factory was built in 1978 as the manufacturing center for computers of Siemens-Computer AG. The biggest part of the business is based in Germany, which explains why the pan-European supply chain management is also based in the German manufacturing facilities. This facilitates a close relationship with suppliers and partners. Due to strong customer orientation, local manufacturing in Germany has never been questioned. The geographical proximity to the main customer base in Central Europe enables the Augsburg factory to satisfy customer needs and custom configurations quickly. The Augsburg factory also plays a role in Europe-wide process development and testing. For example, manufacturing tools and methods for the outsourced site in Paderborn and their new site in the United Arab Emirates (UAE) were designed and managed by senior Fujitsu Siemens Computer staff from Augsburg. The FSC site in Augsburg is made up of 11 buildings in which the company's main manufacturing and development center, as well as R&D, marketing, sales, logistics and administration are located. In manufacturing, 2,000 employees produce professional PCs, Intel servers, so called "tablet" PCs, professional notebooks and components such as main boards and keyboards. A big focus of this plant is mobility technology and custom configuration of PCs and servers. All important functions of the supply chain are located in Augsburg. Ten production lines run 24 hours a day, 5-6 days a week, producing over 2 million PC system boards per year. Up to 1995, they produced mainly standard PCs and servers. Nowadays, 75% of all computers are configured according to customer specifications. Offering this capability is one of their key market skills. Flexible production and test solutions are embedded in their processes so that test, diagnosis, repair and quality management can be performed cost-effectively.

6.1.3 Phase 1: Before the 1990s

6.1.3.1 Market and customer evolution

In 1978, FSC started production in their facility in Augsburg. **Product technology** was changing rapidly and the main challenge to the factory was testability. The typical customers were data center managers demanding the latest technology and best

performance. Collaboration with these people was technology based. Communication between customers and factory was channeled through the sales and service organization. As a consequence, **the market** was constantly challenged by new technologies, and new products and margins were high. Mainly technology-oriented or bigger companies started to buy computers, and computers turned out to be an important tool for many companies to automate the control of manufacturing processes and to simplify office tasks. This resulted in a steady and significant market growth of about 15% per year. Right from the beginning, the factory served both types of **customers**, the SME businesses via the indirect channel and the enterprise customers directly. Moreover, FSC started to focus on specific customer niches. In most customer companies, the purchasing decisions were made directly by the CIOs and the data center managers, known to be very technology-oriented people. Everything was about technology and performance. The discussions within the factory were also only technology oriented. At that time, the management never thought about logistics, DFx or even SCM. The factory staff did not really know a lot about suppliers and nothing at all about customers. On the other hand, quality was regarded as extremely important. This was to do with the fact that the technology was not reliable or robust, and a lot of process and quality control was needed to achieve an acceptable yield.
The **competition situation** during this phase was not very challenging, and competition was a matter of product technology management and quality management. Customers demanded high performance technology, and they were prepared to pay high margins for better computing performance. The major competitors in Europe at that time were IBM, HP, and Sun, and at the end of the decade, Compaq, founded in 1982, and Nixdorf, until it was taken over by Siemens in 1990. As a consequence, **prices and margins** in this decade could be kept high due to the rising technological evolution and the fact that costs were not a major area of concern.

6.1.3.2 Supply chain evolution

When the factory was built in 1978, the evolving product technology was at the center of attention. The scope of **supply chain process technology** development was limited to internal affairs with much emphasis on product quality. Manufacturing depth was high because of a lack of technology partners and an absence of cost pressure. The customer was more or less unknown to the factory employees in those days. FSC described manufacturing as an isolated function with one major goal: to produce the product technology developed by R&D and to achieve acceptable yields. "*It was about technology management and quality management*" {Supply Chain Manager}. **Inbound partners**, like suppliers and contractors, did not play an important role. During that period, nobody at FSC thought yet in terms of supply chain and supply chain management. The factory staff did not really know a lot about their suppliers. A major reason for this was simply the non-availability of capable suppliers. It was all about the procurement of components and parts such as screws, labels, etc. Suppliers were not handled carefully by the procurement organization, which again was not integrated into the company processes and strategies. In procurement, the goal was to buy components at reasonable prices and make technology available. **Outbound partner**s – such as sales and distribution partners – operated outside of the factory. The only communication link was the document containing the order information.

6.1.3.3 Factory evolution

Product manufacturing was complicated because of the complexity of the products with their new technologies. Consequently, **process technology** followed product technology and people were mostly concerned about the ability to build and test the new products. "*In the 1970s, the only product design goal was testability*" (source: FSC interview, 2007). FSC had two major goals: time-to-production of the new technologies and process quality to maximize production yield. In the late 1980s, FSC started to invest in discrete manufacturing process optimization. The main focus was not on cost efficiency but on process reliability and effectiveness. For example, process engineering started to look for technologies which would increase the quality of picking the right components in assembly. Test engineers developed test routines to improve product quality. Delivery speed or **cost** reductions were not important because customers accepted the lengthy delivery times and high prices as long as they got the new technology. Thus cost was not a major driver in this decade and FSC had no stringent cost-saving programs. Major technical investments were usually made to enable the production department to produce new technology. The associated costs were not considered important. **Flexibility and speed** was not an important differentiator for FSC at that time: customers did not expect fast deliveries and controllers did not demand lower inventory costs, which could usually be achieved through flexible and fast processes. The customer order cycle time for a server was around 15 days and OTD-against-acknowledgment was not even measured. "*We estimate it was around 70-80%. In the 1980s, the customers received many acknowledgement dates. The first acknowledgement date sent out was seldom met*" {Manufacturing Manager}.

Fulfillment services and customer solutions were not needed to compete, nor were they discussed in this decade. PCs were built to stock and servers were built to customer order because of the wide diversity of options. This fact, and the lack of technology partners, explains why **business networks** had not yet been developed – the FSC factory was still organized along vertical lines. Intra logistics management was important and FSC started to link procurement and order management with manufacturing to better manage order flows with material flows. Vendors were only linked operationally and purchasing was limited to the procurement of components such as screws, labels, processors and memory chips. In short, the operational functions were not integrated. Sales and marketing were not yet linked with manufacturing, and channel partners were not part of the business model in this decade. Neither did customer integration take place. "*The customers were not known at the factory in those days*" {Manufacturing Manager}.

In summary, this decade was driven by the technical evolution of the products produced and the related efforts to manufacture them. Cost efficiency and process speed were not regarded as important, and the factory was vertically integrated with only little interaction with the "outside" world.

6.1.4 Phase 2: From about 1990 to 2000

6.1.4.1 Market and customer evolution

The picture changed in the early 1990s. This period was characterized by falling **prices and margins**. In the late 1980s, FSC noticed a major shift toward price sensitivity on the part of their customers. They assumed that this was to do with the fact that their customers started to cut costs because of market saturation – especially in the automotive and machinery industries. Another major margin reduction happened in the second half of the 1990s because of the increasing number of competitors, on the one hand, and the change in customer behavior on the other – from technology-oriented to cost-oriented. At customers' companies, the purchasing decision makers changed because of increasing cost pressure in most industries. Now, it was the controllers and procurement experts who released the computer purchasing orders. It was in the nature of these new decision makers to look more at cost than at technology, and they considered the computer performance of the installed base to be sufficient. New customer purchases were evaluated against the real need and against cost efficiency. Walter Degle, site manager, commented: "*Earlier, we had proprietary products. The procurement people pushed cost and this again pushed standardization and exchangeability. We also started to buy standardized components, e.g., power supplies, and we had to deliver standardized products including the technologies and the form factors. Earlier, everything was proprietary and we designed all components and related manufacturing processes on our own. Now, it was about cost and value. Product modularization is a major challenge for the business and for manufacturing*" {Sales Manager}. As a result, **market growth** could only be achieved through a reduction of margins to develop a newly evolving consumer kind of market. Supply chain management became important due to cost pressure which again resulted in a more segmented and globally structured supply chain. FSC started to focus on certain industries such as automotive, banks and telecom. The increased product portfolio on the one hand, and the greater standardization of components and modules on the other, allowed a push/pull supply chain structure. **Product technology** evolved from proprietary technology to industry standards and modularization. The **competition situation** was rougher than ever before. According to FSC management, some companies like Compaq and especially Dell, delivered very price-competitive products. They used standard components and developed new supply chain strategies. Most customers no longer demanded leading-edge technology. A good price/performance ratio and ease of installation turned out to be important. Dell implemented "demand supply matching" to be faster at a lower cost. Thus, FSC saw the major competitive range in the 1990s in the areas of cost reduction and hence lean management.

6.1.4.2 Supply chain evolution

In the late 1980s, manufacturing process technology management became more important due to the changing market situation but the **supply chain process technology** was still reduced. Cost reduction, lean management and material flow optimization affecting the whole factory became major goals at FSC so that processes needed to be designed more flexibly. The factory switched from the mode of "getting the product produced" to producing it effectively and efficiently in the Breathing factory. Automation through computer integrated manufacturing (CIM) increased the efficiency of the factory – especially in a high-labor-cost country like Germany. All efforts were still internally focused and a supply chain management view was not considered. In the mid-1990s, **inbound partners** and procurement acquired a more important function within the company. Some people started to think about a supply chain and in 1998 a supply chain management function was installed in Augsburg. The center of attention was the improvement of the inbound part of the supply chain and in particular how to collaborate with suppliers. The company realized that they needed to look at the total cost of ownership instead of solely caring about lowest component prices. The total cost of ownership included, for example, quality cost, cost of uncertainty, warranty cost and cost of cooperation. The supply chain manager started to think about reducing the "make" segment to reduce the fixed cost risk. Outsourcing became a major strategy for FSC at the end of this decade (see below). **Outbound partners** still operated independently.

6.1.4.3 Factory evolution

Because of weaker markets and higher cost sensitivity on the part of customers, FSC had to switch strategies. Time-to-production was still important but no longer a big challenge. The **product technology** evolution slowed down and all partners in the value chain, including R&D, were at this time measured according to cost efficiency. Quality was still important, but cost was becoming more important. Investments were evaluated carefully, and for each product, make or buy discussions in combination with off-shore vs. local manufacturing discussions started. Product complexity decreased with enduring product modularization in the late 1990s. Some vendors such as Intel and Microsoft turned out to be dominant, and FSC's role moved more toward niche solutions, marketing, and speed of delivery. Thus, the Augsburg factory in Germany faced enormous **cost** pressure from the market while the speed of the computer industry further increased (e.g., Fine, 1998). Several programs had been started to save cost and increase process **flexibility** and delivery **speed**. "*Within this decade, we started to draw down the process of the delivery process to improve it step by step across the whole supply chain*" {Manufacturing Manager}. The volumes varied from 10,000 to 16,000 systems a day (Figure 19) and could only be managed by means of a flexible workforce model.

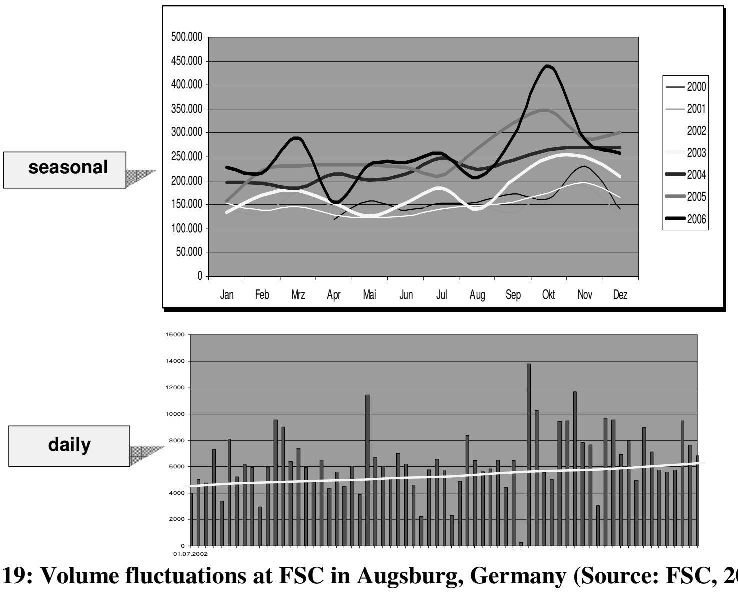


Figure 19: Volume fluctuations at FSC in Augsburg, Germany (Source: FSC, 2007)

The manufacturing management pushed toward a balanced evolution: First, they started an initiative to optimize internal processes: the maximization of process automation i.e., of test processes and capacity utilization, combined with a powerful process cost evaluation in all areas. The second initiative was about flexible manufacturing and logistics. The so-called "Breathing factory" concept was installed in 1998, and it focused on workforce flexibility since people costs were the biggest cost driver in computer assembly. This approach not only enabled the company to have comparable cost advantages compared to near-shoring, but it also provided the advantage of having the final assembly close to the customer market. The concept was as follows: Work times at the site could be adapted to incoming orders (see Figure 20). FSC developed a multi-level employee structure within the factory with skilled FSC employees and less skilled, but more time flexible, employees from employment agencies. The first level was the flex-time model, varying between six hours a day, four days a week and eight hours a day, six days a week. As a second layer, Fujitsu Siemens Computers tried to achieve flexibility with the integration of temporary workers. Thus, a great deal of the added value created at the German plant was realized with temporary workers accounting for 50% of all employees in production. The transfer of former FSC operators to employment agencies added additional flexibility – the third layer. The temporary workforce also had a positive impact on fixed cost reduction. According to the FSC management, this indirect form of outsourcing was no more expensive than moving production to the Czech Republic. Even though the Czech plant had lower labor costs, the expenditure on controlling and management, as well as the cost of transporting material to and from the remote plant, led to comparable end-to-end costs.

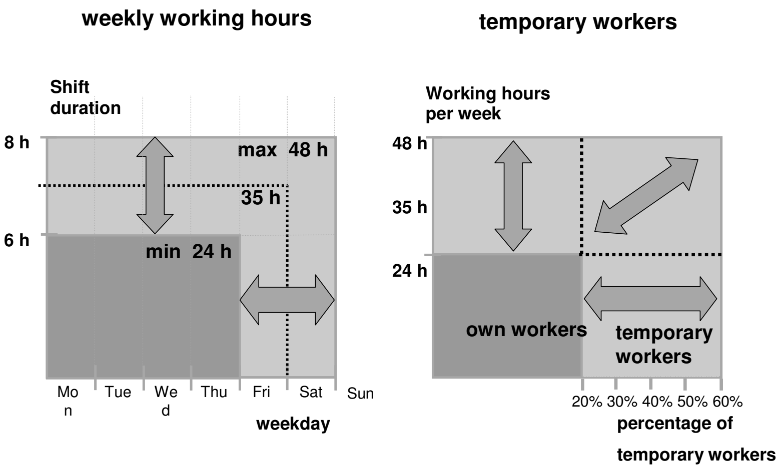


Figure 20: Workforce flexibility model at FSC in Augsburg (Source: FSC, 2007)

Machine capacity could be maximized without too many investments because of the increasing simplicity of the product structures. To increase flexibility, the factory concept was switched to a 100% pull system, not only for servers but also for PCs. The factory layout was designed in modules and adapted to facilitate a mass-customization concept and also to increase flexibility within manufacturing. All important assembly functions were kept at the site in Augsburg, like printed circuit assembly, keyboard configuration, final assembly, test and integration. Procurement was now integrated to link suppliers with manufacturing and R&D to increase speed of product development and time-to-production. The third initiative was about local outsourcing and the introduction of contract manufacturers who bought parts of FSC's manufacturing. Since managers were questioning manufacturing in Germany more and more, costs had to be reduced and fixed costs had to be minimized. "*To reduce the risk of fix costs, there was a trend to outsource whatever was reasonable. Local outsourcing changed many things. A major strategy became the reduction of the manufacturing depth which was achieved through partnerships and outsourcing. Thus, we developed a network of people and partners*" {Supply Chain Manager}. The outsourcing strategy was continued in the following decade (see "the bare-bones strategy").

Services and Solutions did not yet play a big role. At the very end of this decade, FSC launched the first steps of a service and solutions strategy and invested in customization. This initiative was extended in the following phase. Servers were now built to order to be competitive with Dell's capabilities. A more flexible factory was needed. This was achieved through maximization of machine capacities and the development of the flexible workforce system. Between 1995 and 2000, a quick delivery program was created for channel partners. Special stock was produced to be able to deliver certain configurations within 24 hours. This was stopped in 2000 because the large number of product options increased the forecast uncertainty and hence required too much inventory to achieve instant delivery capability.

Networking was still inbound oriented and from a sales perspective the factory continued to play an isolated role. "*The role of manufacturing was just an important support job within the SC, but it was not a major driver within the sales process*" {Supply Chain Manager}. Vendor integration started to become significant and in the late 1990s FSC developed strong partnerships with strategic vendors. In the late 1990s, a joint product development between suppliers, R&D and the factory was started. The complementary know-how from the factory and from suppliers was brought together. Production plans were communicated on a monthly basis and the ordering process to main suppliers became standardized. Common logistics equipment boxes with vendors were used to ease integration into the factory logistics. Intense EDI networks were implemented with the six major suppliers to secure delivery and to reduce risk, and thus inventory levels. Up to 1995, FSC had only a direct model without channel partners. The introduction of the indirect channel was launched by the new CEO, a former HP manager who was responsible at HP for the European Hardcopy and Imaging business. The HP Hardcopy and Imaging business was based completely on an indirect distribution and sales channel. Collaboration between the factory and customers was still on a case-by-case basis. It was still not a strategic approach top down from the FSC board.

To sum up, the key challenge in this decade was triggered by the new way of thinking in procurement. Customers changed their way of conducting computer procurement and switched from technology-oriented to cost-oriented purchasing. This again triggered the modularization and standardization of products and the components inside to achieve the cost targets. Market transparency grew, and hence competition. Several cost reduction and speed and flexibility improvement programs were launched. In addition, flexible manufacturing was considered to be important for achieving faster output and for adapting to order volume fluctuations. This increased from year to year.

6.1.5 Phase 3: From about 2000 to 2004

6.1.5.1 Market and customer evolution

The **price and margin** erosion during the 1990s could not be stopped. In the late 1990s and the early 2000s, the **market** became even more customer dominated with a corresponding impact on prices and margins. In fact, product **technology** evolution slowed down because a dominant product design was evolving. Now, a competitive advantage was achieved by means of services leadership or price leadership. To compensate for some of the profit losses, FSC's strategic answer was to offer new and more profitable services around computer hardware and to expand the product portfolio. The extended product range now included pocket PCs, servers, storage solutions and mainframes. Several aspects prompted a change in business dynamics, and with that, the uncertainty of the supply chain: i) The extended product portfolio mentioned above, which made forecasting more difficult; ii) increased market volume sensitivity, which was caused, among other things, by FCS's competitor, HP, and its open system strategy; iii) the life cycle reduction of some products, which came down to six months or less, combined with weekly new product introductions. To stop the margin erosion, FSC switched its strategy by changing the **product technology** focus. They experienced increasing demand for customer-specific configurations. Enterprise customers wanted to save IT service engineering costs – the employees who installed and configured the servers and PCs – and thus asked for ready-to-run computer systems directly from FSC. Design for manufacturing turned out to be another important strategy at this time. To run their SC efficiently, FSC-R&D were asked to ease the manufacturing process by using standard and easier-to-assemble designs.

Cost efficiency continued to be an important goal for **customers**, too. In addition, factors such as on-time delivery and later lead time to customers became competitive differentiators. "*The pressure came from the customers and thus many hardware vendors thought that this was a competitive advantage*" {Sales Manager}. Inventory management and control turned out to be a major cost saving area. "*Inventory cost could be reduced if delivery speed could be increased*" {Supply Chain Manager}. Meanwhile, the quality focus started to erode. Quality became a less important factor because the technology in general became more robust and needed less control, and even more so as cost pressure dominated the discussions. The competitive factors were now cost efficiency in combination with on-time delivery and lead time reduction. This again explains why R&D was measured from now on against design for supply chain goals. "*We have been doing design to supply chain since 2000. In the 1980s, such discussions were not accepted. Standardization has now had a major influence on the supply chain design because it is the basis for transferring the prefabrication to low-cost countries in order to exploit the considerably lower production costs*" {Supply Chain Manager}. Customers started to demand more convenience in the way products were delivered and how the products were configured. However, institutionalized cooperation between enterprise customers and factory had not yet developed. The **competitive situation became dramatic**. Most of the competitors offered similar levels of operational excellence and product differentiation continued to be difficult. Configurability for PCs and product solutions, in terms of completely customized and integrated hardware and software bundles for PCs and servers, became more important. As mentioned above, at the beginning of this decade, price competition was pushed even harder by HP's open system approach, which continued to drive modularization of the products. IBM started to restructure their business: they switched from being a computer hardware vendor toward being a consulting company offering services and hardware solutions. At FSC, this timeframe was defined as the decade of collaboration and partnering on the inbound side. At the same time, the "staging of rack systems" with customer-specific solutions had become a market requirement. To offer so much efficientcy, partners and vendors started to play a more significant role since they were providing complementary fulfillment skills. "Linking fast" with vendors and partners now became a competitive advantage.

6.1.5.2 Supply chain evolution

Structural changes and new **supply chain process technologies** finally facilitated a completely new organization of the factory: From 2000, process engineering was extended to include the supply chain view. The FSC factory management introduced a global supply concept – "the bare-bones strategy" – in combination with a new factory shop-floor design – the "mass customization concept". Mass customization helped to produce the elevated bandwidth of standard and customized products efficiently. The bare-bones strategy helped to reduce material cost by developing new **inbound partners** in off-shore countries. This enabled FSC to achieve an impressive annual cost reduction of 10%.

Off-Shoring – the barebones strategy

It was primarily integration with inbound partners in off-shore countries that became a strategic goal. FSC's supply chain design was now based on the idea that standard components should be produced in Asia. Figure 21 shows the split. New partners in Asia now became important and a global supply system was developed. In 2002, FSC identified ten levels in the value-added of its products; of these, the Asian suppliers were in the top five. As the manufacturing of standard components did not require a great deal of know-how, this could be carried out by unskilled workers. Thus, sourcing in Asia was now essential for FSC to stay profitable. FSC proceeded after level five because the number of options increased significantly if products had to be personalized through mass customization, build-to-order or configure-to-order. The extent of prefabrication varied with the product. For instance, a notebook had more standard components than a server. This supply chain strategy was called the "barebones supply chain strategy" (see Figure 22). The idea behind the concept was that all labor-intensive standard components and the pre-assembly of computers, the so-called "barebones", should be produced inexpensively in low-cost countries to take advantage of the more favorable cost structures of off-shore providers.

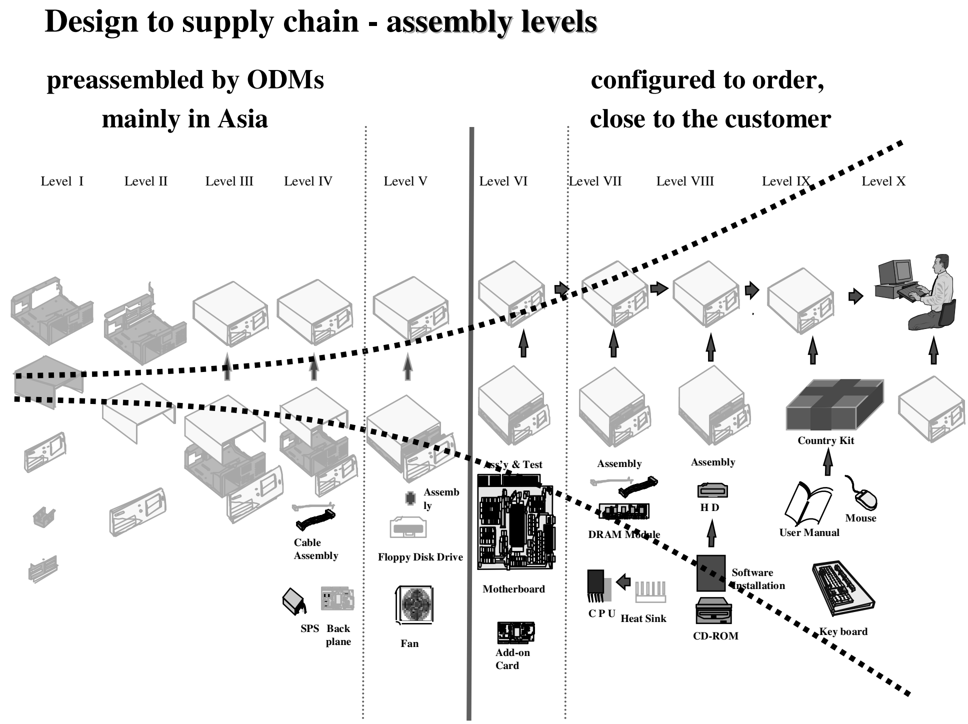


Figure 21: Design for supply chain to facilitate the barebones strategy (Source: FSC, 2007)

“Barebones” are pre-fabricated computers which are neither customized nor localized yet. In the HP case they were called Lowest Common Denominator boxes. “*Real SCM started in 2000-2003, or even later. We started the barebones strategy and bought SKUs from Asia. The barebones strategy was developed in 2003. Since 2004, we can talk about design to supply*” {Supply Chain Manager}

Combining advantages of Asian and European production sites

Pre-production of cabinets / barebones in Asia/China utilizing low wage workforce

Final assembly close to the customer in Europe with
- **high configuration flexibility**
- **short lead-time to customers**
- **low inventory levels**
- **low risk due to price / currency fluctuations**

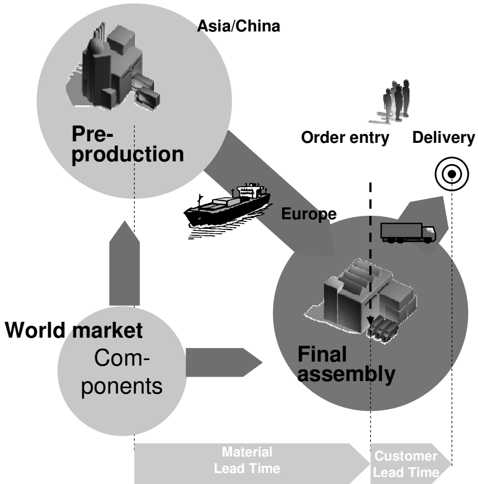


Figure 22: The barebones strategy (Source: FSC, 2007)

Outsourcing strategy

Outsourcing helped FSC to achieve two goals: i) a reduction in the overall cost if contract manufacturers or suppliers had greater expertise and volume in their area. It is important that the partner had multiple customers to be able to profit from the leverage effect; ii) to increase the flexibility and to reduce fixed costs. The passing on of fixed costs enabled the company to share the business risk with its supplier.

FSC generally considered the consequences that its decisions had on strategic partners since their well-being was also in the interest of the company. Cooperation exceeded the mere exchange of operative information, since regular strategic meetings were arranged to discuss the strategy with the supplier. Furthermore, meetings were set up to review performance, such as productivity, costs and delivery performance. Each supplier had, in principle, its own quality control. However, FSC hired, in addition, a source inspector in the relevant country to check the quality of the components. Moreover, random samples were taken at the production plant of FSC. For FSC, it was important to build up strategic partnerships with the suppliers because it regarded long-lasting supplier relationships as favorable. The company saw the key to a durable and mutually beneficial relationship in the provision of a highly-developed interface with the partner. The employees at the interface had to keep their knowledge up to date and they needed to observe the developments of the outsourced component. Moreover, successful outsourcing was possible if the outsourcing company had structured the activity in a clear process. For the partner, the activity had to be transparent and calculable. The required information had to be compiled and edited to a greater extent than was necessary only for internal usage.

6.1.5.3 Factory evolution

Markets were now saturated and product **technology**, as well as the manufacturing processes, no longer evolved to a significant extent. FSC's new strategy was to become cost and service leader in Europe, which explains why the center of attention switched toward supply chain process development. Manufacturing depth was cut down to 20%, material making up 80-85%, and OH 15-20% due to the implementation of the barebones strategy and other outsourcing. This included all activities in Augsburg – including printed circuit assembly. The continuing standardization, combined with the reduction of manufacturing depth, facilitated simple plug-and-play assembly. Flexibility and cost variability requirements led to a flexible workforce model combined with 50% non-FSC contracts. In summary, product complexity decreased and eased the manufacturing process for hardware production, but the upcoming solutions and services business compensated for this development and thus increased complexity for manufacturing in other areas. The company continued to realize any **cost** saving opportunities within the whole supply chain. Inventory was stored at different vendors, at the manufacturing site in Augsburg, and at the channel partners. The integrated manufacturing approach in Augsburg, from printed circuit assembly to final assembly and solution integration, was implemented because of the inventory efficiency of this model. Transportation from one building to the other took a matter of minutes. This approach stood in contrast to all other supply chain models in the computer industry.

From 2000, high manufacturing and supply chain **flexibility and speed** were considered a standard requirement for survival in this market. The demands placed on delivery performance varied according to the different products. Commodity products were shipped faster than complex server products. Citing the jury's criteria for presenting the above-mentioned award, it is clear that they placed special emphasis on the facility's exceptional production flexibility regarding worker schedules as well as customer and market requirements. "*Today, 2007, we measure deliveries against first acknowledgement data and achieve 95%, while delivery cycle time is in the range of 7-8 days*" {Manufacturing Manager}. Most achievements in this area were accomplished in the previous decade, and the company wanted to maintain this level. Moreover, the challenge was to transfer the good results for the regular build-to-order business as well as for the new solutions business. According to FSC management, the current core competencies will stay in Germany in the medium term since it is important to be close to customers and to keep transportation costs down.

In 2004, FSC again changed its strategy. Cost competitiveness and delivery performance speed of delivery were no longer enough for FSC to compete. Customers started to demand individual products at lower prices. Consequently, the development of **services and custom solutions** became the central strategy in order to stand out in the market. Hence, the factory with its flexible fulfillment capabilities now became important for sales and marketing. Sales could offer custom solutions. In early 2000, about 30% of the orders required customer-specific customizing.

From 2003, customer-specific supply chain models were developed, too (see Figure 23). For SMBs, FSC offered a program called "Value-4-you", where channel partners could pick customer-specific predefined bundles. FSC started to offer a program called "Made-4-you" especially for business customers: Here, customers could get tailored hardware and software solutions including specific logistics or life cycle services. For all customers, FSC offered configurability via an Internet configurator called "Built4you". FSC now offers special services for laptops, too. "*We build customer specific notebooks for some big customers. Example: Golden images with work-space specific configuration of the customers' environment. This configuration job is done in the factory*" {Manufacturing Manager}.

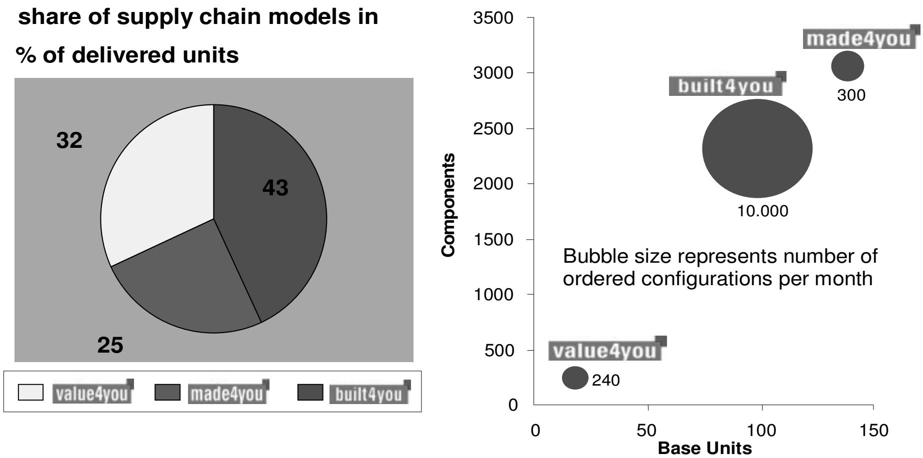


Figure 23: Supply chain models for specific customer needs (Source: FSC 2007)

To be able to offer this variety of capabilities and volumes, people and machine capacities and capabilities had to be adapted. New work time models and payment systems have already been explained above. The mass customization concept included modular and simple process modules where standardized component modules were assembled and tested. The shop-floor system was now able to handle the routing flexibility needed to build individual custom solutions. Within the server production lines, material handling equipment was kept as simple as possible to offer a broad range of mobility.

Future potential solution and services possibilities for the FSC factory
"*The idea is that we use the factory know-how for after-sales services. Can we even offer repair services out of the factory?*" {Manufacturing Manager}. Especially within the commodity business, the factory management thought that they should go into after-sales services. After-sales support and installations support seemed to be interesting. They want to use the factory know-how to generate services in different areas.

Networking: When the SC organization was founded in 2000, they first connected different internal functions. In a second step, real partnerships with vendors and channel partners were developed. The product manager now became responsible for the success of the components or modules, and with that the related supply chain design. These product managers considered the factory to be a service provider which offered manufacturing opportunities. "*We have a SCM- function in Germany which is located at the factory but not organized as part of the factory*" {Supply Chain Manager}. The major shift within the supply chain was the creation of the barebones strategy described above. The factory now received preconfigured computers. Productivity and capabilities could be increased with the new network of partners and vendors where most processes were now pull-based. The plant finally became a competitive advantage for sales since they could go out and offer custom solutions to their customers. It became a center of order-fulfillment expertise due to the nearby located supply chain and procurement function. The geographical proximity to customers was one of the most important assets of the factory in Augsburg. Sales were using the factory for integration services, but always in collaboration with the customers. Vendor integration became significant and an intensive partnership was built up with the Asian barebones vendors. This was aligned with the total SC concept, even including R&D who had to design products in a way that supported the supply chain model. In 2000, collaboration with channel partner distributors came into effect. "*We work together with distributors but more from a logistics perspective*" {Supply Chain Manager}. Customer integration increased during the same timeframe and the factory could now benefit even more from their central location in the middle of the main customer market. "*We do not have a real direct customer interaction. We have sales who own that and we again work with sales to create the right services programs. Mostly, we do just customizing. More and more, we include special delivery services to gain competitive advantages"* {Manufacturing Manager}.

Summing up, in 2000, FSC finally started to evolve the factory capacity toward solutions and services. The total supply chain had to be restructured to incorporate a push/pull strategy including a postponement concept.

6.1.6 Phase 4: From about 2004 to 2006

6.1.6.1 Market and customer evolution

The **competitive situation** switched toward solutions and fulfillment services. This was triggered by new **customer** expectations to get custom product solutions fast and at lower cost. For FSC, solutions were demanded from time to time and more opportunistically. "*Yes, we do something but not area wide. We do customizing. We also include special delivery services to gain advantages*" {Factory Manager}.

6.1.6.2 Supply chain evolution

Structure and process technology

In 2004, the strategic direction was defined as moving toward solutions and services. The staging of rack systems with customer-specific solutions required more capabilities within the factory. A Partner Park model like HP's had not yet been considered.

FSC has a worldwide supply chain network and most of its suppliers are globally operating companies. Manufacturing within a high-wage environment like Germany makes cost management for FSC crucial. Consequently, FSC manages "total supply chain cost" and

developed the “barebones supply chain strategy” to compensate for their higher expenditure. FSC collaborates with 35,000 qualified partners for small and medium businesses and 2,600 technology and solution partners for larger enterprises. The number of key suppliers can be limited to 50 companies, including well-known global players like Intel or Cisco. FSC now has 95% of its suppliers located in China, Taiwan and Japan. Sourcing in Japan is predominantly concentrated on Fujitsu Ltd., one of the company’s shareholders. In Europe, they source, for example, packaging material, engineering services and a number of electronics components.
Availability is very important for FSC as the company prefers multiple-sourcing whenever possible. By way of exception, FSC uses single sourcing for strategic components, e.g., processors, to obtain leading-edge technology or to achieve a greater cost advantage, but only if reliable delivery can be assured.

6.1.6.3 Factory evolution

FCS started to develop the factory toward solutions and services. An intense link toward sales and marketing has not been installed but is under development. This explains why solutions deals are so far more opportunistic and do not cover a big portion of FSC’s business.

6.2 Analysis of the FSC manufacturing concept evolution

In this section we present the result of this first validation of our propositions. We compare the predefined theoretical characteristics for each variable of the TLC and each variable of the types of factories with the case study. The goal is to understand at what time FSC developed what type of factory. The interpretation of the results in combination with our findings from our case description will lead us to first conclusions regarding the validity of the research propositions. This analysis was done in cooperation with FSC management. In Chapter 8 the results will be linked and compared with the exploratory case.

6.2.1 Interpretation and conclusions

The tables below show the FSC pattern matching results. Our corresponding measurement system was developed in Chapter 4. Table 9 shows at what point in time which type of factory was developed at FSC. This table is called the “ToF-table” (type of factory table). Table 10 is showing the TLC phases validation and is called the “TLC-table”. The center-of-gravity value there shows which phase of the theoretical descriptions of the TLC occurred at what time phase measured at FSC. Details of these evaluation tables are shown in Appendix VI.

OM- EVALUATION

Possible values of variables:

2 = Situation of the case largely matches the theory
1 = Situation of the case matches the theory to some extent
0 = Situation of the case does not match the theory
- = non-existent

	Time-Phase 1					Time-Phase 2					Time-Phase 3					Time-Phase 4				
Type of Factory	H	C	V	S	N	H	C	V	S	N	H	C	V	S	N	H	C	V	S	N
Sub Variables																				
Customer requirement and products - Requirements - Product portfolio characteristics	2	0	0	0	0	1	2	1	0	0	0	2	2	1	0	0	1	1	2	2
Competitive Strategy of the factory - Leadership through - Goal - Strategy	2	0	0	0	0	1	2	1	0	0	1	2	2	2	1	1	2	2	2	1
Process Strategy - Focus	2	0	0	0	0	0	1	1	0	0	0	2	2	1	-	0	1	2	2	1
Total Value	6	0	0	0	0	2	5	3	0	0	1	6	6	4	1	1	4	5	6	4
# of variables	3	3	3	3	3	3	3	3	3	3	3	3	3	3	2	3	3	3	3	3
Mid Value	2.0	0.0	0.0	0.0	0.0	0.7	1.7	1.0	0.0	0.0	0.3	2.0	2.0	1.3	0.5	0.3	1.3	1.7	2.0	1.3

Table 9: The FCS Type of Factory (ToF) table

Index: H = High-tech factory; C = Low-cost factory; V = Velocity factory; S = Solution factory; N = Cooperative factory (network).

TLC- EVALUATION

Possible values of variables:

2 = Situation of the case largely matches the theory
1 = Situation of the case matches the theory to some extent
0 = Situation of the case does not match the theory

- = non-existent

	Time Phase 1					Time Phase 2					Time Phase 3					Time Phase 4				
TLC Phases	I	II	III	IV	V	I	II	III	IV	V	I	II	III	IV	V	I	II	III	IV	V
Grand Total Value	23	18	0	0	0	0	15	14	2	0	0	4	17	18	4	0	0	3	10	2
Grand # of variables	12	12	12	12	12	12	12	12	12	12	12	12	12	11	10	8	8	8	8	8
Grand - Mid Value	1.9	1.5	0.0	0.0	0.0	0.0	1.3	1.2	0.2	0.0	0.0	0.3	1.4	1.6	0.4	0.0	0.0	0.4	1.3	0.3
Grand - Centre of gravity		1.44					2.58					3.56					3.93			

Table 10: The FSC TLC Table

FSC Phase1: Before the 1990s

This timeframe matches the TLC Phase I with some tendencies toward Phase II. The TLC-table shows a total center-of-gravity value of 1.44. The factory is a High-tech type of factory with a match of 2.0/ 0.0/ 0.0/ 0.0/0.0 (see ToF-table).

The focus is on high-tech process development and quality. Until the mid-1980s, only a few major players competed in the market and functional product performance is the basis of competition. FSC grew faster than the competition.
Impact on the factory: Initially, in 1978, the factory developed skills to be able to produce the new technologies developed by R&D. The management focus in the 1980s was on

product technology, management and quality, and later on discrete manufacturing process optimization with its emphasis on process reliability and effectiveness. The FSC management explained that their strategy was always a few years behind that of HP. The pressure to change was lower than at HP due to FSC's superior business growth.

Conclusion 6
In Phase 1 of the TLC, it was necessary for FSC to develop a High-tech factory to be best-in-class. Hence, proposition P1 is confirmed.

FSC Phase 2: From about 1990 to 2000
This timeframe matches the TLC Phase II with a tendency toward Phase III. The TLC-table shows a total center-of-gravity value of 2.58. The factory capabilities were extended toward the Low-cost factory, and to some extent a Velocity factory with a match of 0.7/ 1.7/ 1.0/ 0.0/0.0, as described in the ToF-table.

Customers became more and more cost-oriented and they evaluated the real technology need and considered the cost to be a dominant factor. FSC started to focus on some customer niches – like automotive and banking. Overall, there was a strong shift toward price competition. Different business models were defined at FSC and the supply chain started to become a competitive differentiator. Many suppliers, some CMs and channel partners started to play a more dominant role, and a supply chain management function was installed.
Impact on the factory: In the mid-1990s, cost reduction, lean management and optimized material flow throughout the factory became important. Cost efficiency turned out to be a major goal for manufacturing. One reason for the merger with Fujitsu in 1999 was to increase the cost efficiency of both companies. Several programs were implemented to save cost, increase process flexibility and delivery speed in order to reduce inventory cost and to satisfy those customers who started to ask for quicker deliveries.

Conclusion 7
In Phase II and at the beginning of Phase III of the TLC, it was necessary for FSC to develop a Low-cost factory and some first capabilities of the Velocity factory to remain best-in-class. Hence, proposition P2 is confirmed.

FSC Phase 3: From about 2000 to 2004
This timeframe matches the TLC Phase III with a tendency toward Phase IV. The TLC-table shows a total center-of-gravity value of 3.56. The factory capabilities were extended toward the Low-cost factory, and to some extent the Velocity factory with a match of 0.3/ 2.0/ 2.0/ 1.3 /0.5., as indicated in the ToF-table.

The product price, and therewith cost control as well as on-time delivery and speed of delivery became important. In the later part of the time phase measured (probably correlating with the first part of TLC-phase 4), FSC saw a first shift toward customization of products because the product hardware differences between competitors were getting

smaller and smaller. In the late 1990s and the early 2000s, speed and flexibility became a significant market differentiator from a customer perspective, but also supported the low-cost goals through the reduction of work in process inventory cost.
Impact on the factory: The barebones strategy – a push/pull concept with a wolrd-wide supply chain network including many suppliers in Asia and the US – was implemented not only to save further costs but also to realign the local factory toward fast deliveries. Flexibility of resources became important and the so-called "Breathing factory" concept was invented by FSC.

Conclusion 8
In Phase III of the TLC, it was necessary for FSC to further develop the Low-cost factory, but the major focus was on the development of a Velocity factory. Hence, proposition P3 is confirmed.

FSC Phase 4: From about 2004 to 2006
This timeframe matches the TLC Phase IV. The TLC- table shows a total center-of-gravity value of 3.93. A Solution factory was implemented with a first trend toward the Cooperative factory. This is shown in the ToF-table with a match of 0.3/ 1.3/ 1.7/ 2.0/ 1.3.

Since the beginning of 2000, customers have been requesting customized products. Cost efficiency and velocity remain important, but are now relevant for the total solution of a product. A solution is defined as a pre-integrated system, enabling the customer to immediately start working with it. Configurability and pre-installation of products have become more important. However, compared to HP, the solutions understanding was less developed.
Impact on the factory: Since 2004, FSC in Germany has been moving toward solutions and services and the plant has been producing customized servers. A direct supply chain link to customers and partners is planned for the future. Concepts like mass customization and supply chain management, as well as inbound and outbound partner integration, were becoming important.

Conclusion 9
In Phase IV of the TLC, FSC was developing the Solution factory, followed by an extension toward a Cooperative factory. The Low-cost factory and the Velocity factory capabilities were still important. Hence, proposition P4 is confirmed.

6.2.2 Pattern matching result summary
In Table 11 we are summing up the results of the validation. We use the following abbreviations:

H = High-tech factory; C = Low-cost factory; V = Velocity factory; S = Solution factory; N = Cooperative factory (network).

Proposition	Empirical evidence
Proposition P1 In Phase I of the TLC, a High-tech factory is necessary for best-in-class manufacturing.	TLC: 1.44 – indicating Phase I of the TLC. Factory: H 2.0/ C 0.0/ V 0.0/ S 0.0/ N 0.0. Proposition 1 is confirmed.
Proposition P2 In Phase II of the TLC, it is necessary for the High-tech factory to evolve and a Low-cost factory to become dominant for best-in-class manufacturing.	TLC: 2.58 – indicating Phase II and first indications of Phase III. Factory: H 0.7/ C 1.7/ V 1.0/ S 0.0/ N 0.0. Proposition 2 is confirmed. FSC develops a Low-cost factory. A Velocity factory started to evolve in a later part of the time phase measured.
Proposition P3 In Phase III of the TLC, it is necessary for the High-tech and Low-cost factory to evolve and a Velocity factory to become dominant for best-in-class manufacturing.	TLC: 3.56 – indicating Phase III and first indicators of Phase IV. Factory: H 0.3/ C 2.0/ V 2.0/ S 1.3/ N 0.5. Proposition 3 is confirmed. FSC develops a Velocity factory. Later in the timeframe measured, a Solution factory started to evolve.
Proposition P4 In Phase IV of the TLC, it is necessary for the Velocity factory to evolve and a Solution factory and later a Cooperative factory to become dominant for best-in-class manufacturing.	TLC: 3.93 indicating Phase IV of the TLC. Factory: H 0.3/ C 1.3/ V 1.7/ S 2.0/ N 1.3. Proposition 4 is confirmed. FSC extended the Solution factory and starts to develop a Cooperative factory. Since the Solutions business is not as developed as at HP, the need for a Cooperative factory is not as strong as at HP (at the time of the interview).

Table 11: FSC - Validating the research proposition

In summary, we can state that the first test supported our propositions developed in Chapter 3. Both companies were in a similar business environment and they both developed very similar manufacturing strategies over time. The differences in the pattern matching tables (ToF-table and TLC-table) between HP and FSC can probably be explained by the different time phases measured. In addition, FSC seems to be slightly slower than HP regarding the factory evolution. According to FSC management, this can be traced back to the fact that R&D, as well as their main customer base, is located in

Germany. Off-shoring of the factory was therefore less questioned at the end of the 1990s than at HP, with its US-centered management approach and its worldwide business. Further interpretations and learning are discussed in Chapter 8.
In Chapter 7 we discuss our second validation case which was selected to be a “less-likely” case.

7 SECOND VALIDATION CASE – AGILENT TECHNOLOGIES

In this chapter we present the study of Agilent Technologies Photonic Test and Measurement business, a global player in photonic test and measurement. The business unit surveyed repeatedly changed its name over time. From now on we will call it “Agilent” for the sake of convenience. We evaluate the business and the manufacturing site in Böblingen, Germany. In presenting this case we have adapted a structure similar to that used for HP and FSC. In the first section we illustrate the case selection process. Then we discuss the different phases measured from a business perspective, a supply chain perspective and a factory perspective. In Section 7.2 we present the results of the pattern matching. We portray our findings and conclusions and examine these against the research propositions.

7.1 Agilent case description

7.1.1 Data gathering

In the following section we discuss why we selected the Agilent case in Böblingen as a case for our study and how this case fits with the proposition. We place special emphasis on where we see literal and theoretical replication with the other cases. We then refer to the interview process and list the data sources applied.

Case selection

Agilent Technologies is engaged in innovative technologies, solutions and services for the communications, electronics, biotech and chemical industries. Its business is structured into four segments. This study looks at the operational unit of the Photonic Test and Measurement Business, which belong to the Test-and-Measurement segment of Agilent Technologies.

Our second test case was chosen according to the selection criteria defined in Chapter 5. However, this is intended to be a “less-likely” case in order to test, in addition, the borderlines and limitations of our propositions.

i. We search for high-tech companies with manufacturing capabilities. In the current case, the organization spends a significant amount of money (15%-17%) on product and process R&D, and is therefore defined as a high-tech company.
ii. Most of the products are completely new technologies in the area of electronics and instrumentation (SIC 38: Instruments [382 laboratory apparatus and analytical optical measuring & controlling instruments]).
iii. Their manufacturing process is low volume with a high mix of options. Production uses a one-piece flow concept. The total order volume per month per family ranges between only 1 and 20 units.
iv. The unit of analysis is about local manufacturing. The factory of the Photonic Test and Measurement business is located in Germany and so matches our pre-defined criteria.

v. Another criterion requires best-in-class performers. First, the factory must have continued to exist in a highly competitive market. The manufacturing organization of the current case “survived” a dramatic downturn in early 2000 and even remained the market leader because of its leading-edge products combined with a leading-edge manufacturing system. The second criterion states that the factory must constantly and significantly contribute to the company’s success. In this case, the company developed manufacturing technologies which are unique worldwide. Operators in manufacturing must have an in-depth understanding of the products, the customers and the technology. Product modularization is minimal and requires particular manufacturing processes. Thus, we conclude that this factory corresponds to best-in-class manufacturing. It offers unique manufacturing capabilities in a very competitive environment and consistently contributes to the company’s success. Agilent has been the worldwide market leader for many years.
vi. The main reason why this case was chosen is its very specific business evolution and its very different market environment compared to the other cases. This gives us insight into the limitations of our proposed model. The Agilent organization offers product technologies which are in different phases of the TLC. Today, some of the products are commodities but others have not passed through the whole TLC. This provides another interesting insight into how manufacturing systems evolve if the technology of the products produced is heterogeneous regarding the status within the TLC.
vii. The research team has easy access to the business segment management, ensuring good quality of data collection.

Data selection

We spent three days at the company interviewing the top management of the business segment. The following managers were our main contacts during the discussions: Jürgen Beck, the business unit manager {Business Unit Manager}; Dietmar Muggele, the manufacturing manager {Manufacturing Manager}; Dieter Kindermann, the European procurement manager {Procurement Manager}; Andreas Gerster, the European marketing manager {Marketing Manager}. They are all senior managers with more than eight years’ experience at the business segment and more than 15 years’ work experience within Agilent Technologies.

In addition, we inspected the plant to form our own impression of the manufacturing process and the products produced. We completed this extensive data collection process by collecting details from company presentations and documentation. General company-wide and public data were collected from Agilent Technologies’ web pages.

The process started with the business segment manager explaining the research idea and describing the top management strategy. He provided us with a detailed introduction to the business and outlined the major events in the company’s history and the associated management strategies. The data collection process continued with a short introduction of the scope of the research process to the complete business segment management staff. Individual interview sessions followed. To ensure a dedicated and efficient exchange, the interview questions were organized according to the functional areas which were business management, marketing, supply chain management and manufacturing.

7.1.2 Company introduction

Industry

This industry is challenged on four fronts: First, the products are technically complex and product technology is still evolving under the threat of new upcoming disruptive technologies. Second, the market is small with many small players. Third, Agilent Technologies is a third or fourth tier actor experiencing strong order volume fluctuations since their products are test systems for other OEMs' business-to-business products. Finally, the company was particularly challenged by the collapse of the "Internet bubble" in 2001, which impacted operational strategies as well as customer behavior.

Agilent Company profile

In 2006, Agilent Technologies was ranked at 319 in the Fortune 500 list of companies, with about $7 billion in revenues. The company had 20,000 employees and served customers in more than 110 countries. It was split into two business groups and two support organizations:[1] the Agilent Technologies Electronic Measurement division and the Agilent Technologies Bio-Analytical Measurement division. These business groups were supported by the Agilent Technologies Laboratories, the central research organization, and the Agilent Sales and Support organization, selling all Agilent products directly to customers. In this case, we define "business customers" as OEMs who buy directly from Agilent and who use Agilent's test systems to build their own products. Those who use network services are defined as "end customers".

The business segment "photonic test and measurement"

In this case we focus on the Agilent Technologies Photonic Test and Measurement Business segment, henceforth referred to as "Agilent" for convenience. The total worldwide market spans about $155 million, of which Agilent covers about $35 million, putting it in the number one position. The second largest competitor makes only about 50% of Agilent's total revenues. Agilent's R&D, Marketing and Order Fulfillment functions are located in Böblingen, Germany. Another important location is Hachioji, Japan, where they have their so-called photonic solutions team, developing and integrating custom solutions. In 2000, Agilent had 550 employees in Böblingen and 600 in other locations. In 2002, only 80 employees were left at the Böblingen site, since Agilent experienced a major market collapse which impacted heavily the factory and supply chain strategy.

Products and customers

Agilent now offers the whole bandwidth of test systems within this industry to measure photonic components in computer network communication systems. The product innovation rate is high as there is ongoing demand for more performance. This can be seen in Figure 24. A second business with a new technology was started in 2004 in fiber sensing to help the company recover from the severe market collapse in 2001.

---

[1] Agilent Technologies. "Compamy History". URL: "http://www.agilent.com/about/companyinfo/history/index.html?cmpid=4491 [status: May, 2007].

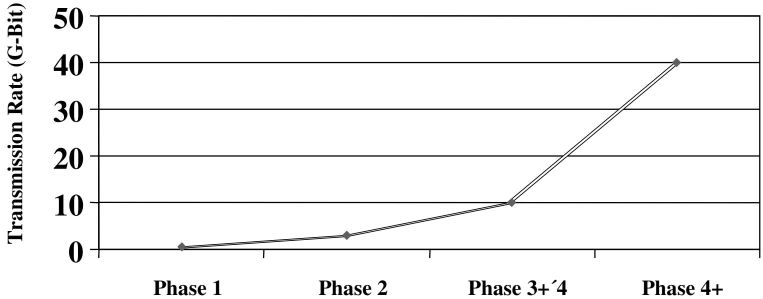


Figure 24: Transmission rate evolution in communication networks (Source: Agilent Technologies, 2007)

Agilent is a Tier-3 or Tier-4 actor within the value chain (see Figure 25). Primary market drivers are Internet applications with data-intensive traffic – like voice-over-IP, video streaming and games. They are served by "network service providers", which offer them communication capacity and services. Their hardware and software systems are the backbone of the business which are provided by Network Equipment Manufacturers, who sell them infrastructure, for example, passive optical networks, wavelength division multiplexers (WDM and DWDM), and tune-able transponders for intelligent and agile optical network capability management. These products must be tested during production and operation. Agilent provides the test systems. The bandwidth of these business customers ranges from small start-ups to major global players such as Fujitsu, Nokia, Cisco and Siemens. Types of business customers are component suppliers, network equipment manufacturers, and network service providers like Deutsch Telekom in Germany and AT&T in the US. In addition, they serve governments, universities and aerospace companies.

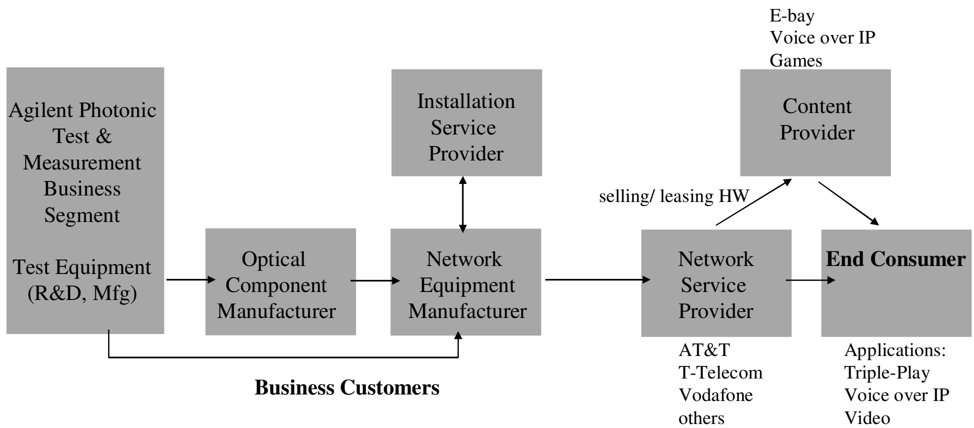


Figure 25: The value chain of the Photonic Test & Measurement Business Segment

"Network equipment manufacturers, who are technology leaders within the optical transmitter business, produce products using the latest technology for high-speed

transmission. They need the latest test technology to test their leading networks. They have no alternative since they need the technology and therefore they are less price, service and design sensitive. For example, the speed class transition of optical broadcasting from 2.5 to 10 G-Bit has been completed. We go now toward 40 GBit. However, products with a high level of commoditization are price sensitive and here customers expect faster availability" {Marketing Manager}.

Supply Chain
The supply chain management of Agilent is highly influenced by the extraordinary product they produce. Their product portfolio is designed for two types of customers: technology leaders and end customers. Orders placed by technology leaders are characterized by substantial investment outlay, limited quantities, as well as the necessity to employ leading-edge technology. End customers or simple technology producers in Asia, on the other hand, order low-volume commodity products. Both require a distinct supply chain strategy. About 25% of revenues are material costs with an upward trend. Today, revenues are in the double digit M$ per quarter, increasing the above market growth of 15%. Most of the value-add processes are outsourced, and only those processes with a unique value contribution by the factory are kept in-house.

7.1.3 Defining the phases of evolution

The most significant business challenge for Agilent was the so-called "Internet bubble". In 2000, market development was impacted by an artificial development of the business with a dramatic increase in market size. Many end customers started to use web tools and this, in turn, motivated computer network service provider to build up infrastructure. From 2001, the infrastructure was available and there was much more capacity offered than needed by end users. This development subsequently led to a collapse of the market. According to Agilent management, this development had a big impact on the overall evolution of the TLC and the factory capabilities. We henceforth define the phases, and on this basis we then define the structure for the case description and the pattern matching:

Figure 26 shows the different phases, based on which we describe the case.

i. The early phase. Here, we describe the beginning of the test and measurement technology evolution. It covers the period from about 1980 to 1995.
ii. Before the bubble peak. In this phase the need for more test capacity evolved due to the rising Internet business. This impacted especially the manufacturing capacity management. It covers the period from about 1995 to 2000.
iii. After the bubble peak. In this phase the market collapsed. The order income was lower than order cancellations. It covers the period from about 2000 to 2002.
iv. The current phase can be described as a phase with solid growth thanks to a rational evolution of market demand. It covers the period from about 2002 to 2006.

In each phase we describe the market and customer evolution, the supply chain evolution and the evolution of the factory. Market dynamics were mainly triggered by the behavior of the end customers. Supply chain and factory strategies were especially influenced by

Agilent's business customers. The key words which were used for pattern matching are marked in bold.

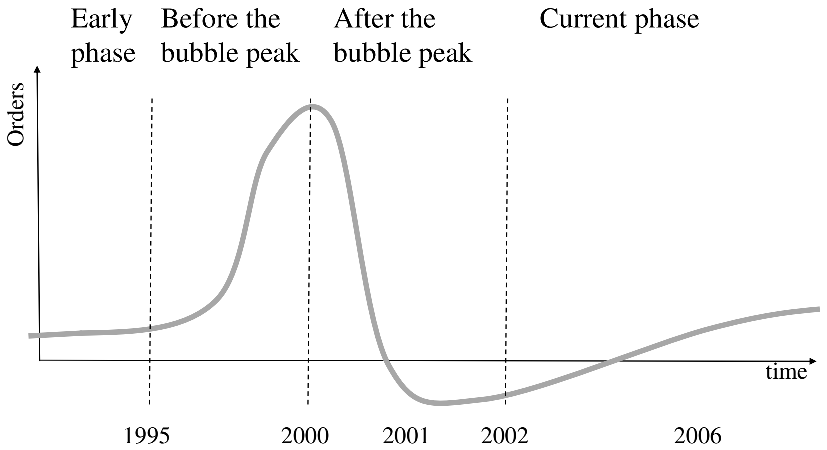


Figure 26: The Agilent business phases

7.1.4 Phase 1: From about 1980 to 1995

7.1.4.1 Market and customer evolution

In the early 1980s, Agilent developed test systems for computer network systems based on copper data lines. The **product technology** was exposed to constant change, and many disruptive new inventions made manufacturing complex. In the market, no product or component standards had yet been defined or implemented. Moreover, the products were specialized, complex, packed with new technology and sold in niche **markets** of network specialists. In the late 1980s, a disruptive technology impacted the market when hardware shifted from copper data lines toward fiber optical devices which then provided an enormous number of end customers. "*However, in the early 1990s, there were no companies which limited their portfolio to optical communication hardware. This business was not important and too small. There were some early adaptors which were using point to point connections*" {Marketing Manager}. It was particularly because of the much higher capacity that trans-oceanic point-to-point copper connections were replaced with fiber optical systems. In the mid-1990s, **end customers** had their telephone, and in a few cases a modem, and some had ISDN (Integrated Services Digital Network). The transfer lines were copper cables with asynchronous technology. E-mail was an application used by some people, but with limited content. **Margins** were reasonably good. From a **competitive** perspective, Agilent management defines technology as the main differentiator up to the late 1990s, whereas now it is regarded as a capability to accurately measure physical variables of a transmission signal or a component in the network.

7.1.4.2 Supply chain evolution

In this timeframe, **supply chain process** management was unknown. Manufacturing was vertically oriented and preassembly, like final assembly, was done by Agilent itself. This was mainly because of the lack of **(inbound) partners** who were capable of supporting Agilent in technological terms. Agilent's products needed special skills to produce, a requirement that made it difficult to produce externally. In the late 1980s, increased availability of capable suppliers and contract manufacturers allowed Agilent to outsource some standardized and simple manufacturing. The number of vendors eventually increased and the corresponding growing fragmentation of the supply chain made supply chain management more important.
Overall, outsourcing was not an important strategy before the bubble. Vendors were not very integrated into the strategy design process and little in the way of data was exchanged. Sales or logistics partners **(outbound partners)** were not yet on the scene and Agilent shipped directly to their business customers.

7.1.4.3 Factory evolution

In the early 1980s, the organization was named 'Böblingen Instruments Division'. All products followed the same manufacturing strategy with much vertical integration. Power supplies, PC boards and metal sheets were produced internally. From a **process technology** perspective, manufacturability and quality were the most important goals while **cost** efficiency and delivery performance (speed and on-time delivery) scored low. Order cycle times were, on average, six to eight weeks. Thus **flexibility and speed** in manufacturing did not play a strategic role. From a **fulfillment services and customer solutions** perspective, all products (hardware and software bundles) were produced to customer requirements and all integrated components were part of the Agilent portfolio. Neither an intense inbound nor an outbound **business network** were developed.

7.1.5 Phase 2: From about 1995 to 2000

7.1.5.1 Market and customer evolution

The business volume increased with the proliferation of fiber as a new and disruptive technology, gradually replacing copper. At the end of the decade, wide area networks (WAN) evolved and optical devices became even more important. Wavelength-division multiplexing (WDM) was the technology used; it applied different wavelengths (colors) of laser light on a single optical fiber cable to carry different signals. This allowed higher capacities. Dense – WDM (DWDM) was later used requiring less channel spacing. Thus, higher resolutions and higher dynamic ranges were possible and enabled transmissions of more wavelength/channels over one fiber cable. This brought about the need to measure these kinds of flexible waves and how components perform at the threshold. In this timeframe, the new fiber **product technology** evolved significantly and early adopters increased their orders dramatically. The products were still not very standardized due to the leading-edge product technology. They were still specialized, complex and packed with new technology, as described in the earlier phase. This made manufacturing difficult and required special manufacturing skills which again made outsourcing difficult.
In 2000, the market saw some artificial business growth followed by a collapse. Many end customers installed web tools and this, in turn, motivated computer network service

providers to increase their installed base. Many Agilent business customers could not get enough components to build the rapidly expanding networks. Thus, they tended to inflate their orders – sometimes by a factor of 10 – to get a bigger share of the available products on the market. *"Within a year, orders grew significantly but shipments did not, which created an enormous backlog*" {Business Unit Manager}. This triggered a "bull-whip effect" – especially at the end of the supply chain – on Agilent.
Figure 27 shows the dramatic business situation the company experienced between 1999 and 2001. The left side shows the order/shipment backlog development per month over time, demonstrating the ups and downs before, during and after the bubble. The graph shows that in 2001 more orders were cancelled than new orders coming in, which resulted in a "negative" order income. The picture finally changed again after 2001, this time with a healthy growth. The right side of
Figure 27 shows the stock price evolution during the bubble of some of Agilent's main business customers. What the business customers experienced was felt even more acutely by Agilent, underlining the company's dramatic situation as a Tier-3 or Tier-4 supplier.

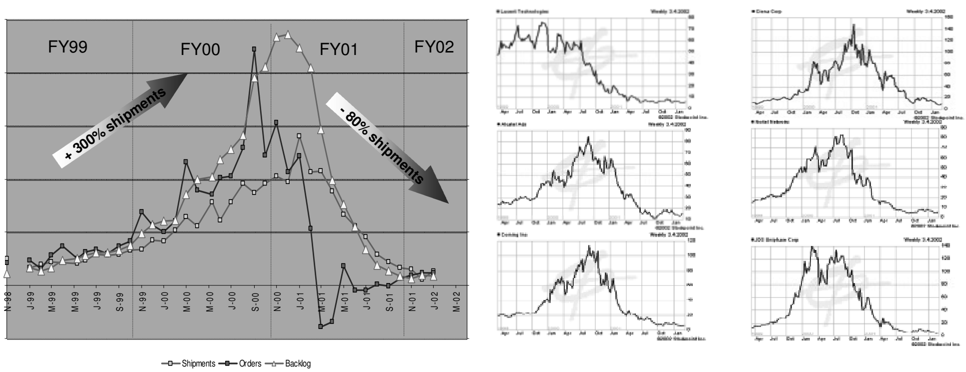


Figure 27: Business development at Agilent (left) and its customers (right)

(Source: Agilent Technologies, 2007)

"Thus, the end customer market grew during this time by a factor of two, where Agilent experienced a growth factor of four. During the bubble, the market was not so much technology-driven anymore but (business) customers paid any price just to get test products at all. This was true because of the newly developed product technology within the first few phases of the TLC, and this artificial market "bubble". There was a need which could not be supplied and which increased prices" {Business Unit Manager}. The **product technology** strategy now included design for manufacturing aspects to better manage the increasing business at the beginning of the Internet bubble. Some products had once been designed for a high-volume market (> 1,000 units per month). During the rising phase of the bubble in 2000, the differentiator was simply a matter of who could fulfill an order with products with reasonably good performance. Availability was a major

competitive differentiator. However, due to the overheated market situation, real competition did not take off. Agilent only had two or three big Japanese competitors. All other competitors were little start-ups or spin-offs from bigger companies. There was no price pressure and margins were good. "*Normally, the technology would have evolved another three years to then transit into a phase where cost would become more important. Customers would then have expected better performance and quality. Not just the measurement quality would have been important but also the usability of the product. But in reality, the Internet bubble-driven market was completely overheated and the component suppliers had a backlog of several years*" {Marketing Manager}.

7.1.5.2 Supply chain evolution

Demand changed by a factor of four from one quarter to another, making forecasts almost impossible. Agilent needed to expand its production capacity to handle the constantly increasing backlog. However, on the one hand, internal growth was limited because it was difficult to train operators quickly and to install production technology virtually overnight. On the other hand, more and more suppliers developed manufacturing skills and became capable of delivering more highly integrated assemblies or modules, and even some finished products, called 'level-5' products. Consequently, a strategy needed to be developed featuring the following cornerstones: capacity gains and operational flexibility through outsourcing, labor flexibility through a flexible workforce capacity management system, and time-to-volume gains through automation. Manufacturing depth was carefully reduced, driven by technological feasibility. As a result, the acquisition of external capacity and the outsourcing of non-core processes increased the need for better **supply chain process management**. Based on the level of production maturity, a specific manufacturing and supply chain strategy was developed for each product family. **Inbound partners,** such as the major CMs, were trained and developed to take over more steps in manufacturing. **Outbound partners** did not play a major role in this phase.

7.1.5.3 Factory evolution

Due to the immense order income, new **process technologies** were applied to get the large backlog shipped at reasonable product quality. In addition to outsourcing, internal process improvements and automation were the strategies to increase the capacity of the factories. Fulfillment **flexibility and speed** was not an important differentiator since all test equipment suppliers had long lead times, and business customers accepted order cycle times of longer than six weeks. Furthermore, delivery speed could not be improved due to the sheer volume of orders which resulted in to lead times of several months in some cases. There was no need for special **fulfillment services and customer solutions.** The colossal number of orders and the low number of product options all but erased the need for special customization. Customers had to integrate these products into their test system themselves. At least, Agilent built hardware and software bundles according to customer requirements. Even Agilent's **commodity** products were built to customer order.

In summary, **business networks** started to evolve on the inbound side to gain capacity**.** On the outbound side, Agilent built up some partnerships with system integrators since the volumes of customer orders were now high enough for those indirect business processes to start to make sense.

7.1.6 Phase 3: From about 2000 to 2002

7.1.6.1 Market and customer evolution

From 2001 onwards, business customers overestimated the needs of the end customers and developed large network infrastructures. As a consequence, operating expenses to run the networks were high while end customers' revenues were low. This triggered great consolidation and the market collapsed completely: *"There was no market*" {Business Unit Manager}. Order cancellations outranged order income and backlog dropped by several million dollars per month. Quite a few of their customers – such as Nortel and Lucent – nearly went bankrupt. Nortel had to write off $60 billion. Agilent allowed business customers to cancel their orders, but on the other side many of Agilent's suppliers would not accept cancellations. Consequently, triple-digit million dollars' worth of obsolete inventories had to be written off. Clearly, Agilent's business **customers** now changed their behavior. Due to market overcapacity and the tremendous inventory levels in the market, business customers now expected immediate availability at lowest possible prices. A grey market of used and unused equipment developed. Sometimes the (grey) market **prices** dropped to only 10% of the original list price. Business customers even started to use e-auctions to achieve better prices. The **competitive situation** was now price-based only. Business customers have retained these expectations up to today. "*This has cost us much work within the last years to move this wrong picture about the industry back to normal. Later customers had to realize that when they replace their test equipment, that they now pay 5 to 80 times the price they once paid right after the bubble. But customers don't understand that because they see the component prices (going into the test products) going down, and in addition, some Asian competitors offer low-cost test products"* {Marketing Manager}. As in early 2000, volumes were much lower than originally planned, and it was sometimes no longer efficient to use the originally designed volume processes. "*CMs just laugh when we come with our current volume*" {Supply Chain Manager}. Moreover, many products became commodities. Agilent radically reduced the number of operators and engineers. At times this caused disproportionately higher costs in other areas. For example, in R&D, investments in design for manufacturing were cut down, resulting in higher efforts in manufacturing.

7.1.6.2 Supply chain evolution

The general company goal to reduce manufacturing depth was stopped right after the bubble because of the surplus of production capacity that had been built up before the peak. The outsourcing strategy in the phase before the bubble peak was motivated by the need for new capacity and operational flexibility. However, outsourcing after the peak was motivated by cost reduction and cost variabilization if it matched with the unused capacity at Agilent and if it helped to enable a new supply chain structure. A new and important supply chain strategy evolved. The company divided its **supply chain** into push and pull segments. The inbound segment combined the activities before order income (push segment) and the outbound segment started after the business customer order had been placed (pull segment). Gradually, many of these activities were outsourced to **(inbound) partners** – for instance, in the case of Multek, BVS and Solectron, who took over board production, board assembly and the production of metal chassis. In particular, mature products with mature manufacturing processes were moved to contract manufacturers if they could do it at lower cost. The advantage was that they could balance and easily shift capacity. Thus, the push-based segment was cost- and not technology-driven. It covered either standard components from vendors or specific components built-to-plan by a CM or the Agilent pre-integration center. Accordingly, cost could be reduced to adapt, to some extent, to the immense cost pressure, and cost variabilization could be realized. However, some of Agilent's components and products were still technically so demanding that outsourcing was neither possible nor desired, due to the competitive advantage. They did not even find vendors for these components. Contract manufacturers delivered simple key modules directly to Agilent for further integration with other products. The major contract manufacturer even produced some modules in a pull mode and built to customer order. Pre-assembly, final assembly and test were then realized at Agilent – mainly in a pull mode. The unique subcomponents were put together followed by intense testing. This was the time-consuming part. The product solution was then sent directly to business customers worldwide. However, the uniqueness of these products made this new strategy difficult. About 80% of the material for the testing device was specially made for Agilent. **Outbound partner**s still did not play an important role since Agilent still delivered its products directly.

7.1.6.3 Factory evolution

Before the bubble peak, everything was about availability and costs were virtually unimportant. Other priorities dominated – like the management of the rising capacity demand. After the bubble peak, **cost** efficiency became as important as quality due to the freefall of margins. However, employees understood the impact of cost of non-quality, inventory cost, direct material cost and cost of supplier management. The top line decreased by 95% and an 80% expense reduction followed in all areas. This included worldwide manufacturing site closures and a massive workforce reduction in all functions. In particular, the local factory in Böblingen was constantly reviewed for cost efficiency. Agilent carried out a great deal of benchmarking (and continues to do so). The sophisticated manufacturing systems in Böblingen, with their high level of automation, were built up during the bubble. Today, it is even underutilized because of the much lower volumes. Off-shoring to Asia (Malaysia and Singapore) was done mainly for cost reasons – not for customer proximity reasons. Inventory costs, in particular, raised a lot of questions. Sometimes, they had more inventory than product lifetime requirements. Much material was scrapped and only little new procurement was necessary. Despite some preventive measures in a controlled environment, there were shelf-life issues with components. "*The technology is getting older, which is our current main problem, and if they run out of components we don't find the suppliers anymore which can deliver these old components*" {Supply Chain Manager}. Although customers required short cycle times, **flexibility and speed** improvements in manufacturing processes were not needed because of the overhanging inventory in the market. Delivery time right after the bubble peak came down to two weeks even though manufacturing processes and **process technologies** were not trimmed to enhance velocity. Before the bubble peak, speed was achieved by the increase of capacities which again was achieved by outsourcing simple processes and the automation of in-house processes. Right after the bubble, speed was boosted by the inventory overhang. Since everything revolved around cost, **fulfillment services and**

customer solutions were not yet being discussed as a strategy to be developed. The **business networks** evolved before the bubble peak declined as the order volumes had become too low.

7.1.7 Phase 4: From about 2004 to 2006

7.1.7.1 Market and customer evolution

From 2004 onwards, markets seemed to be stabilizing, and a lot of technological changes generated a healthy and sustainable growth. New end customer devices got faster and faster, and networking with its data transmission became an important bottleneck technology. Online games, voice-over-IP (e.g., Skype®) and video streaming were new applications requiring real time data transfers and a massive data communication, together with a lot of network capabilities. However, end users who wanted to download movies on Friday evening but not the rest of the week caused data volume fluctuations. Such behavior triggered the need for intelligent and dynamic technologies. These applications, on the one hand, increased data content, and on the other hand, facilitated long-term customer contracts, like monthly rates to allow streaming for subscribers. This explains the new healthiness of the market since growth was now based on the technical evolution of the products and not on a new business model. Accordingly, business customers' revenues allowed for profits and investments in network equipment. They developed new network products – such as network terminals, line terminals, 1/32 splitter and installations of optical systems in whole neighborhoods. Some Agilent business customers even developed a "67 G" system, after having trouble finding a test system vendor. Agilent could measure this speed. "*If there is still a need for demanding technology, Agilent is in a much better shape to deliver than others"* {Marketing Manager}. Consequently, Agilent's electronic measurement products had to meet the rapidly changing market needs of their business customers, who were seeking products that could reduce their time to market, reduce manufacturing costs for their own products, ensure high quality, and cut capital and operating costs (Agilent Technologies – Fact Book, December 2006).
After the bubble, Agilent also looked for new technical differentiators and for new markets where they could use their technology. A new product was developed and a new technology cycle evolved. This new product was born only because of the critical phase after the bubble (DTS: = the digital temperature measurement system for oil production).

In addition, the **competition situation** changed. In the phase before the bubble peak, Agilent had only a few competitors. Now, they saw some bigger companies buying test knowledge from smaller companies which had gone bankrupt when the bubble collapsed. The number of competitors increased in this phase and the market became very diversified and fragmented with about 35 competitors in all. Most of these competitors were little start-ups or small ventures of larger network companies for "point solutions". "*Seventy percent of our products are more commodities, and we share the market with six other significant competitors. We are the biggest, but the competition there is tough and delivery speed becomes a concern. At the moment, we have 2-16 weeks – because we often have problems in our own supply chain. Partly for older products, we don't get the components for our products anymore. We are, in many cases, just a small customer for our vendors and must be happy enough if we get a bit of the cake. This is a big challenge for SCM.*

Sometimes, business customers ask for fast delivery, which always needs extra efforts and rescheduling in production" {Marketing Manger}. Consequently, fulfillment speed became of some importance.
Business customers bought the product because it delivered best test quality or could measure the speed at lowest total cost of ownership. They did not care about the components inside (no Intel inside symptoms), the OEM brand counted. The competitive differentiators were now price and speed for the commodity kind of products. For more sophisticated products, Agilent competed through quality and total cost of ownership. For high-end and leading-edge products, the technology and the capabilities of the test system were most important to measure high speed (e.g., 40G components or multimode components). Asians put more focus on price whereas for Western business customers ease of handling seemed to be more important so that products could be easily integrated into their OEM products. Especially in cheap labor manufacturing, business customers needed easy-to-handle test systems that were very simple to use – like traffic light systems or just an on/off switch. However, investing a lot in ease of handling was difficult from a financial perspective because of the low unit volumes. As a result, some required manufacturing capability developments were not implemented for financial reasons.
"Our products are in different phases of the TLC. Some products are mature today and there we see a 'me too' technology, and with that we have a price competition. Sometimes you can even buy these components at a do-it-yourself-store. On the other hand, we have complex solutions where we offer leading technology and where technology plays and important role. There, the price is less important since it is all about the technology. In Asia, we have mainly a price war. For some business customers, we even do not quote anymore. In the US, we have a strong price competition because there are some strong competitors with important business customers and we want to break this. In general, price is important but not as important as in the computer industry, and the situation is fair" {Marketing Manager}. Summing this up, Agilent provided **product technologies** which were in different phases of the TLC. While new technologies continued to evolve, the commoditization of other products proceeded. Thus Agilent offered products for R&D specialists at OEMs and for simple manufacturing test in Asian mass production. In addition, business customers continued to look for lowest prices, but many of these products were low runners where it seemed to be difficult to become cost efficient. To bring this complexity of demand variation under control, different supply chain capabilities were developed. The product portfolio has been dramatically reduced since 2002. Some products became obsolete and some investments were stopped altogether. Agilent particularly did not want to invest in standardization, but in areas where they were market leaders they had more or less set the standards. "*Especially for standard measurement like optical power – there we have set an industry standard with our N8153 products. This was copied by other competitors*" {Marketing Manager}. The modules within the product were not interchangeable with competitor modules. There were no open standards, even though the functionality was similar. Business customers demanded open systems, but investment in this would be too high for each market participant. Proprietary platforms were still the majority at the installed base. Before the bubble, some market participants had started to drive open systems and tried to entice some business customers away from their competitors by offering standards. This evolution slowed down after the bubble. The optical test systems segment lost its attraction among many competitors, and this impacted

the transition through the TLC artificially. The markets in total were too small compared to standard electrical markets, and optical systems were still technologically complex with high requirements compared to the electronics business. "*The open systems concept matches well for lower complex and higher volume markets*" {Marketing Manager}. However, Agilent does not believe that proprietary platforms will survive long term.

7.1.7.2 Supply chain evolution

The Agilent supply chain needed to manage several challenges:

i. The demanding product technology. This required significant investment in leading-edge technology.
ii. The low sales volume. For some components, the annual demand was as low as ten units.
iii. The high mix of products. This was a result of the diverse needs of the business customers. The business customer could choose between various options, making the product configuration highly complex. Products could be considered as **solutions**.
iv. The mix regarding technological maturity. In the meantime, Agilent offered some commodity products where price and speed of delivery was important – and they still offered their leading-edge products, where quality and total cost of ownership made the difference.

Therefore, different **supply chain process technologies** and models and different factory capabilities were provided simultaneously. Agilent continued to develop the push/pull supply chain construct.

The integration level of **inbound partners** (suppliers) increased in the meantime, with a clear trend toward turn-key materials and products. Turn-key is defined as a solution which comes from a vendor. Agilent developed about 350 vendors and 200 inactive vendors spread all over the globe. Since 2004, more and more pull activities have been moved to CMs.

For complex and technologically demanding products, geographical proximity of contract manufacturers was important to allow real-time support and easy development of the contract manufacturer. However, these contracts manufactures and vendors were constantly benchmarked with global suppliers. Even for the box-built kind of business, some geographical proximity to suppliers and CMs seemed to be important: First, they had specific tasks, and second, they had well integrated IT and communication processes with those contract manufacturers. "*It must not be on-site, it must not be in-house, but it must be at an easy going distance*" {Supply Chain Manager}. Agilent now used the whole bandwidth of suppliers from component vendors to system vendors. The underlying outsourcing strategy could be characterized as follows (see Figure 28): "*It is a function of complexity and core competence and is based on the so-called box level*" {Supply Chain Manager}. Complexity defined the possible level of integration of a product a supplier could deliver. Box levels one to three were complex products which were, in general, not standardized. Every product with in-depth optical technology belonged to box levels one to three and was built in-house. These products required a lot of new technologies and special manufacturing skills. Both reasons made it difficult to make them outside. Some simpler products were pre-integrated or integrated at contract manufacturers. These were defined as box levels four and five and accounted for 20-30% of the products. Level-four products were easy to assemble with a low integration level. Box level five products were finished and packaged, and came ready to be shipped from suppliers or contract manufacturers. These products turned out to be much more modularized, which facilitated outsourcing. Agilent named as their core competences all in-depth optical technologies with complex and specific manufacturing processes (box levels one to three).

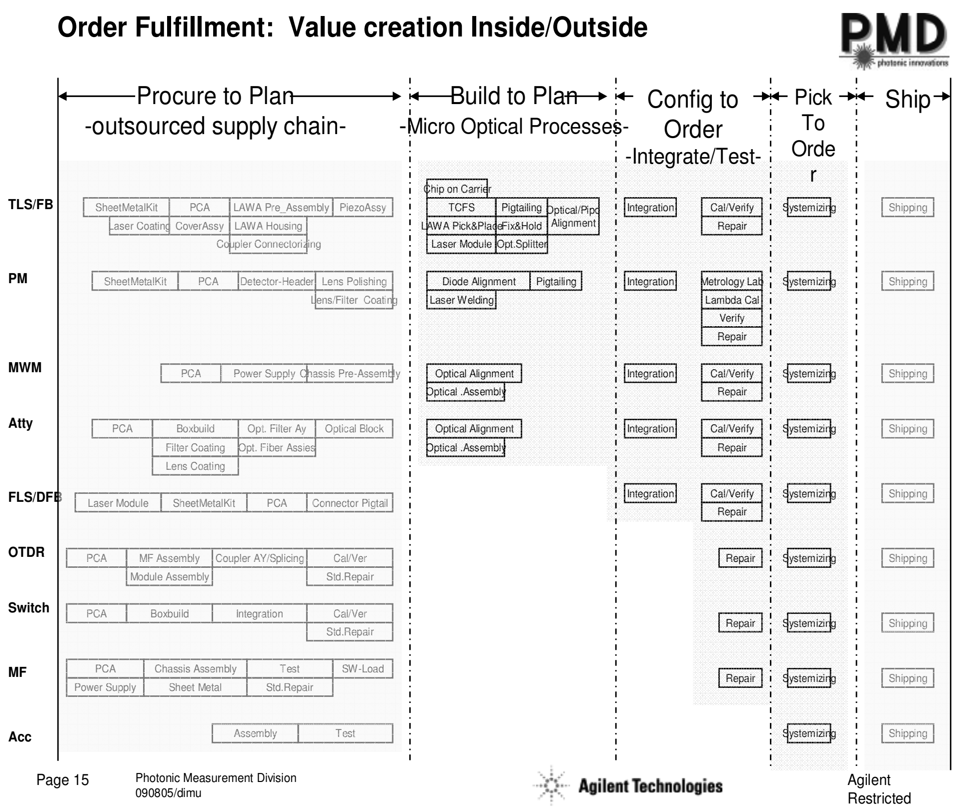


Figure 28: Supply Chain and manufacturing strategy based on the box level (Source: Agilent Technologies, 2007)

Agilent now implemented intense cooperation with a handful of **outbound partners** (vendors). Electronic interfaces for invoicing and forecasting had been installed. Agilent procurement representatives met these vendors regularly, and a rigid vendor measurement system had been put in place. Especially when new products were developed, vendors were intensively integrated. From 2006, CMs and suppliers were motivated to implement a vendor managed inventory (VMI) concept.

Agilent did not use many **outbound partners** such as sales or channel partners. All sales and all shipments went directly to the business customers, except for a few low-end commodity products. Only in the US was a small volume sold by channel partners. Channel partners were also used in smaller countries that did not have their own direct sales force. "*There is certainly a need for such a channel, and some competitors are very good there. We might lose about 10-20% of our deals because of a missing indirect channel because we don't get access to some small and medium businesses (SMB). But we don't need a real distribution, it is more about sales. SMBs in Germany are not covered at all because of the missing indirect channel. Our sales organization does not see these customers. All products which are below $10,000 should go through a channel because our sales do not make any money when selling these low-margin products*" {Marketing Manager}.

7.1.7.3 Factory evolution

Today, quality is still most important, but cost, delivery performance and the demand for custom products have picked up. Agilent's manufacturing strategy **(process technology)** followed the supply chain strategy, as described. Processes were designed according to the complexity of the product and the box levels defined above.

i. Products in box levels four and five were directly delivered from the CM to Agilent's shipping zone. Some of them were even built to end customer order. All products were merged in the shipping zone for "systemizing" and packaging. Systemizing is the integration of the product module into a rack, connecting the modules and testing them.
ii. Box level three covered the medium complex or more mature product families, which were built in one final assembly step. Here, many components came from suppliers, some even pre-integrated. Outsourcing seemed to be an important strategy here, to cut down cost and increase speed.
iii. Box levels one or two, complex or new product families, followed a two-step approach. First, pre-integration (housing), and second, the complex micro-alignment, micro-assembly and test of the optical modules. The latter was the challenging part for manufacturing. It became most critical if several optical components were combined and adjusted, since they were not plug-and-play components. If, for example, they had to integrate an optical hybrid with six to eight components, the system quality was good if all components pulsated in a way that the overall specifications matched. If not, operators needed to exchange components until the quality of the overall system was good. All this required well trained people. This quality, plus the achievable "hard-spec'ed" performance, was a market differentiator and a reason for business customers to buy from Agilent. This manufacturing process was technologically so demanding that it needed to be handled in a push mode to ease the complexity of manufacturing. It was mainly kept in-house for several reasons: to keep better control of quality in this challenging technology, to be able to give feedback to product R&D, and above all because of the difficulty of finding external suppliers and CMs who had the necessary know-how.

Thus production in Böblingen still faced the challenge of high-tech product technology due to the steady growth and still evolving technology of some of the products. "*At the moment, we are happy to get quality and performance right – and if manufacturing at least delivers according to customers' wishes. But we even have problems here"* {Marketing Manager}. Since 2004, material cost reduction has become even more important than in the earlier phase. "*The commodity products are the major challenge from a cost perspective since the price is a major differentiator. At the moment, the problem is that our margins are too low to make further price cuts. That means the fulfillment organization must further become more cost-sensitive"* {Marketing Manager}. Cost reduction had even been achieved by the consolidation of vendors and the development of some key vendors with intense collaboration and VMI approaches. Furthermore, the number of contract manufacturers had been reduced to cut management and tooling costs, to decrease the prices through higher volume and to facilitate a more intense collaboration in data exchange and process development. This had even been done at division and at corporate level by bundling the company-wide procurement policy. They also installed TQM (total quality management) and moved process quality control toward the vendors to reduce the quality control cost. Agilent held regular, so-called "cross-margin improvement meetings", where they looked at the products and the integrated associated supply chain to discuss what they could do to improve processes at Agilent and suppliers.

Business customers

The very dynamic business environment, from a technology point of view, the extreme volatility of demand, and periodical changes were the main reasons why Agilent's business required higher fulfillment **flexibility and speed.** After the bubble, it turned out to be important because of the competitive situation and the overflow of products on the (grey) market. Product technology and quality were no longer enough to differentiate. In addition, the need for fast delivery could be explained by the fact that the test system for a new network device was very expensive (up to $500,000). Thus, business customers typically waited until they could be absolutely sure that they needed the device. Since the decision regarding the purchase was typically taken at the last possible moment, the business customers were naturally dependent on fast delivery and reluctant to wait. Consequently, assembly after the customer order was placed was time-driven as the device was built to order. The driver of these instabilities was the changing demand of the company's business customers who had to react to unpredictable demand changes among their own customers in a faster supply chain. However, business customers typically contacted Agilent long before they sent the order to discuss specifications and prices. This information was forwarded to manufacturing, with a probability rating from marketing, so that the operation could prepare itself. This reduced, to some extent, the time pressure and the need for a fast supply chain. The total supply chain cycle time of 60-120 days was exceptionally long and very different from the outbound portion which was around two to six weeks. *Since 2004, the market has been back to "normal" and now business customers expect fast deliveries once they have passed their time-consuming internal budget release process*" {Marketing Manager}. This difference in cycle times, combined with fluctuating demand and a demanding manufacturing technology, required pre-fabrication to be plan-based (push) with some pre-assemblies and components in the warehouse.

The major problem was that processes for the new and complex products were not really robust enough. Sometimes, they only had 40-60% yield. Since the process capacity had been so greatly increased before the bubble peak, there was no natural evolution of installing newer machines. This had impacted performance. Agilent also tested to improve **speed** by pre-building products before order income (push) to flatten out capacity. The big disadvantage of this concept was the increase in inventory and the planning risk which drove costs upwards. Because of the great number of options, this was virtually unmanageable.

Process **flexibility** was difficult to implement from several perspectives. The product mix was high, and experienced people were needed for each product since products were also different from a manufacturing perspective. It was not easy to switch people and move them to another production line. Nevertheless, short-term capacity demand fluctuations were managed by adapting the business customer order cycle times. The workforce flex model was limited to the daily work hours of the operators (8-10 hours), but the major flexibility came from the team itself, who understood the business situation and acted accordingly. "*We can forecast the average over three months very well. However, if a certain, very complex order comes in, the OF system is at its limits quickly"* {Manufacturing Manager}. Medium term, the temporary workforce could be adapted to the order situation. Variabilization of **cost** was still difficult because the volume was too low and the previously highly automated processes ran at minimum possible speed. This also explains why a flexible workforce model was difficult to implement. Flexibility regarding capabilities was achieved through the team skills. Flexibility in volume could also be achieved by increasing the throughput of the automated processes and by using the workforce model and adding shifts. With the introduction of the new ERP system in 2003, production started using flexible routing concepts, based on the order structure. Before that, this had been managed manually.

Fulfillment services and customer solutions

The voice of the customer was very important to Agilent for measuring customer value. "*Customer orientation has evolved over the last years, and we are now very customer-oriented. Manufacturing does not talk anymore about products which they must build, but about customers they have to supply. Second, they have a stringent metrics system regarding delivery quality and product quality*" {Marketing Manager}. Business customers ordered either test systems defined in Agilent's portfolio or complex and specifically designed systems. If business customers started to ask for new applications and wanted to measure specific things at best quality, Agilent considered building it and later developing new products or solution systems for all business customers. Japanese customers were integrated through the Japanese solutions engineering team. They designed special solutions for business customers, and even bought third-party hardware and integrated that. Agilent only offered this in Japan, since only Japanese business customers paid for this service. This approach was under review as a potential worldwide concept.

Agilent talked about product **standard solutions** if several stand-alone test products – incorporating many options – were built to customer order. Software was also integrated and all products were then racked and stacked. Some of these racks included five products or more – even from external suppliers. Here, they developed **specialized solutions** by combining them. This was called a solution because normally the business customers carried out this integration themselves by buying different "building blocks" and developing their own software. Sometimes, financial services, like leasing products, were offered as well.

Business networks

From an inbound perspective, Agilent used vendors and system vendors, as discussed earlier, and a few CMs which were deeply integrated in the Agilent processes. Thus, collaboration between the factory and external partners was mainly limited to suppliers. To increase the vertical integration of Agilent, two strategies were possible: either a backward integration if, for example, a component manufacture developed a product with an in-built test system, or a forward integration, if Agilent did the network system integration, which had been done so far by the network equipment producer itself. Agilent would then take over the core activities of the network equipment producer, which would generate a competitive situation. Alternatively, a network equipment producer might include its own test systems. "*At the moment, we hope that it is not efficient to include the test system. However, the more complex the applications are or the simpler the test, the more the risk that this will happen*" {Marketing Manager}. From an outbound perspective, direct links between business customers and fulfillment were not strong yet. Agilent collaborated mainly with suppliers but also with some independent software vendors (ISV). A virtual network with business customers and out-bound channel partners had thus far not been developed. All previous collaboration had been deal-based when a specific solution had to be developed or if the integration of different hardware and software modules had to be taken over by Agilent.

7.2 Analysis of the Agilent manufacturing concept evolution

In this section we illustrate the pattern matching results of this second validation case. By applying our measurement model as developed in Chapter 4, we evaluate the predefined theoretical characteristics for each variable with this case study. The objective is to understand which phase of the TLC and which type of factory was present at what point in time. In Chapter 8 the results will be linked and compared with the exploratory case.

7.2.1 Interpretation and conclusions

The tables below show the Agilent pattern matching results. The analysis was done in cooperation with Agilent management. We call the table showing the TLC phases validation "TLC-table", and the table showing the types of factory "ToF-table" (type of factory table). These evaluation tables are shown in detail in Appendix VII.

OM- EVALUATION

Possible values of variables:

2 = Situation of the case largely matches the theory
1 = Situation of the case matches the theory to some extent
0 = Situation of the case does not match the theory
- = non-existent

	Time-Phase 1					Time-Phase 2					Time-Phase 3					Time-Phase 4				
Type of Factory	**H**	**C**	**V**	**S**	**N**	**H**	**C**	**V**	**S**	**N**	**H**	**C**	**V**	**S**	**N**	**H**	**C**	**V**	**S**	**N**
Sub-Variables																				
Customer requirement and products - Requirements - Product portfolio characteristics	2	0	0	0	0	2	0	0	0	0	2	2	1	0	0	2	2	1	0	0
Competitive Strategy of the factory - Leadership through - Goal - Strategy	2	0	0	0	0	1	0	1	0	0	1	2	1	1	0	1	2	1	1	1
Process Strategy - Focus	2	0	0	0	0	2	0	2	0	0	2	2	2	0	1	2	1	1	0	1
Total Value	6	0	0	0	0	5	0	3	0	0	5	6	4	1	1	5	5	3	1	2
# of variables	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
Mid Value	2.0	0.0	0.0	0.0	0.0	1.7	0.0	1.0	0.0	0.0	1.7	2.0	1.3	0.3	0.3	1.7	1.7	1.0	0.3	0.7

Table 12: The Agilent Type of Factory (ToF) table

TLC- EVALUATION

Possible values of variables:

2 = Situation of the case largely matches the theory
1 = Situation of the case matches the theory to some extent
0 = Situation of the case does not match the theory
- = non-existent

	Time Phase 1					Time Phase 2					Time Phase 3					Time Phase 4				
Phases	**I**	**II**	**III**	**IV**	**V**	**I**	**II**	**III**	**IV**	**V**	**I**	**II**	**III**	**IV**	**V**	**I**	**II**	**III**	**IV**	**V**
Grand Total Value	24	11	0	0	0	4	7	13	1	0	2	5	6	7	0	2	3	11	13	0
Grand # of variables	13	12	13	13	13	12	11	11	12	12	11	11	11	11	11	10	10	10	10	10
Grand - Mid Value	1.8	0.9	0.0	0.0	0.0	0.3	0.6	1.2	0.1	0.0	0.2	0.5	0.5	0.6	0.0	0.2	0.3	1.1	1.3	0.0
Grand - Centre of gravity		1.33					2.45					2.90					3.21			

Table 13: The Agilent TCL table

Phase 1: From about 1980 to 1995

In the defined timeframe we measured the first phase of the TLC. The TLC-table shows a total center-of-gravity value of 1.33. The factory is a High-tech type of factory with a match of 2.0/ 0.0/ 0.0/ 0.0/0.0 (see ToF-table).

During the 1980s, network test systems for copper data lines were new technology. In the late 1980s, a disruptive technology impacted the market with the shift from copper data lines toward fiber optical devices which could then manage an enormous number of end users. Technology was the main differentiator in the market, and only a few participants competed in this market.

Impact on the factory: Manufacturing depth was high at that time. There were hardly any suppliers or service providers who were capable of supporting Agilent. Manufacturability and quality were the most important goals.

Conclusion 10
In Phase I of the TLC, Agilent's customers expected high performance products at best quality. Cycle time, low-cost or integrated product solutions were not demanded. During that period, Agilent clearly installed a High-tech factory in order to cope with the constantly evolving new technologies and to sustain best-in-class manufacturing. Hence, proposition P1 is confirmed.

Phase 2: From about 1995 to 2000 (Timeframe before the bubble)
This timeframe matches the TLC Phase II with an apparent affinity to Phase III. The TLC-table shows a total center-of-gravity value of 2.45. The factory capabilities were extended toward the Velocity factory with a match of 1.7/ 0.0/ 1.0/ 0.0/0.0 (ToF-table).

The new fiber product technology evolved significantly. There was no standardization and early adopters increased their orders drastically. Market growth was paramount. Many Agilent business customers were not getting enough components to build the extensively growing data networks. The competitive situation was based on availability only.
Impact on the factory: Much outsourcing took place – not due to cost but to capacity reasons. The major challenge was to get the orders shipped as fast as possible at good product quality. Process improvements, automation and outsourcing were the strategies to increase the capacity of the supply chain, to increase delivery velocity, and to manage growth.

Conclusion 11
In Phase II and at the beginning of Phase III of the TLC, Agilent still had a High-tech factory in place but later extended this toward a Velocity factory to manage the sheer volume growth. The reasons for developing a Velocity factory were business driven (revenue growth) and not customer driven, as in the computer cases. Hence, proposition P2 is rejected.
We note that this Velocity factory had different characteristics from those defined in Chapter 4.

Phase 3: From about 2000 to 2002 (Timeframe after the bubble)
This timeframe matches the TLC Phase III with a center-of-gravity value of 2.9 (see TLC-table). The type of factory match is: 1.7/ 2.0/ 1.3/ 0.3/0.3 (see ToF-table). The High-tech factory and the Velocity factory capabilities were developed during the time phase before the bubble. Agilent now extended their factory toward the Low-cost factory.

Overcapacity in the market regarding data network infrastructure resulted in a huge consolidation and the market collapsed completely resulting in tremendous inventory levels in the market. Business customers realized the extent of the competitive pressure on the test

system suppliers and changed their behavior: They now expected immediate availability at lowest possible prices.
Impact on the factory: The factory further developed the process velocity to build the products fast. However, most important to Agilent was to adjust the cost structure to the much lower business volume. Manufacturing depth could not be further reduced due to overcapacity in the factory, which was a result of the market collapse.

Conclusion 12
In Phase III of the TLC, Agilent continued to further develop a Velocity factory as it was needed for best-in-class manufacturing. Therewith proposition P3 is confirmed.
It must be noted that Agilent put more focus on developing in parallel a Low-cost factory due to the specific business situation.

Remarks
Agilent developed the Velocity factory before the Low-cost factory. This is in contrast to the sequence of what was seen in the two computer company cases. The importance of velocity was already there in the second timeframe where, according to our theoretical model, the Low-cost factory should have been developed. In this second timeframe a Low-cost factory was not developed. Thus, P2 was rejected. However, the trigger for velocity in Phase 2 did not come from customers but from the very specific business situation with an unusually high revenue growth of several hundred percent per year. This explains why Agilent's Velocity factory had different process characteristics to those defined in chapter 4. Nevertheless, P3 was confirmed because in the third timeframe that was measured a Velocity factory existed and was further developed. Because the availability of products had become a major market differentiator, Agilent developed strategies to increase fulfillment velocity by boosting the manufacturing capacity.
If we look at both time phases together, the validation would show that both capabilities had been developed according to our propositions P2 and P3. However, the sequence of capability development does not match the propositions.

Phase 4: From about 2002 to 2006
This timeframe matches the TLC Phase III with a tendency toward Phase IV. The TLC-table shows a total center-of-gravity value of 3.21. The pattern matching is illustrated in the ToF-table with a match of 1.7/ 1.7/ 1.0/ 0.3/ 0.7.

A TLC score of 3.2 can be explained by the fact that Agilent produces products in all phases of the TLC simultaneously. During the interview sessions, Agilent management considered their whole business and on average weighed the market between Phases III and IV of the TLC.
They still developed very new technologies which were sold directly. In addition, they sold standard test systems via retailers or simple-to-use test systems for operators at Asian network-equipment manufacturers who are not capable of using complex and difficult technologies. Thus, Agilent offered products to a very diverse customer base – from innovators to late adopters. Late adopters included, for example, operators at assembly lines of their business customers, as mentioned above.

Impact on the factory: To best serve these different types of customers, Agilent developed in this phase several types of supply chain models and factories in parallel. These supply chains differed in particular with respect to the manufacturing outsourcing strategy. At Agilent's local factory the real focus of the local factory was still high-tech and low-cost, and to a limited extent velocity. Only some solutions capabilities were being developed in this phase, for example with the Japanese solutions team. Agilent's CMs increasingly focused on the commoditized products. These were the products which were bought by TLC-Phase IV types of customers. These CMs were located close by and thus formed a virtual factory with Agilent's local factory. Their focus was on velocity and low-cost capabilities. This explains why Agilent could afford to only gradually switch the capabilities of their local factory. The High-tech factory was still the center of attention, with some low-cost and velocity skills.

Conclusion 13

In Phase III and at the beginning of Phase IV of the TLC, Agilent still valued the High-tech factory because of the continuing inventions in new technology. The cost and velocity focus was slightly reduced since the market again showed healthy growth. The Cooperative factory was evolving since contract manufacturers were increasingly taking over a bigger part of the manufacturing portfolio. Collaboration with outbound partners or customers had been developed on small scale only. A real Solution factory was not yet developed. Therefore proposition P4 is rejected.

Conclusion 14
If a company offers technologies which are simultaneously in different phases of the TLC, it will be necessary to provide all respective types of factories simultaneously to be best-in-class. Due to its closeness to customers the local factory will focus on those technologies which are in the earlier phases of the TLC.

Recap and further explanation of exceptions
Regarding the exceptions, two more conclusions were deduced in a final discussion of the results with Agilent management.

i. The phenomenon of capital-intensive products and its impact on speed:
Today, the motivation for the development of a Velocity factory is lower, as in the computer business. Agilent is contacted early by its OEM-customers for technological and price discussions. Thus manufacturing can obtain relatively good forecasting data early. A big portion of the fulfillment cycle can be prepared and planned with a certain probability that deals will come in.
ii. A different type of a Velocity factory:
Before the bubble, the Velocity factory at Agilent was developed in response to business – as opposed to customer – imperatives. However, a Velocity factory as defined in our research must enable quick fulfillment. In our definition there are two fundamental differences compared to what Agilent developed: First, the trigger for velocity in fulfillment is requested by customers. Second, fast

fulfillment is achieved through more processes where flexibility is an important cornerstone to achieve this. At Agilent, the need for velocity was demanded by shareholders to capitalize on the growing market. From a process perspective, speed was achieved through capacity extension where flexibility did not play a major role. After the bubble, customers demanded velocity mainly because of the dominant situation they were in.

iii. Competing with customers' core competences:
Selling solutions is typically combined with a forward integration strategy within the supply chain. A forward strategy implies that the company gets into competition with the next actor within the supply chain. According to Agilent, the core competence of their OEM-customers is testing. Testing requires the utmost expertise and insight into the communication network. Agilent evaluated the option to sell test capacity as a solution instead of test equipment. However, most OEM-customers did not want Agilent to take over their testing because that was their core competence to measure their product quality, and because of the risks associated with it: The test strategy knowledge could be misused by Agilent or provided to other network equipment manufacturers. Also, it would allow Agilent to gain too great an influence in the fulfillment performance of their customers regarding end user delivery.

7.2.2 Pattern matching result summary

Table 14 shows the summary of this validation. We use the following abbreviations:
H = High-tech factory; C = Low-cost factory; V = Velocity factory; S = Solution factory; N = Cooperative factory (network)

Proposition	**Empirical evidence**
Proposition P1 In Phase I of the TLC a High-tech factory is necessary for best-in-class manufacturing	TLC: 1.33 Factory: H 2.0/ C 0.0/ V 0.0/ S 0.0/ N 0.0 Proposition 1 is confirmed
Proposition P2 In Phase II of the TLC it is necessary that the High-tech factory evolves and a Low-cost factory becomes dominant for best-in-class manufacturing.	TLC: 2.45 – indicating phase II and some first characteristics of Phase III. Factory: H 1.7/ C 0.0/ V 1.0/ S 0.0/ N 0.0 Proposition 2 is rejected regarding the second timeframe of our validation. Agilent developed a Velocity factory but not a Low-cost factory. Proposition 2 is partly confirmed if we consider the timeframe before and after the bubble as a whole. Agilent developed these capabilities but not in the sequence expected, which again can be explained by the extraordinary business context.

Proposition P3 In Phase III of the TLC it is necessary that the High-tech- and Low-cost factory evolves and a Velocity factory becomes dominant for best-in-class manufacturing.	TLC: 2.90 – indicating Phase III of the TLC. Factory: H 1.7/ C 2.0/ V 1.3/ S 0.3/ N 0.3 Proposition 3 is partly confirmed. In this third phase of the TLC, there is still a strong weight regarding the development of a Velocity type of factory. However more importance was put on the development of low-cost capabilities.
Proposition P4 In Phase IV of the TLC it is necessary that the Velocity factory evolves and a Solution factory and later to a Cooperative factory becomes dominant for best-in-class manufacturing.	TLC: 3.21 – indicating that during the fourth time phase measured Agilent experienced on average (over all products) the TLC Phase III with some first characteristics of Phase IV. Factory: H 1.7/ C 1.7/ V 1.0/ S 0.3/ N 0.7 Proposition 4 is rejected. Agilent did not develop the Solution factory. This is also true for those products which were clearly in Phase IV of the TLC. This has to do with the fact that they are a fourth tier supplier where a forward integration strategy toward solutions and services would collide with their OEM customers core competences.

Table 14: Agilent - validating the research proposition

This case was selected because of its differences regarding some important characteristics within our unit of analysis. First, Agilent experienced a specific business evolution (the bubble). Second Agilent was a very low volume and 3rd tier supplier with a relatively small manufacturing organization. In summary we can state that this second validation supported some of our research propositions but showed some important limitations regarding our conceptual model. Specifically, the bubble impacted their strategy significantly and led to a different sequence of capability development from that under "normal" business conditions. The requirement for velocity appeared before costs started to be important. Velocity was achieved through production capacity enhancement and not through faster processes and flexible routings. Furthermore, solutions did not play a major role, although some of their products were in TLC Phase IV. We learned that this can be explained by the facto that Agilent is a third and fourth tier test equipment supplier and solutions would negatively impact their customer's business model. Further interpretations and learning are discussed in Chapter 8.

8 EVALUATION OF EMPIRICAL RESULTS

In this chapter we sum up the findings and present the analysis of the research results. We validate the research propositions by analyzing the empirical results. We start with a discussion of the validity of the measurement model and go on to discuss how it was applied. Next we sum up the findings of the explorative case with a special emphasis on the HP TLC model. We then continue validating the cases which were used to validate the propositions. Based on a cross-case analysis we develop our theory and appraise the conceptual model. A brief discussion of the value of the "local" factory will follow, deduced from our test results and the propositions.

8.1 Validity of our measurement model

Our measurement model is two dimensional and covers the multifarious world of OM and the complex dynamism of high-tech markets caused by the evolution of a technology. As testing manufacturing companies in the high-tech electronics business and how they switched their types of factories over the TLC is new, a new measurement model needed to be developed to prove its applicability. However, some practical obstructions were realized which we discuss briefly.

Ideally, the center-of-gravity value should be an integer one. An integer value would demonstrate that the exact time zone of a TLC-phase had been found. However, the test reality was different and the outcome shows that the center-of-gravity results of our validation are not integer figures as expected. This means that we were unable to find the exact time-zones matching with the theoretical TLC phases. This can be explained by the fact that the time sections measured had been defined prior to the interview in accordance with the judgment of the company management. In addition, within our evaluation we do not deal with mathematical terms, but with verbal and incomplete descriptions of real-life situations, dealing with degrees of truth. These decimal numbers may then be interpreted as imprecise concepts like "very", "quite" or "slightly". In our model the bandwidth of the "center-of-gravity values" is 1-2, 2-3, 3-4, and 4-5. The conclusions are not "yes or no" but a "weighted yes or no". These indicate that a certain TLC-phase has been found but that some characteristics of the previous or next TLC-phase were discovered as well. This problem is discussed by fuzzy logic theory (e.g., Seising, 2005).

A more precise match of time sections measured and the time phases described by the TLC could be achieved if an iterative interview process were applied where the defined time-phases measured (e.g., the 1970s) vary until integer center-of-gravity values are obtained. However, this would mean re-doing the interviews and changing the time phases until they matched with the theoretical TLC descriptions, which is not feasible from an economic perspective.

Conclusion 15

The complexity of measuring the TLC can cause fuzzy results. This could in theory be eliminated by conducting a sequence of interviews per case where the defined timeframes are altered until the center-of-gravity values are integer ones. However, this is not possible in practice. Alternatively, we allow fuzziness and accept decimal values which will be taken into account during the interpretation of the validation results.

8.2 Cross case interpretations

In this section we give an overview of the results of the analysis. Assuming that our exploratory case - the HP factory in Germany – represents a typical case in the computer industry, we start with a summary of our findings and how the technological evolution changed the environmental conditions and with that the manufacturing strategy. Then we continue by discussing the results of the two validation cases, FSC and Agilent. We conclude with a cross-case pattern matching from which we prove our theory.

Case overview

The cases were chosen according to our case selection criteria and were treated as single instances.

From **HP, our explorative case,** we deduced the following theory**:** Within the computer business, companies start with a High-tech factory. We called this Phase 1. As the technology evolves and more competitors enter the market, customers realize that there is more competition, which has the effect of moving the technology transition points into Phase 2. A Low-cost factory evolves. "Off- shoring" and outsourcing of major manufacturing processes are ways in which some companies try to compete in this phase. Later, customers start to demand "standardization" which has the effect of accelerating the transition to Phase 3, with the crossing of the 'Commodization Intersection' point. It is worth noting here that in a consumer business (e.g., home electronics industry), standardization actually may occur much earlier. Establishing a set of standards, i.e., MP3, is a form of collaboration which impacts a product's design in the areas of form, fit and function. Once these standards are established, companies then compete on supply chain efficiencies, brand recognition and time-to-market strategies. Speed of customer order delivery for convenience reasons and of the supply chain for cost reasons calls for a Velocity factory. If lowest prices and fast delivery of commoditized products becomes common, customers will choose computer vendors which offer customized products (solutions). This is the entry into Phase 4. Now the Solution factory evolves, moving the complexity of system and data center integration from the customer site to the factory. Later on in this phase, collaboration with local outbound partners becomes a way to compete effectively in this complex environment. The Cooperative factory evolves, which is more than just cooperation with suppliers and outbound partners. The HP Solution factory and later the HP "Partner Park" are experimented with, and the data shows their effectiveness in generating successful business. This type of relationship will probably work in a low-volume, high-end segment of the market but not in high-volume consumer electronics. However, collaboration in any form is a clear sign that a technology is maturing.

Validation 1, the FSC case supported all research propositions. FSC is in a similar business environment as HP is applying very similar manufacturing strategies over time, but implementation seems to be slightly slower than at HP.

Validation 2, the Agilent case was selected because, within the bandwidth of the given case selection criteria, it differs in many areas with the HP-case and the first validation, the FSC case. This case was considered a "less likely case" to extend our validation and with that the scope of the model. We wanted to find out whether the propositions hold under different conditions to verify the scope of generalizability. In some areas the validation supported the propositions but also showed some differences.

Conclusion 16

Understanding the "Life-Cycle of a Technology" and recognizing when a technology enters Phase II/ III/ IV has been vital to the business strategy of the companies evaluated. The investment in capability switching was a dynamic process and their best-in-class factories had enough flexibility to shift priorities quickly.

Cross-case result and overall conclusion

The conceptual model presented in Chapter 4 motivated us to compare the results via a cross-case analysis. The cases are treated as single instances where we compare the observed pattern with the expected pattern in each of the validation cases.

We built the measurement model based on the experience of the HP case and the literature. This measurement model was applied in a post-validation to the HP case to test the quality of the measurement model and to make comparisons between all three cases possible. Table 15 summarizes the results.

Propositions	HP	FSC	Agilent
Proposition P1 In Phase I of the TLC a High-tech factory is necessary for best-in-class manufacturing	confirmed	confirmed	confirmed
Proposition P2 In Phase II of the TLC it is necessary that the High-tech factory evolves and a Low-cost factory becomes dominant for best-in-class manufacturing.	confirmed	confirmed	rejected
Proposition P3 In Phase III of the TLC, it is necessary for the Low-cost factory to evolve and a Velocity factory to become dominant for best-in-class manufacturing.	confirmed	confirmed	confirmed
Proposition P4 In Phase IV of the TLC it is necessary for the Velocity factory to evolve and a Solution factory and later a Cooperative factory to become dominant for best-in-class manufacturing.	confirmed	confirmed	rejected

Table 15: Summary of cross-case analysis

HP and FSC developed very similar manufacturing strategies in a similar business environment. The FSC case is similar to HP regarding the products and the market. Both companies developed the types of factories in a certain sequence and in accordance with the TLC phases. Both companies start out developing a High-tech factory to manufacture complex and new technology with only a limited knowledge of the market. In the second phase both companies felt cost pressure from customers. This is in accordance with the theoretical descriptions in the TLC literature and the description of the adjusted TLC-graph based on the HP case. Customers no longer seek the latest technology as they get more performance than they need; second-best is good enough to support their needs. New competitors enter the industry, competing in the price segment and thus increasing the momentum of price competition. In the third phase of the TLC, both companies developed in addition a Velocity factory. Speed becomes important because both the computer companies and their customers are able to lower inventory cost through supply chain speed. In addition, the continuous product evolution toward a dominant design – and with itt the continuing standardization and modularization of the offerings (Fine, 1998) – enable customers to buy products from different vendors for the same value. Thus customers start demanding standards. This is a major driver because it prevents a company from locking customers exclusively into its products. Standards drive more competition and thereby put more pressure on profits, which in turn puts more pressure on the supply chain for low cost and high speed. Thus availability becomes important and is expressed in this competitive environment via the order fulfillment time. We note that this is a Build-to-Order environment. Build-to-Stock is not suited to this business due to the product complexity within the high-tech electronics environment. In the final timeframe, both companies went through the fourth phase of the TLC and developed a Solution factory to offer complete solutions to those customers who see the financial benefits and convenience of buying completely pre-installed computers compared to computer hardware where the installations and configurations must be organized or performed by the customer himself. Later in this time phase HP developed a Cooperative factory, the HP Partner Park. These capabilities had not yet been developed by FSC to the same extent. This can be explained by the fact that selling solutions is part of HP's company strategy and that its biggest division is HP Consulting. This is not the case at FSC.

Agilent developed different strategies in two phases of the TLC. As discussed, the Agilent validation confirmed the first and third proposition. In the second phase Agilent did not develop a Low-cost factory due to the immense market growth so that Proposition 2 was rejected. The Velocity factory was developed for internal reasons, not because customers expected it. However, the velocity factory developed during this phase does not really match with the descriptions of the Velocity factory defined in our research. Agilent increased fulfillment speed by capacity extension. This strategy followed the company's needs based on environmental business conditions before the bubble. In the third phase Agilent still had a High-tech and a Velocity factory. The Velocity factory development was extended but based on the need to continue to cut down work in process inventory. This type of a Velocity factory is now closer to our theoretical description of a Velocity factory. Thus Proposition 3 is confirmed. However, in this phase Agilent paid more attention to low-cost capability to manage the market collapse and so a Low-cost factory was implemented too. Thus the velocity capabilities were developed but the motivation was slightly different from that described by the measurement model. Consequently, we must state that Proposition 3 was confirmed.

Conclusion 17

The companies analyzed the business situation to recognize irregularities which may lead to a different timing or sequence of capability development than that expected under normal business conditions.

Regarding the workforce size, we did not find any indications that our findings would be impacted.

8.3 Shaping our theory of capability switching in manufacturing

In this section we answer the research questions, summarize our findings and refine the propositions and the conceptual model.

At HP and at FSC, the upcoming new capabilities were developed in a certain sequence with regard to the changing environmental characteristics described by the phases of the TLC. In addition, we found that these capabilities remained more or less important during all phases of the TLC. Some of these capabilities remained essential but were no longer the focus of further development since they had become standards, and were seen as "common" and therefore no longer constituted a unique selling point. For example, we found that high-tech manufacturing capabilities become standard when manufacturing process technology matures. Therefore we state that capability switching must be defined as adding new capabilities while reducing or maintaining old capabilities. The overall conclusion can be stated as follows:

Conclusion 18

Understanding the "Life-Cycle of a Technology" and recognizing when a technology is transitioning is vital to a business strategy. Thus the investment in capability switching needs to be a dynamic process and companies need to have the flexibility to shift priorities quickly.

The Agilent case in particular showed that switching capabilities does not have to be done in-house and may be acquired from external partners to keep the factory focused. To cut costs or reduce fix costs much outsourcing was done in the computer cases, which supports this statement. A High-tech factory continues to be developed as long as new technologies appear. The Agilent case showed that companies managing different technologies in different phases of the TLC simultaneously will continue to use their factory as a High-tech factory and prefer to develop their outsourcing partners to take over the roles of the other types of factories (Velocity factory and Low-cost factory). A Low-cost factory is less important as long as there are more customer orders than products available. As soon as this reverses, the demand for lower prices evolves. A Velocity factory in terms of rapid fulfillment is less important in those cases in which the number of customers demanding fast deliveries is low. The High-tech factory can then employ workarounds and manual interaction to satisfy these few customers. The same is true for solutions fulfillment. In addition, a Solution factory is desirable if a forward integration is possible without creating conflicts with the next customers' core competences. In this case either no solutions selling will ever be demanded or these business customers (e.g., Agilent's business customers) move forward themselves along the supply chain by offering higher solution integration levels to their customers. In this case they would free up the space for their suppliers, like Agilent, to deliver higher integrated products or even solutions.

Shaping our propositions

If the TLC evolves under normal business conditions as described by the two computer cases, we achieve a 100% match with our theoretical propositions. To achieve a 100%

confirmation of all the cases regarding our four propositions, we would have to rephrase two of our propositions so that they would also cover the exceptional business situation Agilent experienced. These two proposition could then look as follows:

Proposition P2*
In Phase II and Phase III of the TLC, it is necessary that the High-tech factory evolves and a Low-cost factory and a Velocity factory become dominant for best-in-class manufacturing.
Proposition P2* would then replace Proposition P2 and P3.

Proposition P4*
If selling directly to the end user market in Phase IV of the TLC, it is necessary for the Velocity factory to evolve and a Solution factory and later a Cooperative factory to become dominant for best-in-class manufacturing.
Proposition P4* would replace Proposition P4.

However it becomes apparent that we would loose clearness regarding our propositions. P4* further limits the domain and P2* reduces the accuracy of the relation validated. P2* simply states that two types of factories (Low-cost factory and Velocity factory) appear anytime in the TLC phases II and III, without naming the exact sequence.

Answering our research questions

Based on the exploratory case we deduced the research questions, which are shown in Section 1.1. The first question was about "what the relationship is between the TLC and the capabilities of the best-in-class local factory". We could confirm a relationship with some exceptions as discussed in Section 8.2. Each product technology matures over time what changes the types of customers in that market and with that their expectations and requirements. This impacts the strategy of a whole company – in marketing but also in fulfillment. The fulfillment strategy again impacts the supply chain strategy and with that the manufacturing strategy. Regarding the manufacturing strategy we could validate that manufacturing capability switching in the high-tech electronics TLC follows a certain sequence for best-in-class manufacturing. This also answers our second research question which was about "how best-in-class local factories switch capabilities during the environmental changes explained by the TLC". Our third question was about "why they change, the triggers of change, and the contribution of the local factory". The contribution of the local factory is answered in Section 8.5. How they change is answered by looking at the definitions of the types of factories (see Section 4.2). The trigger of change comes from the customer and the changing market conditions as defined by the different phases of the TLC (see Section 4.1).

8.4 Linking theory to conclusions

We now compare the empirical findings with the theoretical proposition. We especially draw conclusions from the findings of the cases and state under what conditions we see literal replication and under which circumstances our model will not work.

The strategic examination of operations management dates at least back to Skinner's ground-breaking work (1969, 1974) in which he rolled out the following major ideas: First, manufacturing can and should be employed as a competitive weapon. Second, a factory that focuses on a limited product mix for a particular market niche will outperform a conventional plant. No factory can be expected to perform well by every yardstick (Skinner 1974, p. 114). Third, cost and efficiency are inadequate goals for manufacturing. Skinner's findings explain the strategy developed by Agilent, which implemented different supply chains with different types of factories for its products if they were in different phases of the TLC. However, we claim that factories must extend their capabilities to be considered best-in-class manufacturing. Extending capabilities means developing new capabilities on current or former capabilities, which became a standard and are no longer enough to compete. A Low-cost factory will always remain cost sensitive, even if it becomes a Solution factory. Corbett and Van Wassenhove (1993) discuss this issue and their findings strengthen our thoughts. They cite Hill (1989) who differentiates between qualifying criteria and order-winning criteria. Qualifying criteria describe capabilities which are the minimum which must be met to prevent looses of market shares. Order-winning criteria are those which are needed to be a leader. However, a competitive advantage loses its strength if customers get used to it or if it has been copied by competitors. An order-winning criterion becomes a qualifying criterion over time. This thought is in line with our findings. Capability switching in manufacturing is therefore vital for ongoing best in class manufacturing. Old capabilities may either no longer be needed if the technology becomes simpler or obsolete, or they become a qualifying criterion. Corbett and Van Wassenhove (1993) write that "… until recently, manufacturing's job was often reduced to not obstructing deployment of the business strategy and being as cost-efficient as possible" (p. 111). They continue that the key question is not "*How can we reduce cost*?" but rather, "*How can we compete*?". We realized that low-cost is especially important in the second phase of the TLC. However, in the later phases low-cost is expected but no competitive differentiator anymore. Other capabilities such as solution integration or customer collaboration become important.

On the other hand, Ferdows and De Meyer (1988) contradict Skinners view. They state that competences are not necessarily mutually exclusive, but can reinforce one another and are dynamic over time. This is in line with our findings as discussed above. However their sequence of capability switching is different from our findings which are: quality, dependability, flexibility and cost. The sequence of types of factories we found is: high-tech (quality), low-cost, velocity (flexibility and speed), and solutions and services. Corbett and Van Wassenhove (1993) state, that all of these dimensions are multidimensional and that a different sequence may easily be possible. In the high-tech electronics business, a different sequence to that from Ferdows and De Meyer may be explained by the fact that in the first phase of the TLC the margins are typically high. If competition becomes tighter, cost savings may be the first and easiest step to realize. Furthermore, the capabilities defined by Ferdows and De Meyer are internal capabilities (Corbett and Van Wassenhove, 1993, p. 108) which are needed to guarantee good process quality. However, customers in the high-tech electronics industry may have a different priority list, which is driving external competitiveness. Thus, we recommend that more empirical research is needed to prove our findings.

The description of the TLC based on the HP case can be directly linked to Markides (2006) and his description of new and innovative business models. A business model innovation is the detection of an essentially different business model in an existing business, enlarging an existing economic pie. Markides explains that – similar to our phases 1 to 4 in the HP case – first a new technology is developed without much competition. Then, markets are invaded by many new entrants which drives the innovation rate up. Subsequently a dominant design appears and a shake-out of participants takes place. Next, the market shifts away from technical performance to other product attributes like quality and convenience or price. Here, new entrants often come up with a new business model with much emphasis on process innovation, challenging the current players who still focus on product innovation. His findings match with our findings. All the transition of types of factories we found can be seen as new business models or better manufacturing models – in particular the transition toward a Solution factory.

Moore (2002) discussed a relevant point in time during the TLC which must be managed carefully, which he called “crossing the chasm”. This describes the point in time where companies must change their whole company strategy to remain successful. The next step when crossing the chasm is creating convenience regarding velocity and later solutions. This conclusion matches our findings where there is a commodity intersection point from where the factory must go though significant changes, switching the business model and moving toward a Solution factory offering custom solutions and services. A solution should include everything that increases customer value. Solutions are easy to buy; they include customized services, training, and support.

Utterback (1996) proved that in operations companies’ strategies switch from a product to a process focus. At the intersection point between the two, product technology plays a less important role since the performance of products is good enough to match customers’ needs. The product design reaches a stage that he calls a dominant design. Now process development begins, when companies start to put the emphasis on process design and with it supply chain design. This matches with our findings: In the first phase of the TLC the company focuses on product technology; supply chain management does not play a role and the High-tech factory is tuned to building the new products at reasonably good quality. Then there is a point in time where the companies start to realign their manufacturing processes. A Low-cost factory and a Velocity factory are confronted with requirements regarding process efficiency and flexibility. To reduce cost or to improve speed fulfillment processes are reengineered and some are even outsourced. Thus, the process and later the supply chain focus accelerate. This holds even truer when the Solution factory and later the Cooperative factory are designed.

Norman (1998) states that as long as the technology’s performance, reliability and cost fall below customer needs on the left-hand side of a so called transition point within the TLC, the marketplace will be dominated by those early adopters who want the latest technology and will pay a high price to get it without considering ease-of-use or convenience of products. They like to take risks inspired by the newness of the technology. This situation changes after the transition point has been passed: People will not easily buy the new technology until it has proven itself in the market and has stabilized. They pay more attention to convenience, good user experience and value. Now, technology has a standard, so more people will purchase it. Our findings regarding the transitions of capabilities and the importance of the "commodity intersection point" (Figure 15) also tie in with those of Norman (1998). During the left side of the transition point discussed by Norman, a High-tech factory is applied. After the transition point, price, fast and straightforward deliveries, and later solutions are offered by the Low-cost-, the Velocity- and the Solution factory.

The double helix model described by Fine (1998) can help us to understand the industry dynamics (see Figure 29). It can decode the rates and the direction of change in an industry.

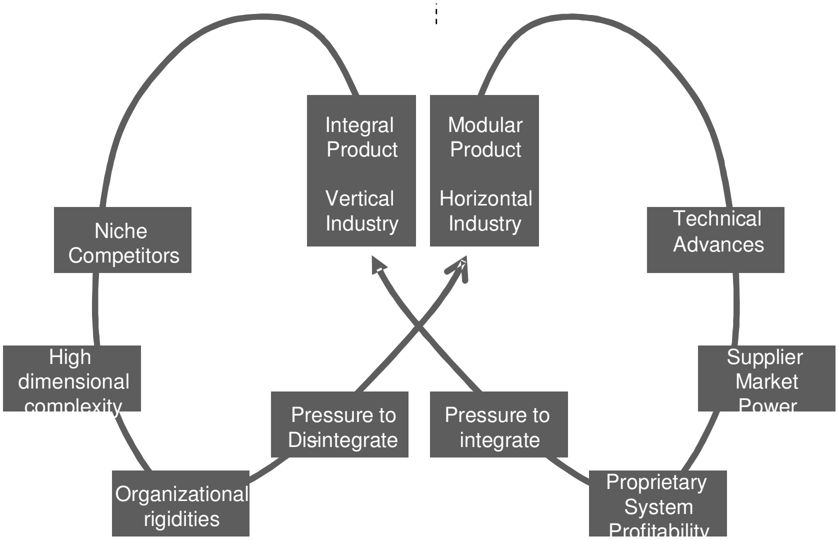


Figure 29: The double helix model (Fine, 1998)

The phases of the double helix can be compared to our findings. Fine describes a number of major phases where the supply chain structure is integral or modular.
Integral architecture and vertical structure: At the beginning no-one else can supply components or products in the quality requested, so these companies develop a vertical strategy. Sometimes companies gain a monopolistic position. There is little or no interchangeability across different companies' systems, with high profits. This complies with the TLC- Phase 1 of our measurement model. A High-tech type of factory is developed.
Modular architecture and horizontal structure: Now new competitors arrive, posing serious challenges to the dominant company. This weakens the dominant and vertically-oriented company and other players take over. This kind of structure may be unstable because more players are in the market and the stronger one in cost, quality, technology and service takes over. Cost focus drives modularization and outsourcing. Since modular and standardized components can be bought on the market, new entrepreneurs enter the market (e.g., Compaq and Dell in the 1980s). There are many dimensions, such as cost, quality,

technology and service – where a company must be best-in-class to keep its position. However, the new vendors take over technology development. Dominant companies focus on product development. Companies must then look for the horizontal approach by modularizing the product and the processes by outsourcing. Low cost or service quality and availability becomes a key sales driver. This conclusion complies with Phases 2 to 4 of our TLC-model, where much outsourcing takes place and the Low-cost factory and then a Velocity and Solution factory are installed. The Solution factory might be the first step backwards in a more vertically-oriented supply chain.
Fine goes on to argue that, "*A company must have the skills to monitor the market to constantly adjust the structure. The company must be flexible enough to respond*" (Fine, 1998, p. 45). He continues: *"No capability is forever. The most important capability is the capability to design the capability chain/ value chain."*

Loch *et al*. (2003) found several capabilities regarding best-in-class OM. They found that cost and productivity are important but not a differentiator. Cost alone is only in rare cases a viable strategy in itself. Later, a winning organization achieves some aspect of uniqueness in the other dimensions - for example, differentiation through closeness to customers and through services. A "to be close to the customer" strategy achieves a unique position by adding services to the manufactured products, services that offer the customer unique value. Then, they mention that networking and collaboration with highly integrated partners are beneficial in highly competitive markets, as in the later phases of the TLC. Partnering allows the organization to continue to improve after all internal improvements have been driven to the limit. They also allude to organizational capabilities that were not validated in our research. These findings support our theory regarding the ongoing evolution of capabilities by switching between different types of factories.

8.5 The value of the local factory

According to our case results, a High-tech factory should be close to the customer base and to R&D. The link between manufacturing and R&D is critical since both must collaborate closely to make the production of new technology possible. Even more critical in this phase is the close link to customers since they are an important source of information regarding the new product technology.
In the next phase of the TLC the major focus becomes cost. In this area, restructuring always bears some risk. The soaring competitive pressure may lead to short-term and merely cost-oriented thinking. Then companies start to assess the structure of their supply chain and challenge the value of their local factories. However, overhasty off-shoring of manufacturing would hollow out their local fulfillment capabilities, which become especially important in a later phase of the TLC when customers start to ask for solutions and services. But what does the strategy of best-in-class manufacturers look like? In this phase, many players in the computer industry moved their manufacturing off-shore. IBM is one example of such a move. However, HP, FSC and Agilent saw many advantages in having the final assembly in the neighborhood of the customers. All these companies offer highly customized products with the latest technology in order to satisfy the high standards of the customers. The product configuration and customer-oriented variety management can be realized more cost efficiently when final assembly of the product is performed in a

pull mode after the customer order has been placed. The proximity to the market helps to decrease the inventory levels and reduces the risk arising from the volatility of prices and exchange rates. This is also true for the third phase of the TLC, where velocity comes into play.
As shown, customers of the manufacturing industry are demanding ever-increasing levels of customer service. In Phase 4 of the TLC, solutions become important in the computer business and, to a lesser extent, at Agilent. Solutions are created by intense collaboration with customers. This requires geographical proximity and with it a local Solution factory. Agilent built this local Solution factory in Japan for the Japanese market. In the computer cases, later on in this phase, the Cooperative factory was developed to make the Solution factory more efficient. To maintain a competitive edge, the validated companies implemented cross-organization business process management. The resulting dynamic resource optimization allowed the flexible sharing, assigning and deploying of resources for adapting to the business or operational requirements. The companies now have the ability to scale up or down to meet fluctuating demands, deliver automated provisioning, re-use server and storage assets, and benefit from the virtualization of server storage and data center environments.

In section 2.2.4 we discussed research in the area of local manufacturing. Our findings fit with the existing literature and the definitions in many areas. Our findings support those from Piore and Sable (1984), who state that a strong inter-firm distribution of labor among clusters of small firms can lead to greater collective efficiency than that of a larger-scaled enterprise, the global factory. Nassimbeni's arguments that the combined effect of specialization and localization carries advantages which justify the development of a local manufacturing system match with our findings regarding the value of local manufacturing in nearly all phases of the TLC (Nassimbeni, 2002). Nassimbeni goes on to state that local manufacturing has a more specialized focus. Local sourcing of the Cooperative factory has a positive effect because of the proximity to partners that offer specific services, a specialized labor, support infrastructures, lower transport cost, simpler interaction and common cultural identities, etc. This fits with our findings of the local factory regarding the high-tech, velocity, and solutions capabilities, which are successful because of their proximity to the main customer base.

9 FINDINGS AND CONCLUSIONS

In this chapter we sum up the findings and present the results of our research. We start with a brief summary of the conceptual model. Then we discuss the findings of our research and their implications for theory and management. We end this chapter by outlining the limitations of our research and recommend possible directions for further theoretical and empirical investigations.

9.1 Introduction

In a dynamic high-tech environment, technological forecasting is key. This is especially true in manufacturing since adaptation is particularly time-consuming and expensive. Our research will support manufacturing managers in their task of shaping the right manufacturing and supply chain strategy. It is about how best-in-class companies in the high-tech electronics industry adapt their local factory to continuously changing requirements by switching roles, responsibilities and capabilities. The local factory in this context is defined as a factory which is geographically close to the main customer base. The research propositions are based on literature and on an exploratory case from HP personally experienced by the author as a manufacturing manager. It was recognized that HP's management team developed different capabilities in a certain sequence which could be explained by the ongoing progression of the product technology. The factory passed through several evolutionary phases which matched the theoretical descriptions of the TLC regarding how markets, customers or innovation focus change over the life cycle of a whole technology. Consequently, in our research we applied the TLC theory to validate the types of capabilities in manufacturing necessary for best-in-class manufacturing so that companies experience a continuous value-add from their local factories and make them stronger vis-à-vis the competition.

Our research propositions state that under normal conditions as experience by the computer cases, where there is one TLC which evolves as described by the literature, the types of factories needed for successful manufacturing follow a certain sequence. But business conditions can be impacted by disruptive factors. For example, new technologies or unusual business conditions as described in the Agilent case. The propositions were validated with two cases from FSC and Agilent.

9.2 Theoretical conclusions and managerial implications

Theoretical conclusions

This study led to four main theoretical conclusions:

First, the literature suggested that there were different types of factories that managers had developed in different industries. However, we found different types of factories in our exploratory case, which belongs to only one industry - the computer industry. We realized that within this industry, these types of factories can be empirically classified into at least five types which differ in terms of their main capabilities: The High-tech factory, the Low-cost factory, the Velocity factory, the Solution factory and the Cooperative factory.

Regarding the environmental changes, the TLC literature suggested that there were five phases. The fifth phase has not been considered in this research because it describes the wind-down of a technology. Based on the environmental dynamism literature we characterized the variation of these phases as a structure of seven variables: Customers, Market Evolution, Profit Situation, Competitors, Supply Chain In-/Outbound Partners, Process Technology and Product Technology.
Both classification*s* of the types of factories as well as the five phases of the TLC may be of possible value to upcoming researchers and are capable of further refinement (e.g., the measurement of the TLC phases).

Second, this study raises the interesting prospect that within the electronics high-tech industry manufacturing strategies need to be continuously realigned to the constantly changing market conditions driven by environmental dynamism and explained by the TLC. We called this capability switching by transferring from one type of factory to another. We refer to the types of factories as discussed above. Even more interesting is that this adaptation follows a certain sequence, but only if the product technology evolves under the conditions as described by the TLC. The computer cases showed such an evolution: There is only one major technology which is representative of the whole industry for high-end computers and there are not many TLCs simultaneously at a company. In addition, the market developed continuously and over a period of time all types of customers appear and buy products – all in accordance with the description of the TLC.
In all cases the companies needed a High-tech factory when they started to produce a new industry technology, corresponding to Phase I in the TLC. This kind of factory is characterized by a high degree of innovation and R&D, where the market position is driven by the capability to build a leading-edge and new technology. The products are complex and expensive to manufacture and quality and manufacturability are the focus. This proposition is supported by the findings of Utterback (1996), who established that innovation is high at the beginning of the TLC product. His findings are discussed in more detail in Sections 2.1 and 8.4. Complexity in manufacturing is driven by the highly vertically- oriented kind of supply chain, as described by Fine (1998) and discussed in Sections 2.2 and 8.4.
Before thinking about product solutions, customers first start to look at price and then velocity. Thus the next step is a Low-cost factory and then a Velocity factory. These findings are supported by other researchers' findings: According to Rogers (1962), when the technology reaches a point where it satisfies basic needs, improvements in the technology no longer make sense. Utterback (1996) (see Section 2.1.4) stated that this is when customers start to look for efficiency, reliability, low cost, and convenience. Due to the ongoing commoditization of the technology customers start to ask for lower cost products as technology is no longer the major market differentiator. The pragmatic type of customer becomes dominant (Moore, 2002). Delivery velocity comes next because it is the subsequent but more difficult-to-reach step to further cut cost in the supply chain at OEMs and their customers, and to increase convenience for the customers.
The next step is a Solution factory and then a Cooperative factory: Moore (2002), especially, argues that an important step toward adapting to increasingly demanding customer requirements is solutions. In both computer cases, solution integration turned out to be a major part of the company and manufacturing strategy. At Agilent, solutions

integration was developed only on a small scale because Agilent would otherwise clash with their customers' core competences. The Cooperative factory is a natural extension of the Solution factory to manage the complexity arising from the solutions business more efficiently and to be able to offer solutions fast and at lower prices. However, it is important to state that this kind of partnership differs from that to suppliers. The Cooperative factory shares processes and skills at the same hierarchical level. Customer solutions are fulfilled as a team of equal partners. Consequently, high-tech capabilities regarding product production no longer played a major role at that stage. Capabilities to manage diversity and the uncertainty regarding required capabilities or just the fluctuating production volume became more important.
Even if the business conditions deviate from the characteristics described by the TLC, we still conclude that all types of factories must be developed but possibly in a different sequence. The Agilent case was picked because of its special business situation and because it was different from the computer cases in products, size, and level within the supply chain as a vendor of test systems supplying data network OEMs. The unnatural growth of the business at Agilent in the early 2000s triggered the need for speed to manage the growth but there was no need for cost efficiency. The Agilent case shows that velocity may come first if customer orders are paramount and customers are not in a position to demand low cost. Then, the Velocity factory may be implemented for the benefit of shareholders, rather than customers, to obtain as much as possible from the growing market. However, Agilent's Velocity factory differs to that which we define in Chapter 4 regarding the strategy to achieve velocity. They achieved velocity through capacity extension and not through process speed and process flexibility improvements. Their strategy matches with the specific business situation they were in at that time. Later, when the business collapsed, customers demanded both velocity and lowest prices. Low cost then turned out to be important and the infrastructure needed to be adjusted. The validation showed that both capabilities were developed according to our Propositions 2 and 3, but in a different sequence than expected. Looking at the cases, we found that the High-tech factory was still important in later phases of the TLC, but only to a certain extent. Thus it is necessary to mention that capabilities are not switched but extended. High-tech capabilities may eventually disappear since products and processes become increasingly standardized and simpler and the technology becomes better understood. Another important aspect is that a factory needs not to transfer from a High-tech to a Low-cost and then to a Velocity factory itself. Agilent demonstrated that these new capabilities need not be developed internally but can be acquired by outsourcing to contract manufacturers.

Third, we found that a company needs to keep local operational capabilities to differentiate in the market along nearly all phases of the TLC and to provide important capabilities to local partners for the benefit of a whole network. All types of factories need to be close to the customer base to work efficiently. Only the Low-cost factory can be achieved off-shore. But off-shoring would not allow the development of efficient Velocity, Solutions nor Cooperative factories. However, it is significant to mention that if a high-tech product becomes a consumer product, a different theory might be applied.

Fourth, based on what was learned from the exploratory case, the TLC descriptions may be extended by plotting down product technology performance over customer requirements.

This graph further facilitates an explanation for capability switching of the local factories described in the cases. The difference between this TLC model and other TLC models lies in the discussion of customer expectations regarding product performance versus available performance supplied by the industry. The delta between available and needed performance triggers customers' requirements and the willingness to pay high prices. The phases after a dominant design has evolved are particularly important since there a management decision must be taken to be either a low-cost producer or to evolve toward solutions and service-oriented technology integrator. In addition, as technology matures, the market entry barriers shrink and new competitors may join with a higher focus on process technology (manufacturing and supply chain processes) than product technology. They offer a given technology at lower cost and faster. In this section of the TLC, more and more suppliers and contract manufacturers develop sufficient capabilities so that outsourcing may be a strategy for the OEM to lower cost. This means that supply chain management then becomes more important than just internal manufacturing process management.

Managerial implications

The study also includes several implications for managers: Managers should carefully evaluate the following indicators, which might be triggers of change to switch capabilities. First, understand customer trends early, such as the requirement regarding standards and the demand for more services (e.g., Reverse logistics as a new customer requirement, which must be considered as well). Second, identify partner collaboration opportunities. Regarding the supplier strategy it is important to recognize the impact of new suppliers such as subcontractors, not just for subcomponents but potentially for solutions. It is also important to understand the evolving CM capabilities – from a process technology perspective as well as from a global network perspective. On the subject of sales partners and channel partners, it is vital to understand the partner strategy in terms of strategic investments and their focus area (e.g., downstream into consulting or upstream into integration). Third, be aware of competitor strategies and if there are new competitors joining. Identify how their strategy differs (e.g., Dell entering the market in the 1990s, with less focus on product and more focus on process R&D). Fourth, identify if there are new process and product technologies and if they support new collaboration opportunities. Especially identify if there are new IT-capabilities which could facilitate global cooperation or different kinds of partnering. This is particularly vital in later phases of the TLC, when the efficiency of processes in the Solution factory start to suffer due to increasing and ongoing requests by customers for specific customized solutions. Then the Cooperative factory must evolve where a division of labor with partners in close geographical proximity is the strategy to increase process efficiency, to leverage infrastructure and to combine capabilities and thereby to be able to integrate more offerings at lower cost. Finally, it is necessary to evaluate whether new and disruptive technologies are appearing.

All these forces have one thing in common: To reduce product cost and enlarge customer offerings over time. The proper response to this is to understand the entire value chain and all the dynamics taking place therein.

9.3 Limitations and recommendations for further research

All research projects have their limits in terms of scope and time. This means that in theoretical research interesting research questions that are outside the scope of the research may be left unanswered. In our research we obtained interesting new insights which lead to new research questions which could not be addressed here. In this section, we discuss these limitations and propose the directions for further studies.

Even though the TLC theory was first put forward by Everett M. Rogers in 1962, the most influential research appeared in the late 1990s (Twiss, 1992; Rogers, 1995; Norman, 1998; Utterback, 1996; Christensen, 1997; Fine, 1998; Moore, 2002). In this dissertation, we have linked these theories with manufacturing theories in literature. However, the research team was not able to refer to a large amount of consolidated findings in literature regarding this link. There still is a lack of descriptions, measurements and theories which fully capture the dynamic aspect of manufacturing capabilities with regard to the TLC. This is especially true of the measurement of the phases of the TLC. Accordingly, our research deals with a new field of questions concerning manufacturing theories which need further testing to strengthen the conceptual model and to probe its boundaries within the domain.

Improving external validity and conducting a test for triviality

Due to time and resource constraints only three cases were discussed in this research. Extending the number of examinations would improve external validity. Further literal replications would be needed to strengthen the conceptual model and the propositions. In addition, further tests should be conducted with less likely cases in order to give better insights into the limitations and the validity of the model. Above all a test for triviality should be conducted. In our research this was neither possible nor needed since we were dealing with a new topic which had not been discussed in literature before. Due to the complexity of the research objective (handling complex manufacturing systems and how they evolve over a very long periods of time), case selection was difficult. The experience of our research now allows a more focused definition of the candidate population and with that the test for triviality. According to Dul and Hak (2007), a way of testing for triviality consists of selecting tests in a different manner from the one used in earlier tests. Consequently, the next cases should be selected based on the absence of the independent concept, or the reverse.

Extending the domain

Even though we do not expect this theory to be applied in high-volume low-tech consumer industries, we expect it to be valid in high-tech areas other than just electronics. On the basis of many discussions of our research with managers in other high-tech industry sectors, we expect the propositions to be applicable to other parts of the “physical” assembly industry. Furthermore, it would be important to research in the chemical or biological sectors. Another aspect would be the domain of slower clockspeed industries (Fine, 1998) in the high-tech and assembly areas. We therefore first recommend tests in other electronics high-tech industries and then in non-electronics high-tech and high clockspeed industries. A third step would be high-tech chemical and biological industries and other lower clockspeed industries. Finally, we recommend further tests regarding high-tech suppliers positioned downstream along the supply chain.

Improving construct validity
Having a good measurement system is vital for good construct validity. The challenges of the measurement model developed have already been discussed in Section 8.2. The biggest challenge is to define timeframes to be measured in a way that they exactly match one of the TLC-phases. An interactive process is suggested.

The speed and excellence of capability switching
Changing the type of factory encompasses a large amount of new considerations and requires new thinking. In addition, changes must be managed. The capability “change management” was not considered during our research; however, it plays an important role regarding the success of manufacturing. When discussing the research results with several managers in our case factories, they named a number of factors which drive the change management capability. These include, for example, company culture, the pressure from market and competitors to change, and management leadership skills. Management methodologies also play an important role, such as scenario planning skills and forecasting skills. Overall, this means that switching capabilities can be faster or slower.

Switching versus extending types of factories
In Chapter 8 we found that capabilities were not switched but rather extended from phase to phase. Thus we concluded that we could call the types of factory also ‘stages’ of factories. Further research might cover this aspect and verify the degree of capability switching from phase to phase.

HP’s view of the TLC
In collaboration with HP, we developed a new way of looking at the TLC. We plotted customers’ technology performance expectations vs. industry available technological performance over time. This view helped to explain capability switching. However this model of the TLC is only a byproduct of this research and needs further research.

In this thesis we have demonstrated the importance of technological forecasting for shaping the right manufacturing strategy early and to gain competitive advantage. We have aimed to improve our understanding regarding the technological evolution of high-tech electronics products and its impact on the manufacturing strategy. We have shown how and in what sequence factories must switch their capabilities to remain best-in-class and have demonstrated the value of local manufacturing in nearly all phases of the TLC. This research combined several disciplines and thus offered an unconstrained freedom in terms of choosing the focus and perspective, making this research process exciting, demanding and challenging at the same time.

REFERENCES

ABERNATHY, W.; UTTERBACK. J. (1978): Patterns of Industrial Innovation. *Technology Review*.

ACCENTURE, INSEAD, STANFORD UNIVERSITY REPORT (2003): "A global study of supply chain leadership and its impact on business performance". URL: http://www.accenture.com/supplychain.html [Status: August 2003].

ADNER, R. (2004): "A Demand-based Perspective on Technology Life Cycles". In: Greenwich, C. Oxford, UK: Elsevier/JAI Press, *Advances in Strategic management*, *Business Strategy over the Industry Life Cycle,* Vol. 21, pp. 25-45.

BACHARACH, S. (1989): "Organizational Theories. Some criteria for evaluation". In: *Academy of Management Review*, Ada, Ohio, Vol. 14, No. 4, pp. 496-515.

BACKHAUS, K.; ERICHSON, B.; PLINKE, W.; WEIBER, R. (2000): *Multivariate Analysemethoden – Eine anwendungsorientierte Einführung*. 9th edition. Berlin et al.: Springer.

BENSAOU, M.; VENKATRAMAN, N. (1995): "Configurations of inter-organizational relationships: a comparison between US and Japanese automakers". In: *Management Science*, Vol. 41 (9), pp. 1471-1490.

BESANKO, D.; DRANOVE, D.; SHANLEY, M.; SCHAFFER, S. (2003): *Economics of Strategy*. 3rd edition, New York: John Wiley & Sons, Inc.

BEST, M.H. (1990): *The new competition*. Cambridge: Harvard University Press.

BIROU, L.; FAWCETT, S.; MAGNAN, G. (1998): "The product live cycle: a tool for function l strategic alignment". In: *International Journal of Purchasing and Materials Management*, Vol. 9 (1), pp. 15-23.

BISHOP, S.K. (1999): "Cross-functional project teams in functionally aligned organizations". In: *Project management Journal*, Vol. 30 (3), pp. 6-12.

BLACKBURN, J. (1991): *Time-Based Competition*. Business One Irvin, Homewood, IL.

BODDY, D.; MACBETH, D.; WAGNER, B. (2000): "Implementing collaboration between organizations: An empirical study of supply chain partnering". In: *Journal of Management Studies*, Vol. 37 (7), pp. 1003-1017.

BOVET, D.; MARTHA, J. (2000A): "From supply chain to value net". In: *Journal of Business Strategy*, Vol. 4, pp. 24-28.

BOVET, D.; MARTHA, J. (2000B): *Value Nets ´Reinventing the rusty supply chain for competitive advantage*. New York: John Wiley & Sons.

BOYER, K.; LEONG, G. (1996): "Manufacturing flexibility at the plant level". In: *Omega – International Journal of Management Sciences,* Vol. 24 (5), pp. 495-510.

BUHMAN, JR.; CHARLES, H. (2003): “Oncoming wave of collaboration”. In: *Industrial Engineer*, Vol. 35 (8), p. 43-48.

BULLINGER, H.J.; KÜHNER, M. (2002): *Supply Chain Management: Stand und Entwicklungen*. München: Carl Hanser.

CAMBASHI, BEST PRACTICE CASE STUDIES (2004): “*HP Best Practices - Solution factory*”. URL: http://www.cambashi.com/research/formfree.htm [Status: August 2006].

CHEN, I.J.; CALANTONE, R.J.; CHUNG, C.H. (1992): “The marketing-manufacturing interface and manufacturing flexibility”. In: *Omega*, Vol. 20 (4), pp. 431-443.

CHESBROUGH, H.; TEECE, D. (1996): *Organizing for Innovation: When Is Virtual Virtuous?*. In: Harvard Business Review, Vol. 80, pp. 127-134.

CHILD, J. (1972): “Organizational structure, environment, and performance: The role of strategic choice”. In: *Sociology*, Vol. 6, pp. 1-22.

CHOPRA, S.; MEINDL, P. (2001): *Supply Chain Management*. Upper Saddle River, New Jersey: Prentice Hall.

CHRISTENSEN, C.M. (1992): *Exploring the limits of the technology S-curve; Part* I: *Component technologies;* Part II: *Architectural technologies. Production and Operations Management.* Boston, MA. Harvard Business School Press.

CHRISTENSEN, C.M. (1997): *The innovator’s dilemma: When new technologies cause great firms to fail*. Boston, MA. Harvard Business School Press.

CHRISTENSEN, C.M.; RAYNOR M.E. (2003): *The Innovator’s Solution: Creating and sustaining successful growth*. Boston, MA: Harvard Business School Press.

CHRISTENSEN, C.M. (2005): *The innovators dilemma. The revolutionary book that will change the way to do business.* Collins Business Essentials.

CLARK, L.; FUJIMOTO T. (1991): *Product development performance*. Boston, MA.: Harvard Business School Press.

COOPER, R.G.; KLEINSCHMIDT, E.J. (1995): “Benchmarking the firm’s critical success factors in new product development”. In: *Journal of Product Innovation Management*, Vol. 12 (5), pp. 374-391.

COPACINO, W. (1999): “The emergence of ‘value networks’”. In: *Logistics Management & Distribution Report*, Vol. 38 (8), p. 38.

CORBETT, C.; VAN WASSENHOVE, L. (1993): “Trade-offs? What trade-offs? Competence and competitiveness in manufacturing strategy”. In: *California Management Review*. Vol. 35 (4), pp. 107-122.

CORSTEN, D.; GABRIEL, C. (2002): *Supply Chain Management erfolgreich umsetzen*. Berlin: Springer.

CRAIG C.S.; DOUGLAS, S.P. (1996A): “Responding to the challenge of global markets: Change, complexity and conscience”. In: *Columbia Journal of World Business*, Vol. 31 (4), pp. 6-29.

CRAIG, C. S.; DOUGLAS, S. P. (1996B): “Developing Strategies For Global Markets: An Evolutionary Perspective”. In: *Columbia Journal of World Business*, Vol. 31 (1), pp. 70-81.

CRAIG, C. S.; DOUGLAS, S. P. (1996C): “Responding to the challenges of global markets: change, competition and conscience”. In: *Columbia Journal of World Business*, Vol. 31 (4), pp. 6-18.

D’SOUZA, D.E.; WILLIAMS, F.P. (2000): “Toward a taxonomy of manufacturing flexibility dimensions”. In: *Journal of Operations Management*, Vol. 18, pp. 577-593.

DAY, G.S. (1994): “The capabilities of market driven organizations”. In: *Journal of Marketing,* Vol. 58, pp. 37-52.

DORNIER, P.; ERNST, R.; FENDER, M.; KOUVELIS, P. (1998): *Global Operations and Logistics: Text and Cases*. New York: John Wiley & Sons, Inc.

DOUGHERTY, D.; BORRELLI, L.; MUNIR, K.; O'SULLIVAN, A. (1998): “The interpretive flexibility of an organization’s technology as a dynamic capability”. In: *Advances in strategic management*, Vol. 15, pp. 169-204.

DUL, J.; HAK, T (2007): *Case Study Methodology In Business Research*. Oxford: Butterworth-Heinemann.

DUYSTERS, G.; HAGEDOORN, J. (2001): “Do company strategies and structures converge in global markets? Evidence from the computer industry”. In: *Journal of Business Studies*, Vol. 32 (2), pp. 347-357.

EISENHARDT, K.M. (1989): “Building Theories from Case Study Research”. In: *Academy of Management Review*, Vol. 14 (4), pp. 532-550.

ELLRAM, L.M. (1996): The use of the case study method in logistics research”. In: Journal of Business Logistics, Vol. 17 (No. 2), pp. 93-138.

ENDERS, A. (2004): *Management Competence. An empirical investigation of the effects of resource-based management on the operational and business performance of plants in the German electronics industry*. Berlin: Springer.

FEAGIN, J.; ORUM, A.; SJOBERG, G. (1991): *A case for case study*. Chapel Hill, NC: University of North Carolina Press.

FERDOWS, K. (1989): “Mapping international factory networks”. In: Ferows, K., *Managing International Manufacturing*. Amsterdam: Elsevier Scientific Publishing Co.

FERDOWS, K.; DE MEYER, A (1988): “Lasting improvements in manufacturing performance: In search of a new theory”. In: Journal of Operations Management, Vol. 9 (2), pp. 168-184.

FINE, C.H. (1998): *Clockspeed: winning industry control in the age of temporary advantage*. New York: Basic Books.

FINE, C. H. (2003): "Clockspeed-Based Strategies for Supply Chain Design". In: Malone, T.W.; Laubacher, R.; ScottMorton, M.S. (Eds.): *Inventing the Organizations of the 21st Century.* The MIT-Press, pp. 205-217.

FLAHERTY, M.T. (1989): "Coordinating international factory networks". In: Ferdows, K., *Managing International Manufacturing*. Amsterdam: Elsevier Scientific Publishing Co.

FOSTER, R.N. (1982): *A Call for vision in Managing Technology*: *McKinsey Quarterly Summer*. New York: McKinsey and Company, Inc.

FOSTER, R.N. (1986): *Innovation: The Attackers' Advantage*. New York: Summit Books.

FRAZIER, G.L.; SPEKMAN, R.E.; O'NEAL, C.R. (1988): "Just-in-time exchange relationships in industrial markets". In: *Journal of Marketing,* Vol. 52 (4), pp. 52-67.

FROHLICH, M.T.; WESTBROOK, R. (2001): "Arcs of integration: An international study of supply chain strategies". In: *Journal of Operations Management*, Vol. 19, pp. 185-200.

GARUD, R.; NAYYAR P.R.; SHAPIRA, Z. (1997): *Technological Innovation Oversights and Foresights*. Cambrige, New York: Cambridge University Press.

GORT, M.; KLEPPER, S (1982): "Time paths in the diffusion of product innovations". In: *Economic Journal*, Vol.92 (367), pp. 630-653.

GOTTARDI, G. (1996): "Technology strategies, innovation without R&D and the creation of knowledge within industrial districts". In: *Journal of Industry Studies,* Vol. 3 (2), pp. 119-134.

GRABHER, G. (1993): "The weakness of strong ties: The lock-in of regional development in the Ruhr Area". In: Grabher, G (Ed). *The embedded firm on the Socioeconomic of industrial networks*. London: Routledge, pp. 255-277.

GREGOR, S. (2006): "The nature of theory in information systems". In: *MIS Quarterly*, Vol. 30 (3), pp. 611-642.

HANDFIELD, R.; MELYNK, S. (1998): "The scientific theory-building process: a primer using the case of TQM". In: *Journal of Operations Management*, Vol. 16 (4), pp. 320-339.

HARDOCK, P. (2000): *Produktionsverlagerung von Industrieunternehmen ins Ausland – Formen, Determinanten, Wirkung*. Mannheim: Universität Wiesbaden (Dissertation), Deutscher Universitätsverlag.

HÄRTEL, H-H.; JUNGNICKEL, R. (1996): *Grenzüberschreitende Produktion und Strukturwandel*. Wiesbaden: Deutscher Universitätsverlag.

HAYES, R.H.; WHEELWRIGHT, S.C. (1984): *Restoring our competitive edge*. New York: Wiley.

HEIDE, J.B. (1995): "Performance implications of buyer-supplier relationships in industrial markets: A transaction cot explanation". In: *Journal of Business Research,* Vol. 32 (1), pp. 24-36.

HELPER, S. (1991): "How much has really changed between US automakers and their suppliers". In: *Sloan Management Journal*, Vol. 15 (6), pp. 15-28.

HENDERSON, R.M.; CLARK, K.B. (1990): "Architectural Innovation: The Reconfiguration of Existing Product Technologies and the Failure of Established Firms". In: *Administrative Science Quarterly,* Vol. 35.

HENDRICKS, K. B.; SINGHAL, V. R. (2003): "The effect of supply chain glitches on shareholder wealth". In: *Journal of Operations Management,* Vol. 21, pp. 501-522.

HEWLETT PACKARD (2004): "Ein Partner für den geschäftlichen Wandel". URL: http://h20219.www2.hp.com/services/cache/13424-0-0-82-150.html [Status: April 2004].

HILL, T. (2000): *Manufacturing Strategy, Text and Cases*. R.D. Irwin, Homewood, IL.

HINES, P.; RICH, N.; BICHENO, J.; BRUNT, D.; TAYLOR, D.; BUTTERWORTH, C.; SULLIVAN, J. (1998): "Value stream management". In: *International Journal of Logistics Management*, Vol. 9 (1), pp. 24-42.

HIRST. P.; ZEITLIN, J (1991): "Flexible specialization versus post-Fordism: Theory, evidence and policy implications". In: *Economy and Society*, Vol. 20 (1), pp. 1-56.

HOLLAND, C.; LOCKETT, G.; BLACKMAN, L. (1992): "Planning for electronic data interchange". In: *Strategic Management Journal*, Vol. 13, pp. 539-550.

HOMBURG, C.; GIERING, A. (1996): "Konzeptualisierung und Operationalisierung komplexer Konstrukte". In: *Marketing – Zeitschrift für Forschung und Praxis*, Vol. 18 (1), pp. 5-24.

HUTCHINSON, J. (1991): "Current and future issues concerning FMS scheduling". In: *Omega, The International Journal of Management Science*, Vol. 19 (6), pp. 529-719.

IANSITI, M. (2007): "The regulation of innovation and economic growth. Assimilation, Specialization, and the technology life cycle". URL: http://innovationforum.gmu.edu/papers/iansiti.pdf [Status: Nov. 2007].

JAWORSKI, B.J.; KOHLI, A.K. (1993): "Market orientation: Antecedents and consequences". In: *Journal of Marketing*, Vol. 57, pp. 53-70.

JOHNSTON, D. A.; MCCUTCHEON, D. M.; STUART, F. I.; KERWOOD, H. (2004): "Effects of supplier trust on performance of cooperative supplier relationships". In: *Journal of Operations Management*, Vol. 22 (1), pp. 23-38.

KICKERT, W.J. (1985): "The magic world of flexibility". In: *International Studies of Management and Organization*, Vol. 14 (4), pp. 6-31.

KIM, J. (1999): "Causation". In: Audi R., *The Cambridge Dictionary of Philosophy* Cambridge, UK: Cambridge University Press, pp. 125-127.

KIM, Y.; LEE, J. (1993): "Manufacturing strategy and production systems: An integrated framework". In: *Journal of Operations Management*, Vol. 11 (1), pp. 3-15.

KINKEL, S.; JUNG-ERCEG, P.; LAY, G. (2002): "'Auslandsproduktion – Chance oder Risiko für den Produktionsstandort Deutschland?', Stand, Entwicklung und Effekte von Produktionsverlagerungen im Verarbeitenden Gewerbe". In: *Mitteilungen aus der Produktionsinnovationserhebung*, Vol. 26. Karlsruhe: Fraunhofer ISI.

KIRK, J.; MILLER, M.L. (1986): *Reliability and Validity in Qualitative Research*. Beverly Hills: Sage.

KODAMA, F. (1991): *Emerging Patterns of Innovations. Sources of Japan's technological edge*. Boston: Harvard Business School Press.

KÖNIG, S. (1996): "Management wandelbarer Produktionsnetzwerke". In: Warnecke, H.J.; Bullinger, H.J: *Gewinnen am Standort Deutschland – Beispiele für Quantensprünge*. Berlin, Heidelberg, New York: Springer.

KÖRBER, C.; GRÖPKE, S.; SALLABA, G.; DENGLER, T. (2003): „Typologisierung von Fabriken: Ein Element der strategischen Zielplanung". In: Schenk, M./ Schulte, H. (Eds): *Schriftenreihe ProTT*, Vol. 3, pp. 1-87

KOPPIUS, O.; VAN HECK, E. (2005): „Supply and demand driven coordination in smart business networks". In: Veryest, P.H.M.; Van Heck, E.; Preiss, K.; Pau, L. (Eds): *Smart Business Networks*, pp. 273-288, Berlin: Springer.

KOTHA, S.; ORNE, D. (1989): "Generic manufacturing strategies: a conceptual synthesis". In: *Strategic Management Journal*, Vol. 10, pp. 211-231.

KRACKLAUER, A.; MILLS, D.Q.; SEIFERT, D. (2002): *Kooperatives Kundenmanagement. Wertschöpfungspartnerschaften als Basis erfolgreicher Kundenbindung*. Wiesbaden: Gabler.

KREIKEBAUM, H. (1998): *Organisationsmanagement internationaler Unternehmen. Grundlagen und Strukturen*. Wiesbaden: Gabler.

KUHN, A.; HELLINGRATH, B. (2002): *Supply Chain Management, Optimierte Zusammenarbeit in der Wertschöpfungskette*; Berlin, Heidelberg, New York: Springer.

KULP, S. C.; LEE, H. L.; OFEK, E. (2004): "Manufacturer Benefits from Information Integration with Retail Customers". In: *Management Science*, Vol. 50 (5), pp. 431-444.

LEE, H.L.; BILLINGTON, C., (1992): "Managing supply chain inventory: Pitfalls and opportunities". In: *Sloan Management Review* 33 (3), pp. 65-73.

LEE, H.L.; PADMANABHAN, V.; WHANG, S. (1997): “Information distortion in a supply chain: The bull-whip effect”. In: *Management Science*, Vol. 43, pp. 546-558.

LITTER, D.; LEVERICK, F.; BRUCE, M. (1995): “Factors Affecting The Process Of Cooperative Product Development: A Study Of UK Manufacturers Of Information And Communication Technology Products”. In: *Journal Of Product Innovation Management*, Vol. 12 (1), pp. 16-23.

LOCH, C.H.; DE MEYER, A.; VAN DER HEYDEN, L.; VAN WASSENHOVE, L.N. (1998): Management quality, continuous improvement and growth in the factory. INSEAD Working Paper, March.

LOCH, C.; VAN WASSENHOVE, L.; VAN DER HEYDEN, L.; HUCHZERMEIER, A.; ESCALLE, C. (2003): *Industrial Excellence. Management Quality in Manufacturing*. Berlin: Springer.

MARKIDES, C. (2006): “Disruptive innovation: In need of better theory”. In: *Journal of Innovation Management*, Vol. 23, pp. 19-25.

MARKLAND R.E.; VICKERY S.K.; DAVIS R.A. (1995): *Operations Management*. Cincinnati, Ohio: South-Western College Publishing.

MCGAHAN, A.M.; ARGYRES, N.; BAUM, J.A.C. (2004): “Context, Technology and Strategy: Forging new perspectives on the industry life cycle”. In: *Business Strategy Over the Industry Life Cycle. Advances in Strategy Management*, Vol. 21, pp. 1-21.

MEREDITH, J. (1998): “Building operations management theory through case and field research”. In: *Journal of Operations Management*, Vol. 16, pp. 441-454.

MEYERS, (2006): Meyers Großes Taschenlexikon; Bibliographisches Institut: Mannheim; Vol. 10.

MILLER, J.; ROTH, A. (1994): “A taxonomy of manufacturing strategies”. In: *Management Science*, Vol. 40, pp. 285-404.

MILLSON, M.R.; RAJ, S.P.; WILEMON, D. (1992): “A survey of major approaches for accelerating new product development”. In: *Journal of Product Innovation Management*, Vol. 9, pp. 53-69.

MITCHELL, A.; BAUER, A.W.; HAUSRUCKINGER,G. (2003): *The New Bottom Line: Bridging the Value Gaps that are Undermining Your Business*. Sussex, England: Capstone Pub.

MOHR, J.; SENGUPTA, S.; SLATER, S. (2001): *Marketing of high-Technology Products and Innovations*. New Jersey, USA: Pearson Education International.

MOHR, J.; SENGUPTA, S.; SLATER, S (2004): Marketing of High-Technology Products and Innovations (2nd Edition); Prentice Hall

MORIARTY, R.; KOSNUK T. (1989): *High-Tech versus Low-Tech marketing: Where’s the Beef?. Boston:* Harvard Business School.

MOORE, G. A. (2002): *Crossing the chasm: Marketing and selling high-tech goods to mainstream customers*. New York, USA: Harper Business,

NARASIMHAN, R.; JAYARAM, J. (1998): "Causal linkages in supply chain management: an exploratory study of North American manufacturing firms". In: *Decision Sciences*, Vol. 29 (3), pp. 579-605.

NASSIMBENI, G. (2002): "Local manufacturing systems and global economy: are they compatible? The case of the Italian eyewear district". In: *Journal of Operations Management*, Vol. 21, pp. 151-171.

NORMAN D.A. (1998). *The Invisible Computer*. 2nd. Chapter. Cambridge, Massachusetts, London, England: The MIT Press.

NOTEBOOM, B. (1999): *Interfirm Alliances: Purpose, Design and Management*. London: Rutledge.

NUNEN, J.A.E.E.; ZUIDWIJK, R.A.; MOONEN, H.M. (2005): "Smart and sustainable supply chains". In: Veryest, P.H.M; Van Heck, E.; Preiss, K.; Pau, L. (Eds.): *Smart Business Networks*, pp. 159-170, Berlin: Springer.

PACKARD, D. (1995): "*The HP way- how Bill Hewlett and I built our company*". NEW YORK.: HARPER BUSINESS

PETERSON, R.R.; PARKER, M.M.; RIBBERS, P.M.A. (2003): Information technology governance processes under environmental dynamism: Investigating competing theories of decision making and knowledge sharing. In: *Proceeding of the international Conference on Information Systems (ICIS).* 23rd International Conference on Information Systems, Barcelona, Spain.

PFEFFER, J. (1982): *Organizations and organization theory*. Marshfield. MA: Pitman.

PICOT, A.; REICHWALD, R. (1999): "Führung in virtuellen Organisationsformen". In: Nagel K.; Erben R.F.; Piller, F.T. (Eds.): *Produktionswirtschaft 2000*, Wiesbaden: Gabler.

PIORE, M.; SABEL, C. (1984): *The second industrial divide*. New York: Basic Books.

POPPER, E.T. (1992): "Industrial Marketing Management". New York: Elsevier Science Publishing Co. pp. 23-31.

PORTER M. (1985): "The Value Chain and Competitive Advantage". In: *Competitive Advantage*, pp. 33-61.

PORTER, M.E. (1980): *Competitive Strategy*. New York: Free Press.

PORTER, M.E. (1981): "The contribution of industrial organizations to strategic management". In: *Academy of Management Review*, Vol. 6, pp. 609-620.

PORTER, M.E. (1985): *Competitive Advantage*. New York: Free Press.

PORTER, M.E. (1990): *The Competitive Advantage of nations*. New York: Free Press.

PORTER, M.E. (1998): *On competition*. Boston: Harvard Business School Press.
POWELL, T.C., (1995): "Total quality management as competitive advantage: a review and empirical study". In: *Strategic Management Journal*, Vol. 16, pp. 15-17.
PRAHALAD, C. K.; HAMEL, G. (1994): "Strategy as a Field of Study: Why Search for a New Paradigm". In: *Strategic Management Journal*, Vol. 15 (5), special edition: summer 1994, pp. 5-16.
PRASAD, S.; BABBAR, S. (2000): "International operations management research". In: *Journal of Operations Management,* Vol. 18, pp. 209-247.
RAJU, P.S. (1995): "Consumer behavior in global markets: The A-B-C-D paradigm and its application to Eastern Europe and the third world". In: *Journal of Consumer Marketing*, Vol. 12 (5), pp. 37-57.
RING, P.S.; VAN DE VEN, A.H. (1992): "Structuring cooperative relationships between organizations". In: *Strategic Management Journal*, Vol. 13 (7), pp. 483-498.
ROGERS E.M. (2003): *Diffusion of Innovations.* Fifth Edition. New York, NY: Free Press.
RYANS, J. K.; SHANKLIN, W. L. (1984): "Ten Mega trends of High Technology Market Behavior". In: *Business Marketing*, Vol. 69 (9), pp. 100-106.
SAKO, M. (1992): *Prices, Quality and Trust: Inter-firm Relations in Britain and Japan*. Cambridge: Cambridge University Press.
SCHENK, M.; WIRTH, S. (2004): *Fabrikplanung und Fabrikbetrieb. Methoden für die wandlungsfähige Fabrik*. Berlin, Heidelberg: Springer.
SCHUH, G.; STRACK, J., (1999): "Virtualität in der produzierenden Industrie". In: *Technology & Management*, Vol. 48 (1/99), pp. 10-14.
SCHWAB, D.P. (1980): "Construct validity in organizational behavior". In: Staw B.M.; Cummings L.L. (Eds): *Research in Organizational Behavior*, Greenwich, CT: JAI Press, Vol. 2, pp. 3-43.
SCHUMPETER, J.A. (1939): *Business Cycles: A Theoretical, Historical and Statistical Analysis of the Capitalist Process.*
SEISING, R. (2005); *Die Fuzzifizierung der Systeme. Die Entstehung der Fuzzy Set Theorie und ihrer ersten Anwendungen – Ihre Entwicklung bis in die 70er Jahre des 20. Jahrhunderts,* Vol. 54, Stuttgart: Franz Steiner Verlag
SETHI, A.K.; SETHI, S.P. (1990): "Flexibility in manufacturing: a survey". In: *The international Journal of Flexible Manufacturing Systems*, Vol. 2, pp. 289-328.
SHANKLIN, W.L.; RYANS, J.K. (JR.) (1985): *Marketing High Technology*, Toronto, Canada: D.C. Heath and Company.
SHANKLIN, W.L.; RYANS, J.K. (JR.) (2001): *Organizing for high-tech marketing*. Boston, USA: Harvard Business Review.

SHI, J.; GREGORY, M. (1998): “International manufacturing networks – to develop global competitive capabilities”. In: *Journal of Operations Management*, Vol. 16, pp. 195-214.

SKINNER, W. (1969): “Missing the links in manufacturing strategies”. In: Voss, C.A. (Ed), *Manufcturing Strategy: Process and Content*, pp. 13-25, London: Chapmann & Hall.

SKINNER, W. (1974): “The focused factory”. In: *Harvard Business Review*, May-June, pp. 112-121.

SLATER, S.F.; NARVER, J.C. (1994): “Does competitive environment moderate the market orientation-performance relationship?”. In: *Journal of Marketing*, Vol. 58, pp. 46-55.

STANK, T.P.; GOLDSBY, T.J.; VICKERY, S.K. (1999): “Effect of service supplier performance on satisfaction and loyalty of store managers in the fast food industry”. In: *Journal of Operations Managemen,* Vol. 17 (4), pp. 429-448.

STEVENS, G (1989): “Integration of the supply chain”. In: *International Journal of Physical Distribution and Materials Management*, Vol. 19 (8), pp. 3-8.

STILLER, A. (2001): “Fröhliche Oldies. Der PC feiert seinen 20sten Geburtstag”. In: Computer Magazine, Vol. 18/2001 (16), pp. 172-177.

STUART, I.; MCCUTCHEON, D.; HANDFIELD, R.; MCLACHLIN, R.; SAMSON, D. (2002): “Efficient case research in operations management: a process perspective”. In: *Journal of Operations Management*. Vol. 20, pp. 419-433.

SWINK, M.L. (1998): “A tutorial on implementing concurrent engineering in new product development programs”. In: *Journal of Operations Management*, Vol. 16 (1), pp. 103-116.

TEECE, D.J.; PISANO, G. (1994): “The dynamic capabilities of firms: An introduction”. In: *Industrial and Corporate Change*, Vol. 3 (3), pp. 537-556.

TEICH, T. (2003): *Extended Value Chain management*. Chemnitz: Verl. der GUC (Habilitationsschriften 1).

TELLIS, W (1997): “Application of a Case Study Methodology”. In: *The Qualitative Report*, Vol. 3 (3). URL: http://www.nova.edu/ssss/QR/QR3-3/tellis2.html [Status: Dec. 2006].

TUSHMAN, M.L.; O’REILLY, C.A. (2002): *Winning Through Innovation: A Practical Guide to Leading Organizational Change and Renewal.* In: Harvard Business School Press.

TWISS, B.C. (1992): *Forecasting for Technologist and engineers*, UK: Peter Peregrinus Ltd. on behalf of the Institution of Electrical Engineers.

US CONGRESS, OFFICE OF TECHNOLOGY ASSESSMENT *(1982): Technology, Innovation, and Regional Economic Development,* WASHINGTON DC.

UPTON, D.M. (1994): "The management of manufacturing flexibility". In: *California Management Review*. Vol. 36 (2), pp.72-89.

UTTERBACK, J.; KIM, L. (1985): "Invasion of a stable business by radical innovation". In: Kliendorfer P., *The Management of Productivity and Technology in Manufacturing*, New York: Plenum.

UTTERBACK, J.M. (1996): *Mastering the Dynamics of Innovation*. Boston, USA: Harvard Business School Press.

UTTERBACK, J.M.; ABERNATHY, W.J. (1975): "A Dynamic Model of Process and Product Innovation". In: *Omega, The International Journal of Management Science*, Vol. 3 (6), Great Britain: Pergamon Press.

VERDUJIN, T. (2004): DYNAMISM IN SUPPLY NETWORKS: ACTOR SWITCHING IN A TURBULENT BUSINESS ENVIRONMENT. TRAIL DISSERTATION SERIES T2004/5, DELFT, THE NETHERLANDS: THE NETHERLANDS TRAIL RESEARCH SCHOOL.

VERVEST, P. PREISS, K. VAN HECK, E. PAU, L. (2005): "The emergence of smart business networks". In: Vervest, P.H.M; Van Heck, E.; Preiss, K.; Pau, L. (Eds.): *Smart Business Networks*, pp. 19-30, Berlin: Springer

VOSS, C. (1988): "Success and failure in advanced manufacturing technology". In: International Journal of Technology Management, Vol. 3 (3), pp. 285-296.

WALKER, G.; POPPO, L. (1991): "Profit centers, single-source suppliers, and transaction costs". In: *Administrative Science Quarterly*, Vol. 36 (1), pp. 66-87.

WATTS, C.A.; HAHN, C. (1993): "Supplier development programs: an empirical analysis". In: *International Journal of Purchasing and Materials Management*, Vol. 29 (2), pp. 2-8.

WEINER, M.; NOHRIA, N. (1997): "Value networks – the future of the US electric utility industry". In: *Sloan Management Review*, Vol. 38 (4), pp. 21-35.

WEIS, H.C (2007): *Marketing*; 12th edition; Ludwigshaven: Friedrich Kiehl.

WERNER, B.; THORN, J. (2003): "Cooperative supply chain planning". In: *WiSt*, Vol. 10, pp. 590-595.

WIENDAHL, H.-P. (2001): *Maßgeschneiderte Fabriken im Dienste des Kunden.* Tagungsband 3. Deutsche Fachkonferenz Fabrikplanung. Stuttgart.

WILLIAM J. ABERNATHY AND JAMES M. UTTERBACK, "Patterns of Innovation in Industry," Technology Review, Vol. 80, No. 7, June-July 1978, pp. 40-47.

WOLTERS, M.J.J.; VERVEST, P.H.M.; VAN HECK, E. (2005): "Building networks in-sync". In: Vervest, P.H.M; Van Heck, E.; Preiss, K.; Pau, L. (Eds.): *Smart Business Networks*, pp. 211-224, Berlin: Springer.

WRIGHT, M. (2003): "Standardization leads to global markets". In: *Semiconductor International*, Vol. 26 (6), p. 118.

YIN, R.K. (2002): *Applications of Case Study Research*. 2nd edition, Vol. 34. London: Sage Publications.

YIN, R.K. (2003): *Case study research: design and methods*. 3rd edition, Vol. 5. London: Sage Publications.

YIP, G. S. (1992): *Total Global Strategy: Managing for Worldwide Competitive Advantage*, Englewood Cliffs: Prentice Hall.

ZADECK, H. (2001): "Strategische Neuausrichtung von Logistikdienstleistern Steuern globaler Produktions – und Dienstleistungsnetzwerke". In: *Industrie Management*, Vol. 5, pp. 28-31.

ZAHEER, A.; VENKATRAMAN, B. (1995): "Relational governance as an inter-organizational strategy: an empirical test of the role of trust in economic exchange". In: *Strategic Management Journal*, Vol. 16 (5), pp. 373-392.

ZHANG, Q. (2001): *Technology infusion enabled value chain flexibility: a learning and capability-based perspective*. Unpublished dissertation. Toledo, OH: The University of Toledo.

ZHANG, Q.; VONDEREMBSE, M.A.; LIM, J.S. (2003): "Manufacturing flexibility: defining and analyzing relationships among competence, capability, and customer satisfaction". In: *Journal of Operations Management*, Vol. 21, pp. 173-191.

APPENDIX I-IX

Appendix I - Research Plan

Overall schedule
Detailed action list
A. Introduction to the research

- A1 Letter of introduction
- A2 Idea and relevance of the research
- A3 Research questions and proposition

B. Field procedure

- B1 Name of sites, contact persons
- B2 Schedule (site visits)
- B3 Preparation work per site
  - Pre information per site
  - Contact persons per site
  - Tools needed for interviewing

C. Data collection

- C1 Case study questions outline
- C2 Format of data collection table including data reference system (database)
- C3 Sources of information

A. Introduction to the Research – A1 Letter of introduction

We appreciate your willingness to support our research on manufacturing strategies within the high-tech electronics business. We strongly believe that in many cases transitions of local factories into off-shore countries were taken too early. Our intent is to find out how factories within Central Europe ("local factories") have to adapt scales of functions and related competences during their factory life cycle to continuously contribute to the competitive strategy of the company. This is especially important in the later stages, when the product technology matures.

Because of certain criteria, your company was selected as a case to be analyzed. Your help would therefore contribute significantly to our research.

We would very much appreciate it if meetings could be arranged within the areas of Supply Chain Management, Manufacturing Management, Sales or Marketing. We would be pleased if one or two senior persons per function would be available for one hour, and if those persons would have many years of experience with the company (to also collect historical data). All other sources of information would also be appreciated (organization charts, reports, presentations, documentation, papers).

The outcome of the research will be sent to you and a personal presentation of the results will be offered by the research team. Confidential information will be treated as appropriate.

Background

Local manufacturing has been increasingly off-shored to low-cost countries. If these decisions are taken too early, companies are likely to lose competitive ground.

Idea: We want to prove that each factory adds to a company's success if it passes through different "capability phases" (at least within the high-tech industry). We believe that the capability transition from phase to phase (from one type of factory to another) is driven by the environmental changes explained by the TLC.

Understanding this relationship allows manufacturing and supply chain managers to take decisions earlier about future roles and capabilities of their local factories and determine how these factories will continuously support the competitive position of the company.

Major interview questions (for information only)

General Management (TLC)

What have been the major goals and strategies of the factory over time (i.e., high-tech focus, low cost, speed, services, networking)?

What was the trigger of change between each phase?

Which manufacturing capabilities within the local factory had been developed over time?

How did the rate of technological evolution evolve over time? Please distinguish between process technology and product technology.

Please draw a timeline of the frequency of changes in product technology within the industry. When was change rather minor? When was it rapid?

How did management focus change related to manufacturing processes versus supply chain process? When was it important, when not so important?

Please draw a timeline showing how the product design evolved: from no or minor consensus within the industry about product design and product technology to having a dominant design within the industry. How did the company differentiate there?

How/when did customer behavior change over time? What was important for them when (Technology demand/price sensitivity/solutions and services/design and easiness of usage) – from not important to important?
How/when did the number of competitors change over time?
What was the role of vendors and service providers over time? When did they play an important role? How/when did the capabilities of the suppliers change over time?
How would you describe the profit situation of your business over time?

Operations Management

How did the manufacturing depth of the local factory evolve over time?
How did the factory system evolve (push, pull, craft production, mass production mass-customization)?
What was the role and thus the competitive situation from a technological perspective of the local factory?
Which cost-saving approaches have been developed over time (when) and what was the contribution of the local factory?
Please outline how customer cycle time expectations changed over time for standard and individual products.
How did the factory delivery cycle time change over time?
At what point did customers expect, respectively, a perfect product, perfect fulfillment and custom solutions and services?
How did the focus change over time concerning collaboration with internal organizations?
How did the external integration level evolve? How would you, in general, describe the level of integration of the local factory with customers and with suppliers over time?
What was the role and thus the competitive situation from a business network management perspective of the local factory?

B. Field procedure – B1 Name of sites, contact persons (management level)

HP Case

- Factory Manager Europe – Hendrik Brumme (Writing down my own experience)
- European SC Manager – Hans-Peter Straub
- Worldwide Supply Chain Manager – Tom Viola
- European Procurement Manager and former Manufacturing Manager - Heinz Schmid
- Literature and articles

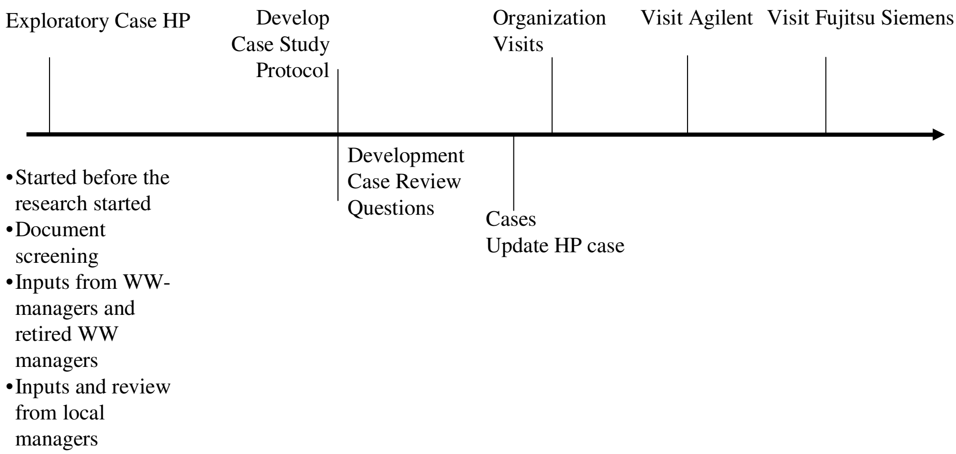
FSC Case

- Manufacturing – Walter Degle
- Supply Cain – Karlheinz Czauderna
- Marketing/Sales – Rolf Kleinwächter
- Literature and articles

Agilent Case

- Business Unit Manager – Jürgen Beck
- Marketing Manager – Andreas Gerster
- Manufacturing Manager – Dietmar Mugele
- Supply Chain Manager – Dieter Kindermann
- Literature and articles

B. Field procedure – B2 Schedule and preparation work per site – Overall Schedule



Appendix II - Interview Protocol
Introduction Question, TLC Questions; OM Questions

Main Question	
Interview Protocol	
Date:	
Interviewee information	Division
Industry	Company
Name of interviewee	Job title
Years in position	Years with company
Years in manufacturing	
	Telefon and E-Mail:
8.1.1 General environmental forces within the computer server industry	
Some figures: revenues, # of people, business segments,	
Funded in, place	
Major innovations	
Describe the general situation in this business. What were the general challenges. Refer to Fine.	
Major areas in the history (mergers, spin offs, new businesses etc, new product technologies…)	
8.1.1 Supply chain evolution overview	
Locations of factories and businesses over time	
Role of factories over time;	s. detailed questions
IT-Systems	
Procurement systems	
Major suppliers and contractors	
Major sales and distribution partners	
8.1.2 Factory evolution overview	
What is the factory producing right now: Revenues, #, products, employees,	
Production range	
Volume fluctuations	
Major capabilities today	
Idea and objectives of the factory over time	
Summary of the major evolution steps (capabilities) without naming them (velocity factory etc)	
Summary of what were important external changes/ What happended over time and What were the major reasons	
What had been the major capabilities of the factory over time and mgmt tools developed over time	
Elements evolution	
Product design: Major technical achievements and major DFx achievements	
Sourcing process	
Order fulfilment process (what was important: flexibility, speed etc)	
IT-System design	

				How would you describe the "independent variables" over its life time				
				What were the major forces influencing this variable				
				How would you rate and characterize an "independent variables" during certain time frames (When what insensitivity of a				
1	Mktg Manager	Mfg-Manager	SCM	Market and Customers Reference No	Main Question	Detailed Question	Detailed Question 2	Data Source
2	x			TC1	How would you describe the change in customer behavior over time. What was important for them when *(Technology demand/ Price sensitivity/ Solutions and services / design and easiness of usage)* - from not important to important? Please splitt into the relevant time frames (from opportunistic to sophisticated)			TLC-Table
3	x	x		TC2	What were the major forces influencing the process technology evolution			
10	x			TC3	How would you describe the market evolution over time: *- Revenues* *- Behaviors /Order Fluctuations* Please split into the relevant time frames			
11	x			TC4	How would you describe the market evolution from a customer perspective: *From Specialist to growth to saturation.* Please split into the relevant time frames			?
16	x			TC01		How would you rate and characterize (in time frames): - MARKET	When was the market in your industry only interesting for specialists and how was the profit situation.	TLC-Table and Enders
17	x			TC02		How would you rate and characterize (in time frames): - MARKET	When was the market in your industry growing.	TLC-Table and Enders
18	x			TC03		How would you rate and characterize (in time frames): - MARKET	When was the market in your industry saturated and price competiton became a major factor	TLC-Table and Enders
4	x			TC04		How would you rate and charaterize (in time frames):	"the technology demand of customer": the importance of technology and the accepting of inconveniance	TLC-Table
5	x			TC05			the price sensitivty (high)	TLC-Table
6	x			TC06			the convenience, solutions and services demand: (importance)	TLC-Table
7	x			TC07			the importance of easiness of usage (or deisgn)	TLC-Table

9	Mktg Manager	Mfg-Manager	SCM	Market, Partners, Competitors Reference No	Main Question	Detailed Question	Detailed Question 2	Data Source
12		x	x	TM1	How would you describe the role of vendors and service providers over time. Indicate their changing roles and capabilities and how important they were for you. Please split into the relevant time frames (from opportunistic to sophisticated)			?
13	x	x	x	TM2	How would you describe the role of competitors over time. Indicate their changing roles and capabilities. Please split into the relevant time frames (from opportunistic to sophisticated)			?
14	x		x	TM3	How would you describe the role of channel partners over time. Indicate their changing roles and capabilities and how important they were for you. Please split into the relevant time frames (from opportunistic to sophisticated)			?
15	x			TM4	What were the major forces influencing the market evolution			?
19	x			TM01		How would you rate and characterize (in time frames): - COMPETITOR	When was competition in your industry not existent /weak to ruthless (Enders)	Enders
20	x			TM02		How would you rate and characterize (in time frames): - COMPETITOR	When did competition in your industry become ruthless (Enders) Since when can you say: One hears of a new competitive move almost every day (Enders)	Enders
21	x			TM03				Enders
22		x		TM04		How would you rate and characterize (in time frames): - SUPPLIERS	Inbound: How/ when did the number of suppliers change over time (Brumme) - whats about their capabilities	Brumme
23		x		TM05		How would you rate and characterize (in time frames): - SUPPLIERS	Inbound: Suppliers were capable and a major force	Brumme
24	x		x	TM06		How would you rate and characterize (in time frames): - PARTNERS	Outbound: How/ when did the number of channel partner change over time (Brumme)	Brumme
25	x		x	TM07		How would you rate and characterize (in time frames): - PARTNERS	Outbound: Partners were integrated in the operational processes - what capabilities	Brumme
26								

28	Mktg Manager	Mfg-Manager	SCM	Profit Reference No	Main Question	Detailed Question	Detailed Question 2	Data Source
29	x			T$1	How would you describe the price or margin evolution over time. Please split into the relevant time frames (from opportunistic to sophisticated)			?
30	x			T$2	What were the major forces influencing the prices / margins			
31	x			T$01		How would you rate and characterize (in time frames):	Wdhl: When did price competition become a characteristic of our industry (Enders)	Enders
32								
33								
34	Mktg Manager	Mfg-Manager	SCM	Process Technology Reference No	Main Question	Detailed Question	Detailed Question 2	Data Source
35	x	x		TT1	How would you describe the technological evolution of the manufacturing processes over time. - *Wie war das vor 25 Jahren: Welche Verfahren, was war wichtig, was war schwierig?* - *Wann kam das Thema SCM auf?* - Wie hat sich d. Fertigungstiefe entwickelt? Please splitt into the relevant time frames (from opportunistic to sophisticated)			Brumme
36		x		TT2	What were the major forces influencing the process technology evolution			
37	x	x		TT01		How would you rate and charaterize (in time frames):	the process technology providing big opportunities in your industry	Utterback / Enders
38		x		TT02			the difficulty to reach minimum quality expectations and yields	Enders
39			x	TT03			the importance of SCM	Utterback
40		x		TT04		When was manufacturing nearly 100% vertical integrated?		Brumme
41								

42	Mktg Manager	Mfg-Manager	SCM	Product Technology Reference No	Main Question	Detailed Question	Detailed Question 2	
43								
44	x			TP1	Product Design: How would you describe how the product design evolved: - From a design vor Mfg/ SCM perspective (also Modular design) - From a technological acceptence persp.: = from no or minor consensus within the industry about product design and product technology = to having a dominant design within the industry. - How did the company differentiate there?		*Nassimbeni deducts for products that "the end-product differs in* *- complexity,* *- variety,* *- maturity,* *- and volume,* *and equally in process mechanization, systemization and interconnection".*	TLC Allg
45	x			TP2	What were the major forces influencing the product technology evolution			
46	x	x		TP01		How would you rate and charaterize (in time frames):	the frequency of changes in product technology within the industry over time (when was it rather minor/ when did it change rapidly).	Enders
47	x		x	TP02			the modularisation and the use of plattforms over time	Brumme
48	x			TP03		Within the last years	when was product technological changes a big opportunities in your industry (Enders).	Enders
49				TP04			when was the technological developments in your industry not of imporatnce anymore (Enders).	Enders
50								

				Folgende Kriterien noch beschreiben: Wann welcher Interviewee - als nach welchem Schema habe ich die X verteilt. Gewichtungskriterien				
				How evolved the dependent variables" /What were the focus areas of the local factory over its life time (how changed something over time)				
				What were the major inhibitors influencing the decision processes				
				What was the competitive role of the local factory				
				How would you rate and characterize an "dependent variables" during certain time frames (When what insensitivity of a variable)				
				Why was it changed				
Nr	Mktg	Mfg-Manager	SCM	**Intro Question** 0 - Org. Capabilities Reference No	Main Question	Detailed Question	Comment	Data Source
1	X	X	X	**Org1**	How evolved the competitive preasure and what were the competitive differentiators over time *Wie hat sich der Druck auf die F. verändert und wie hat die F versucht, Wttbewerbsvorteil zu bleiben?*			
2		X		Org2	Which **process capabilities were developed** over time and Which processes were under **perfect control** within the local factoy over time (process mastery (Beherrschung): *Wettberwerbsfähigkeit: Wie wurde diese entwickelt* *z.B. Flexibilisierung;Kosten…*		**Nassimbeni (2003)** **First: manufacturing tasks,** which are - system flexibility and - flexible specialization volume, - variety, - process and material handling flexibility **Second: the manufacturing choices which represent** **- the strategies** which can be chosen for the manufacturing system. - the complexity of manufacturing technology, - the maturity of the processes and - the sophistication of the product and the production method.	Loch
3								
4								

OM

5				**1 - Mfg Technology** Reference No	Main Question	Detailed Question	Comment	Data Source
7	X	X	X	MT1	How evolved **the capabilities (the degree of innovation)** of the local factory over its life time (how changed something over time) *Welche Fähigkeiten (generell) wurden wann entwickelt und waren Fokus.* Warum?			
8		X	X	MT2	How evolved the **manufacturing depth** of the local factory over its life time (how changed something over time)			Brumme
9		X		MT3	What was the **manufacturing system strategy** *Wann wurden welche generellen Produktions-Konzepte eingeführt - warum:* - push, pull // - Craft Production, - Mass Production -mass-customization of the local factory over its life time (how changed something over time)			Loch
10		X	X	MT4	How evolved the manufacturing choices (the strategies which can be chosen for the manufacturing system) - what was when important: - the **complexity of manufacturing technology**, - the **maturity of the processes** and - the **sophistication of the product** and the production method. *Also etwas konkreter: Wie haben sich die Prozesse entwickelt bzgl. der oben genannten Charaktere?*			auch Körber s 10
11		X	X	MT5	What were the **major inhibitors influencing** the manufacturing strategy decision processes			
12	X	X	X	MT6	What was the **role and therwith the competitive contribution** from a technological perspective of the local factory?			Brumme

14		X	X	MT01		How would you rate and characterize an “the **importance** of the 4 competitive capabilities: **Quality, delivery, flexiblity; cos**t contribution during certain time frames (When what insensitivity of a variables) Why was it changed	How would you rate and characterize **- “the importance of quality & yield vs. Cost and investment" vs. - time to production** during certain time frames (When what insensitivity of a variables) Did you ever **compromise quality with cost**? Why was it changed	Körber
15		X		MT02		How would you rate and characterize the **process R&D investments** during certain time frames (When what insensitivity of a variable) Why was it changed		
16		X	X	MT03		How would you rate and characterize “**the complexity of processes vs. The complexity of products"** during certain time frames (When what insensitivity of a variables) Why was it changed		Körber
17								
18								

20	Mktg	Mfg-	SCM	2-Cost Control Reference No	Main Question	Detailed Question	Comment	Data Source
22				**See TLC**	*How evolved the price over time and especially:* *- When started the marekt to dictate the prices(how changed something over time)* *- When was product quality and OTD not a differentiator anymore _> price as major competitive tool*			Körber
23	X			**CC1**	How evolved the **cost as an important differentiato**r or what other differentiators did you include into the strategy over time			Loch
24		X	X	**CC2**	How evolved the **cost saving importance of the local factory** over its life time (how changed something over time) *Wie waren die Argumente bzgl. Kostenvorteile durch die LF*			Brumme Loch
25			X	**CC3**	How evolved the **cooperation along the total SC** to save cost of the local factory over its life time (how changed something over time)? What was done?			Körber s. 16
26	X	X	X	**CC4**	What were the major **inhibitors i**nfluencing the decision processes			
27	X	X	X	**CC5**	What was the **competitive contribution of the local factory** regarding cost efficiency			
28		X	X	CC01		How would you rate / when did you started to **carefully manage cost** / have tarket costing/ having low cost buildings and low cost labor etc (When what insensitivity of a variable) Why was it changed		Körber / Brumme
29		X		CC02		How would you rate /when did you started **to make fix cost variable** through workforce models, flex space models and flex mashinery models (When what insensitivity of a variable) Why was it changed		Brumme
30		X	X	CC03		How would you rate and characterize **the importance of Outsourcing from a cost perspective or off-shoring from a cost perspective**" during certain time frames ((please draw down the percentage of how much had been outsourced of the overall work over time)) Why was it changed		Körber s. 16
31		X	X	CC04		How would you rate the **integration of suppliers AND customers** into the cost targets and what role played the local factory here during certain time frames (When what insensitivity of a variable) Why was it changed		Körber s. 16
32								
33								

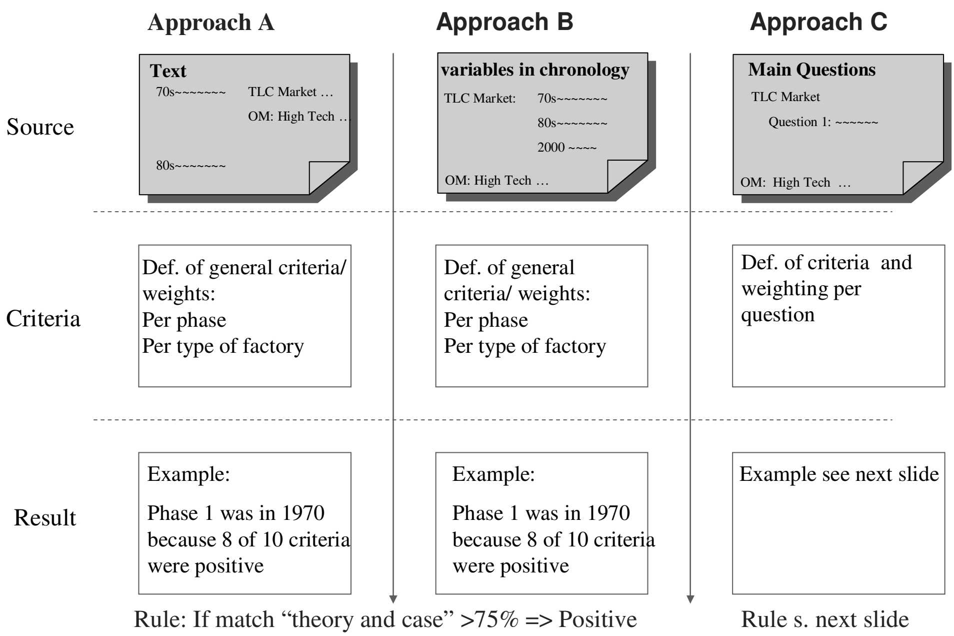
Mktg	Mfg-	SCM	**3 - Speed and Velocity** Reference No	Main Question	Detailed Question	Comment	Data Source
X		X	SV1	How evolved the **customer expectations regarding orderfulfilment cycle time** for standard and for individual customized products.			??
X	X		SV2	How evolved the effectiveness and **speed within the factory** **-** and what was done? for **standard and for individual** products. /What were the focus areas of the local factory over its life time (how changed something over time)			Körber
	X		SV3	How evolved **felxibilty** over time and why whas flexiblity important (to save cost or to increase speed?). (Die Athmende Fabrik) What was done? Processes - Highly flexible **ressources** (work force models etc) - Fractal factories (self organized teams) - Different qualification levels of the **employees** - **Modular layout** which can be adapted fast - Designed for **max capacity.** - Mass Production Products - Modules and **Push**/**Pull**		Zhang: How would you rate and characterize during certain time frames (When what insensitivity of a variable) the **flexibilty approaches:** 1. product development flexibilty (through a collaboration in-between Mfg and R&D)? 2. Machine flexibility 3. Labor flexibility 4. material handling and routing flexibility Comment: (9) Operational flexibility capabilities and competences: An important asset is flexibility of capabilities/ competences and capacity (Kickert, 1985, p 24). Value chain flexibility is what customers need which enables quick deliveries of a variety of high-quality, low- cost products. How were flexiblity capabilities of the LF evolving concerning the following items (s. sub question) and how supported the LF the competitive situation with that?	Körber and Zhang, 2001)
X	X	X	SV4	What were the major **inhibitors** influencing the decision processes			
X	X	X	SV5	What was the **competitive contribution** of the local factory from a speed perspective			
	X		SV01		How would you rate and characterize the **shop floor layout optimized for speed** during certain time frames (When what insensitivity of a variable) Why was it changed		HP Case Zhang
	X		SV02		How would you rate and characterize **the management of capacity** - flexibility and adaptability of workforce (skills and payment system), - machines and space) Why was it changed		HP Case Zhang
	X	X	SV03		How would you rate and characterize the **importance of total SC-speed** to control cost and improve customer satisfactoin and how contributed the LF? during certain time frames (When what insensitivity of a variable) Why was it changed		HP Case Zhang
	X	X	SV04		Did you **increase flexibilty to increase velocity**? If yes: How did you increase it (mshine flex; labor flex; routing flex; material handling flex; volume flex)?		

47	Mktg Manager	Mfg-Manager	SCM	**4 - Services, solutions and customer intimacy,** Reference No	Main Question	Detailed Question	Comment	Data Source
49	X		X	SS1	How/ why evolved the **customer expectations regarding orderfulfillment services** (i.e. no expectations, perfect product, OF services, solutions) How would you rate and characterize **customer binding from the factory** during certain time frames (When what insensitivity of a variable) How had the **different types of customers** (enterprise, channel partners, VARs, ISVs etc) been treated concerning fulfilment (special treatments vs. standard treatments)		Customer service is Pre-sales customer service is the ability to support the customer during their purchasing decision. Product support is the support of the customer after sales happened to ensure a continuing customer satisfaction. Responsiveness to customers measures the time how fast customers get informed, how fast their order is confirmed and the speed to react to customer complaints. Delivery dependability is the on-time of deliveries. Delivery speed	Körber Brumme Brumme
50	X	X	X	SS2	How evolved solution fulfilment over time - **What kind of solutions** did you offer? - **What kind of partners** were included into the solutions delivery process (HP-Case) and what was their contribution/ how did you collaborate - How was **sales included** - Why was it changed/ why had they been involved			Körber Brumme
51	X	X	X	SS3	What were the major **inhibitors influencing** the factory evolution regarding theses customer expectations			
52	X	X	X	SS4	What was the **competitive contribution** of the local factory regarding customer satisfaction and solutions and services			Körber
53	X	X	X	SS01		How would you rate and characterize product services delivery from the factory during certain time frames (When what insensitivity of a variable) Why was it changed		Brumme
54	X		X	SS02		How would you rate and charaterize the **customer expectations regarding a perfect product,** when in addition perfect fulfillment and when in addition custom solutions and services? Why was it changed		Körber
55		X	X	SS03		How did you built up the requested **flexiblity for solution fulfilment**		Körber
56	X	X		SS04		How would you rate and characterize **customer orientation witin the factory** over time (understanding of customers needs, direct communications to customers, measurement of customer feedback etc.) (When what insensitivity of a variable) Why was it changed		HP-Case

57	X	X		SS05		How would you rate and characterize **information sourcing on customers** preferences. What role played the local factory? (Shawnee et al., 2003) (Have you ever build cross-functional teams in-between customers and the local factory? during certain time frames (When what insensitivity of a variable) Why was it changed		(Shawnee et al., 2003)
58			X	SS06		How would you rate the importance of a poftfolio management over time		Körber
59			X	SS07		When did R&D develop modular structures to suppor solution fulfilment		Körber
60								
61								
62	Mktg	Mfg-	SCM	**5 - Network. & coop.** Reference No	Main Question	Detailed Question	Comment	Data Source
65		X	X	NC1	How evolved the **internal collabortation intensity** of the local factory over its life time (how changed something over time) Internal organizations, partners, vendors, customers) (when was this important and new and when did it become standard):			Körber Zhang Nassimbeni
66		X	X	NC2	How evolved the **external collabortation intensity** of the local factory over its life time (how changed something over time) Internal organizations, partners, vendors, customers) (when was this important and new and when did it become standard) **Did you develop an industry park** (Körber)/ The importance of complementary know-how		1. Inward facing: if only poor integration was measured in both directions. 2. Periphery facing: if either a more intense collaboration was measured with suppliers or with customers - but not with both / Joined R&D? 3. Supplier facing of an intense cooperation was measured with suppliers and a poor collaboration with customers. 4. Customer facing: if an intense cooperation was measured with customers and a poor collaboration with 5. Outward facin: total integration with customers and suppliers.	Frohlich(Frohlich and Westbrook, 2001)
67	X	X	X	NC3	What **role played the factory when within the global mfg-network:** - High-End complex product manfuacturing/ Global high-labor or low complex produ - Mfg-Process development and testing / Global operation if processes mature - Closeness to customers			
68	X	X	X	NC4	What were the major **inhibitors** influencing the collaboration processes			
69	X	X	X	NC5	What was the **competitive contribution** of the local factory			Brumme

70		X	X	NC01		How evolved the <u>external collabortation areas:</u> Körber: - Joint R&D - Complementary Know-How - Reconciling product planning - Standardization of process interfaces - Capacity sharing Frohlich: - Access to planning system, - Sharing production plans, - Joint EDI networks, - Knowledge of inventory mix and levels, - Packing customization, - Delivery frequencies, - Common logistics equipment and - The common use of 3rd party logistics		
71								
72			X	NC02		When and why did you start to **link your factory system with outbound system** partners of your supply chain to reduce your complexity and increase the overall flexibility, quality and time to market? Why was it changed		Körber Zhang Nassimbe ni
73		X	X	NC03		How would you rate and characterize the **development of virtual networks** during certain time frames (When what insensitivity of a variable) Why was it changed. What was the role of the factory		Körber HP-Case
74	X	X	X	NC04		How would you rate and characterize the I**nternal Integration level of the factory into sales and marketing:** What, how, why. (joint meetings, specialized services, communication links, PR of factory services, usage of the factory services; sales using the factory as a sales enabler (factory tours, meetings with factory staff etc) (HP-Case). during certain time frames (When what insensitivity of a variable) Why was it changed		HP-Case

Appendix III – Case structuring



Approach A

- Approach: Case is noted according to historical events (chronological), covering all areas of interest (variables) in a time period.
- Advantage: Easy to read flow of text; no redundancies within text; matches with open interview structure.
- Disadvantage: Complicated pattern matching process.
- Analysis: Pattern Matching is done via a uniform framework stated as Word tables (Yin, 2003; p. 134).

Approach B

- Approach: For each area of interest (variable), all events are noted in chronological context.
- Advantage: Pattern matching here is direct and simple because of the direct link "event to time".
- Disadvantage: Lots of redundancies in text because many strategies of the companies support several of our variables defined. Example: The workforce

model of HP supports the Low-cost factory and the Velocity factory (speed through flexibility).

- Analysis: Pattern matching. See "First dimension".

Approach C

- Approach: Questions and answers are directly linked.
- Advantage: This is used as a control process for major key areas (major questions). Pattern matching here is direct and simple because of the direct link to the question.
- Disadvantage: Since we used the open-ended interview technique (proposed by Yin, 2003; p. 89), answers might cover different and new areas than originally planned.
- Analysis: The criteria and weighting will be defined in detail before analyzing. We will use a scale (0, 1, 2) to see the strength of the variable (the weight) over time.

Appendix IV – A Criteria Database for the TLC Pattern Matching

Market: Customers							
Reference No	Main Question in Interview Protocol	**Parameters**	Phase 1	Phase 2	Phase 3	Phase 4	Phase 5
TC1	How would you describe the change in customer behavior over time. What was important for them when *(Technology demand/ Price sensitivity/ Solutions and services / design and easiness of usage)* - from not important to important? Please split into the relevant time frames (from opportunistic to sophisticated)	**Characteristics of customers (people)**	**- Innovators;** **who are product knowledgeable and able to buy based on their understanding of the products technologically attributes.** - who appreciate new ideas and likes to test them - who do not care about price. '- Customers have not jet developed their own sense of ideal product design Customer accepts the	**- Early adopters** **- who will buy nearly any new item, or whose needs for the newly developed functions are so greate that they are willing to put up with any other problems.** - They are not technologist; but find it easy to imagine, understand, and appreciate the benefits of a new technology, - who are quick to accept the function and benefits of new technology '- They buy into new	**- Early majority** **who like to accept new technology, but they are driven by a strong sense of practicality and want the most value of their money.** - who are driven by a strong sense of practicality (products must make practical sense to them). '- They are willing and able to become technologically capable	**- Pragmatic late adopters** **who wait until the new technology stabilizes** **-** even stronger focus on cost - they wait until something has become an established standard they are NOT willing and able to become technologically capable)	**- Laggards** who simply do not want anything to do with new technology. '- This people simply don't want to do anything with new technology
		Relevant to customers (They need/ demand/ focus on etc; They do not expect...)	**- Need: early access to latest technology and its performance** - They continue demanding better technology and higher performance. - Performance is more important than cost ------------------------------------- - Don't expect convenience - Don't expect special features or a final solution	**- They demand technical breakthroughs that will create an advantage** - The need new but not latest technology and it's performance. - They need lots of support	***- The start to demand good price / performance/ become cost oriented*** - they want to see well-established references before investing substantially	**- They start to expect services and solutions around the product or demand low prices (become cost oriented)** - When the technology reaches the point where it satisfied basic needs, then improvements in the technology makes no sense to them. At this time customers start to look for efficiency, reliability, low cost, and convenience: Thus: - They demand lots of support and tend to buy, therefore, from large, well-established companies.	**- This people simply don't need technology**

Market: Market Evolution							
Reference No	Main Question in Interview Protocol	**Parameters**	Phase 1	Phase 2	Phase 3	Phase 4	Phase 5
TC3	How would you describe the market evolution over time: - *Revenues* - *Behaviors /Order Fluctuations* Please split into the relevant time frames	**Market evolution and characteristics (growth)**	**- Niche market. Slow evolvement** - A specialist market where technical performance and function characteristics outweighs the unreliability and high cost	**- Market begins to grow** Product designs are focused upon the needs of particular groups of buyers. More competitors appear (see competitors) - Products begin to be accepted	**- Rapid growth** - Market for a bigger majority because products become easier to use - Market is transferred from supply side of high-tech marketing to demand side - Changes from technology push to market pull	**- Saturation evolves** - Market with biggest slize over ist life cycle; - The market is now driven by customer needs - Price and production cost: for granted (selbstverständlich) and look for price, prestige, appearance, convenience	**- The market my disappear entirely** -The market may disappear entirely or come up with a new technology for the same customer need.
		Marketing strategies	***-Testing of market niches*** *-"High-Tech" marketing: Focus on technology and performance;*	***- Some market niches identified.*** Customer needs become more clearly understood.	**- Companies offer products for specific customer segments**	**- Customer value** (or the ration quality to cost) becomes important companies try to customize their products, build complete solutions for their customers and offer services	**A new emerging technology starts** (market is being satisfied by a significantly different product solution). No market strategy.

Market: Competitors			mainly based on Moore (2002)				
Reference No	Main Question in Interview Protocol	**Parameters**	Phase 1	Phase 2	Phase 3	Phase 4	Phase 5
TM2	How would you describe the role of competitors over time. Indicate their changing roles and capabilities. Please split into the relevant time frames (from opportunistic to sophisticated)	**Strength of compeition**	**- # of competitors is small** - No real competition	***- More competitors appear***	***- # of competitors increases***	***- many competitors***	- **The market may disappears** entirely or be satisfied by a significantly different product solution
		Competitive strategies	- **Functional product performance** is the basis for competition	- **Functional product performance** is still the basis for competition	***- New competitors with different business models w*** *hich better match to the this phase of the market.*	**- differences between products of competitors are often small** (equal product performance)	n/a

Market: Profit							
Reference No	Main Question in Interview Protocol	**Parameters**	Phase 1	Phase 2	Phase 3	Phase 4	Phase 5
T$1	How would you describe the price or margin evolution over time. Please split into the relevant time frames (from opportunistic to sophisticated)		**- high margins**	**- high margins**	**- medium margins**	**-margins are closely associated with the ability to manufactured low cost or the ability to offer services**	***Margins small for products Medium for services***

Supply Chain: In-/ outbound partners							
Reference No	Main Question in Interview Protocol	**Parameters**	Phase 1	Phase 2	Phase 3	Phase 4	Phase 5
TM1	How would you describe the role of vendors and service providers over time. Indicate their changing roles and capabilities and how important they were for you. Please split into the relevant time frames (from opportunistic to	**Strenght of suppliers/ CMs/ partners**	***- No CMs; - Not many suppliers***	***- No CMs; - Few suppliers;*** *sometimes founded by employees from OEM*	***- Some CMs appear because of more intense outsourcing from OEMs. - Enough supplier and channel partners available***	***- Many CMs because of outsourcing. - Many supplier and channel partners available***	***Complex supplier network***
		role of suppliers/ CMs / partners	***minor role***	***Some product components can be supplied by vendors***	***Modules, can be supplied by vendors. System suppliers appear***	**suppliers become dominant; CMs appear to take over manufacturing**	***major outsourcing to CMs and suppliers***

Process Technology (Mfg and SC) (Utterback)							
Reference No	Main Question in Interview Protocol	**Parameters**	Phase 1	Phase 2	Phase 3	Phase 4	Phase 5
TT1			**Cutting Edge**	**Advanced**	**- Mainstream**	**Mature**	**Decline**
	How would you describe the technological evolution of the manufacturing processes over time. Please split into the relevant time frames (from opportunistic to sophisticated)	**Process technology and technical evolution (importance of process technology)**	- manufacturing and supply chain process do not play an important role.	- Product and process innovation are still interdependent.	- a growing rate of process innovation at the factory evolves. SCM started -	- Supply chain management plays an important role; *- Integrated networks*	
		Characteristics of manufacturing (how do companies control processes))	(all Utterback) **Manufacturing:** - uses general purpose equipment and - skilled labor - Small scale plants - often located close to source of technology (R&D) - High manufacturing depth *- Focus on yield / quality*	(all Utterback) **Manufacturing:** - Factory floor becomes important - skilled and unskilled labor - Still located close to source of technology (R&D) - Manufacturing depdth reduced - Outsourcing plays an important role	**Manufacturing:** - Factory floor becomes even more important - Large scale production - Product and process innovation links - managerial controls is important - Mass customization evolves	**Manufacturing:** '- Must be capable to manufacture very specific products at a high level of efficiency (solutions). - Quality to cost becomes important - Linkage in-between product and process are now extremely close (Dfx)	see cell or the left since Utterback provides only three phases.

Product Technology - Reference No							
Reference No	Main Question in Interview Protocol	**Parameters**	Phase 1	Phase 2	Phase 3	Phase 4	Phase 5
TP1	Product Design: How would you describe how the product design evolved: - From a design vor Mfg/ SCM perspective (also Modular design) - From a technological acceptance persp.: = from no or minor consensus within the industry about product design and product technology = to having a dominant design within the industry. - How did the company differentiate there? Nassimbeni deducts for products that “the end-product differs in - complexity, - variety, - maturity, - and volume, and equally in process mechanization, systemization and interconnection”.	**Product technology evolution**	- In the early phase of a new technology product innovation is the driving factor.	- rapid performance improvement due to its commercialization	- Innovation which is leading to better product performance become less likely unless they are easy for the customer to evaluate and compare.	- In its mature stages, the technology will approach a natural or physical limit and additional efforts to innovate are only marginal improvements in technical performance - Firms attempt to maximize revenues by developing products which clearly focus towards potential customers (Solutions)	- Displaced by other new technologies
		Product characteristics and design	The new product is often crude, expensive and unreliable but satisfies some customer niches.	- Now the main features of products with new technology tends to become stable. - Users develop loyalties and preferences.	- Product: Becomes customer friendly; more reliable - Price and production cost degrease. Better price / performance ratio. - A dominant design evolves	- a dominant design has been accepted - difficult to differentiate since products from competitors are similar in performance and look and feel. - Functionality and reliability is given and taken for granted - Cost, appearances, convenience become important. - Custom solutions and product / service hybrids	- Displaced by other new technologies

A Criteria Database for Types of Factory Pattern Matching

Parameters	**High - Tech - Factory**	**Low Cost Factory**	**Velocity factory (speed and**	**Solutions Factory (Die Variantenflexible Fabrik)**	**Cooperative factory (networking) as an extended version of the solutions factory**
Basic parameters					
Customer requirement and products **-**	**- Requirements:** Best product and manufacturing process technologies **- Product characteristics:** These factories produce complex and new technologies with an innovation rate >25% per ann..	**- Customer require:** Low prices **- Product characteristics:** These factories produce commodity products. Cost of goods sold are relatively high or companies with heavy engineering work/ manufacturing plants	**- Customer require:** shortest delivery times for (individual) products and where supply chain speed is important to control cost. Market volatile. **- Product characteristics:** These factories either produce complex end-products based (on platform strategies and modules to enable quick deliveries) or consumer goods.	**- Customer require:** specific custom solutions or a high bandwidth of products and options . **- Product characteristics:** These factories produce solutions including many variants and options of end products (Pull) combined with services. - products are modular products using platform strategies. - products are constructed to support a push-Pull SC	**- Customer require:** specific custom solutions or a high bandwidth of products and options . - cost are important (economy of scale). Markets are volatile; **- Product characteristics: see Solutions**
Competitive Strategy of the factory. Capabilities: increased information visibility and operational knowledge procedures of coordination of all internal and external groups and the knowledge transfer to better synchronize the demand management Comprehensive information sharing inpacting the operational capabilities: quality, delivery flexibility cost contribution	**- Leadership through:** First time to production => to be as fast as possible from the stage of development of a product to introduction into production. **- Goal:** To create best process quality fast; maximize production yield. **- Strategy:** Less focus on optimization of the surfaces and investments than rather on the control the technology and smooth start-up of the processes. (Körber)	**- Leadership through:** Cost competitiveness and efficiency. **- Goal:** Within a given cost bandwidth planners and suppliers have to get along to achieve the cost targets. **- Strategy:** All cost categories are consistently and carefully defined and controlled to determine operating cost and investments	**- Leadership through: Fast procesesses and high velocity** to satisfy customer expectations and reduce inventory and capital asset cost. **- Goal:** Flexible resources and processes and short manufacturing cycle times; low inventory **- Strategy:** - Supply chain and factory process needs a radical conversion towards process orientation and pull processes	**- Leadership through:** custom solutions (product - service hybrids) at shortest time to customer and convenient delivery. **- Goal:** Customer intimacy through delivering product/ service hybrids **- Strategy:** All resources, especially people adapt to the current order volume and need of capabilities. - A consolidation of craft production and mass production toward mass-customization	**- Leadership through:** low priced and quickly delivered solutions. Collaboration enables fast and efficient fulfillment of complex orders. **- Goal:** Resource flexibility (capability and volume). Quality and time to market by including system partners into the supply chain. **- Strategy:** '- Internal and external cooperation - Geographical proximity to customers - Complementary know-how
Process strategy	**- Focus: Much emphasis in Q insurance** - Products difficult to produce (yield)	**- Focus:** ***Process efficiency through tight control.*** - Target cost management - Low cost buildings - Flexibility only if it helps to cut cost - Employee mix of low cost and high skill people - Quality and on-time is either not a differentiator anymore or even becomes less important compared to price	**Focus:** ***flexibility and speed (to adapt quickly)*** - Much emphasis on low assets and low inventory - Often pull systems and one-piece flow - Having all the substantial processes under one roof - Being organized towards a process flow and not hierarchical with only view manufacturing steps (Körber) - Only view workplace changes. As much as possible functions at one work place. Die Atmende Fabrik - Highly flexible resources	**Focus:** ***Mass customization*** - Pull manufacturing and logistics - Product portfolio management - Modular and reliable processes - flexible routing - New work time models and payment systems as well as fractal factory structures are need.	**Focus:** ***Quick links to partners. / network management*** - Capacity sharing - Standardized process interfaces (modular processes) - Highly reliable performance (OTD etc) - Pull manufacturing and logistics - processes temporarily limited (virtual factory)

High Tech: Additional parameters for special indication					
		N/A	N/A	N/A	N/A
Low Cost: Additional parameters for special indication	N/A		N/A	N/A	N/A
Supply Chain Management/ Outsourcing and Off-Shoring (Loch)		**- Off-Shoring** - **Cost and productivity increase:** it requires extreme organizational discipline and frugality. This is true for companies with a high mix of TLC phases: Off-Shoring – Building of expertise in the low-cost location by piloting and testing processes in the local factory. - Expertise being built in (local) manufacturing to offshore in a true partnership and mutually	N/A	N/A	N/A
Speed and Flexibility: Additional parameters for special indication	N/A	N/A		N/A	N/A
Flexibility Zhang et al. (2002)			Machine flexibility is the ability of equipment to perform different operations economically and effectively. Measurement is the number of operations a machine could perform and the related speed. - Labor flexibility allows the workforce to perform a great variety of manufacturing tasks economically and effectively (i.e. Upton, 1994). Measurement could be the number of tasks a worker could perform and the related speed of execution and the ability to		
Collaboration with Suppliers Cooper and Kleinschmidt (1995)	N/A	N/A	following attributes to speed up the innovation process: The use of CAD, supplier involvement, overlapping product development stages (i.e. CE), and multifunctional teams and supplier involvement. (Cooper and Kleinschmidt, 1995)	N/A	N/A

Solutions: Additional parameters for special indication	N/A	N/A	N/A		N/A
Customer Service (Shawnee et al. ,2003)	N/A	N/A	N/A	Customer service is Pre-sales customer service is the ability to support the customer during their purchasing decision. Product support is the support of the customer after sales happened to ensure a continuing customer satisfaction. Responsiveness to customers measures the time how fast customers get informed, how fast their order is confirmed and the speed to react to customer complaints. Delivery dependability is the on-time of deliveries. Delivery	N/A
Flexibility (Zang)				Flexibility is needed to enable solutions manufacturing. This requires the same capability as the Velocity factory. Machine flexibility - Labor flexibility - Material handling flexibility and routing flexibility - Volume flexibility	N/A
Networking: Additional parameters for special indication	N/A	N/A	N/A	N/A	
Collaboration with suppliers, CMs and partners (Körber et. al. (2003); Frohlich and Westbrook's (2001))	N/A	N/A	N/A	N/A	**Networking** – Collaboration with partners - Global networking. - Networking and **collaboration with highly integrated partners**. Partnering allowed the organization to continue to improve after all internal improvements had been driven to the limit. (Loch et. al 2007) Independent variables: Access to planning system, Sharing production plans, Joint EDI networks, Knowledge of inventory mix and levels, Packing customization,

	Collaboration (Körber et. al, 2003)				N/A	**Virtual cooperation** - Independent companies - Time wise limited - Complementary skills - Defined rules of cooperation - Transparent pricing - Extended service portfolio through the network and degreased cost (Körber)
	Collaboration with suppliers, CMs and partners (Brumme)	N/A	N/A	N/A	N/A	Intense collaboration with value added partners who are included in the fulfillment process (see HP-Partner Park - Brumme)
	Shawnee et al. (2003)					Integrative IT and supply chain integration, supplier partnering, a closer customer relationship, and cross-functional teams.
	Droge et al. (2004)					importance of external (supplier and customer) and internal (design and concurrent engineering) integration: Supplier partnership and development, close customer relationship, concurrent engineering, design for manufacturing, standardization, and the use of CAD as a tool for interactive engineering.
	Carr and Person (1999)					The existence of a strategic purchasing organization; supplier evaluation; an actively managed buyer-supplier relationship; a loyal and value-based cooperation; frequent face-to-face meetings; high corporate level communication; and direct EDI links.
	Boddy et al. (2000)					Common business processes; technology, which includes the type and location of fixed assets like buildings, machinery, and the information systems used by all partners; understanding how to deliver the goods and services – internally and externally; the people and their related knowledge, skills, attitudes and goals; the culture; and the power of the people participating in a collaboration.
	Vervest et al. (2005)					a common understanding and common ethics are important. They have compatible goals and a mechanism to share risks and rewards, where actors, play in unison. Wolters *et al*. (2005) found modular processes, products and networks important.

Appendix V – Pattern Matching HP Case (post evaluation) – TLC and Types of factories

OM- EVALUATION																									
Possible values of variables:																									
2 = Situation of the case largely matches the theory																									
1 = Situation of the case matches the theory to some extent																									
0 = Situation of the case does not match the theory																									
- = non-existent																									
	Timeframe <85s					Timeframe end					Timeframe mid					Timeframe end					Timeframe >2003				
	Time-Phase I					Time-Phase II					Time-Phase III					Time-Phase IV					Time-Phase V				
Type of Factory	H	C	V	S	N	H	C	V	S	N	H	C	V	S	N	H	C	V	S	N	H	C	V	S	N
Structure Variable																									
Basic Variable																									
Customer requirement and products																									
- Requirements																									
- Product portfolio characteristics	2	0	0	0	0	2	2	0	0	0	2	2	2	1	0	1	2	2	2	2	1	2	2	2	2
Competitive Strategy of the factory																									
- Leadership through																									
- Goal																									
- Strategy	2	0	0	0	0	1	2	0	0	0	0	2	2	0	1	0	1	1	2	2	0	1	1	2	2
Process Strategy																									
- Focus	2	0	0	0	0	1	2	0	0	1	0	2	2	2	1	0	1	1	2	1	0	0	0	2	2
Total Value	6	0	0	0	0	4	6	0	0	1	2	6	6	3	2	1	4	4	6	5	1	3	3	6	6
# of variables	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
Mid Value	2,0	0,0	0,0	0,0	0,0	1,3	2,0	0,0	0,0	0,3	0,7	2,0	2,0	1,0	0,7	0,3	1,3	1,3	2,0	1,7	0,3	1,0	1,0	2,0	2,0
High Tech: Additional parameters for special indication																									
Low Cost: Additional parameters for special indication																									
Supply Chain Management (Loch)		0					2					2					2					1			
Outsourcing and Off-Shoring (Loch)		0					2					2					1					1			
Speed and Flexibility: Additional parameters for special indication																									
Flexibility			0					0					2					2					1		
Collaboration with Suppliers (Kleinschmidt)			0					2					2					1					1		
Solutions: Additional parameters for special indication																									
Customer Service (Shawnee et al. ,2003)				0					0					1					2					2	
Flexibility (Zang)				0					0					1					2					2	
Networking: Additional parameters for special indication																									
Collaboration with suppliers, CMs and partners (Körber/ Frohlich and W // Körber // HP Case					0					1					1					1					2

TLC- EVALUATION

Possible values of variables:

2 = Situation of the case largely matches the theory
1 = Situation of the case matches the theory to some extent
0 = Situation of the case does not match the theory
- = non-existent

		Time Phase 1					Time Phase 2					Time Phase 3					Time Phase 4					Time Phase 5				
	Theoretical TLC Phases	**I**	**II**	**III**	**IV**	**V**	**I**	**II**	**III**	**IV**	**V**	**I**	**II**	**III**	**IV**	**V**	**I**	**II**	**III**	**IV**	**V**	**I**	**II**	**III**	**IV**	**V**
Market: CUSTOMER																										
	Characteristics of customers	**2**	**1**	**0**	**0**	**0**	**0**	**2**	**0**	**0**	**0**	**0**	**0**	**2**	**0**	**0**	**0**	**0**	**0**	**1**	**0**	**0**	**0**	**0**	**0**	**0**
	Relevant to customers	**2**	**2**	**0**	**0**	**0**	**0**	**2**	**0**	**0**	**0**	**0**	**0**	**2**	**0**	**0**	**0**	**0**	**0**	**2**	**0**	**0**	**0**	**0**	**2**	**0**
	Total Value	4	3	0	0	0	0	4	0	0	0	0	0	4	0	0	0	0	0	3	0	0	0	0	2	0
	# of variables	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
	Mid Value	2,0	1,5	0,0	0,0	0,0	0,0	2,0	0,0	0,0	0,0	0,0	0,0	2,0	0,0	0,0	0,0	0,0	0,0	1,5	0,0	0,0	0,0	0,0	1,0	0,0
	Centre of gravity			1,43					2,00					3,00					4,00					4,00		
	Graph																									
Market Evolution	**Marketing evolution and characteristics**	**1**	**2**	**0**	**0**	**0**	**0**	**2**	**0**	**0**	**0**	**0**	**2**	**2**	**0**	**0**	**0**	**0**	**0**	**2**	**0**	**0**	**0**	**0**	**2**	**0**
	Marketing strategies	**2**	**0**	**0**	**0**	**0**	**0**	**2**	**0**	**0**	**0**	**0**	**2**	**2**	**0**	**0**	**0**	**0**	**0**	**2**	**0**	**0**	**0**	**0**	**2**	**0**
	Total Value	2	0	0	0	0	0	2	0	0	0	0	2	2	0	0	0	0	0	2	0	0	0	0	2	0
	# of variables	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	Mid Value	2,0	0,0	0,0	0,0	0,0	0,0	2,0	0,0	0,0	0,0	0,0	2,0	2,0	0,0	0,0	0,0	0,0	0,0	2,0	0,0	0,0	0,0	0,0	2,0	0,0
	Centre of gravity			1,00					2,00					2,50					4,00					4,00		
Competitors																										
	Strength of compeition	**2**	**1**	**0**	**0**	**0**	**1**	**2**	**2**	**0**	**0**	**0**	**1**	**2**	**0**	**0**	**0**	**0**	**0**	**2**	**0**	**0**	**0**	**0**	**2**	**0**
	Competitive strategies	**2**	**2**	**0**	**0**	**0**	**0**	**2**	**1**	**0**	**0**	**0**	**1**	**2**	**0**	**0**	**0**	**0**	**1**	**2**	**0**	**0**	**0**	**0**	**2**	**0**
	Total Value	4	3	0	0	0	1	4	3	0	0	0	2	4	0	0	0	0	1	4	0	0	0	0	4	0
	# of variables	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
	Mid Value	2,0	1,5	0,0	0,0	0,0	0,5	2,0	1,5	0,0	0,0	0,0	1,0	2,0	0,0	0,0	0,0	0,0	0,5	2,0	0,0	0,0	0,0	0,0	2,0	0,0
	Centre of gravity			1,43					2,25					2,67					3,80					4,00		
	Graph																									
Profit																										
	Evolution of margins	**2**	**2**	**0**	**0**	**0**	**1**	**2**	**0**	**0**	**0**	**0**	**0**	**0**	**2**	**1**	**0**	**0**	**0**	**2**	**2**	**0**	**0**	**0**	**2**	**2**
	Total Value	2	2	0	0	0	1	2	0	0	0	0	0	0	2	1	0	0	0	2	2	0	0	0	2	2
	# of variables	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	Mid Value	2,0	2,0	0,0	0,0	0,0	1,0	2,0	0,0	0,0	0,0	0,0	0,0	0,0	2,0	1,0	0,0	0,0	0,0	2,0	2,0	0,0	0,0	0,0	2,0	2,0
	Centre of gravity			1,50					1,67					4,33					4,50					4,50		
	Graph																									
Partners																										
	Strenght of suppliers/ CMs/ partners	**2**	**1**	**0**	**0**	**0**	**0**	**1**	**2**	**1**	**0**	**0**	**0**	**1**	**2**	**0**	**0**	**0**	**0**	**2**	**2**	**0**	**0**	**0**	**0**	**2**
	role of suppliers/ CMs / partners	**2**	**1**	**0**	**0**	**0**	**0**	**1**	**2**	**1**	**0**	**0**	**0**	**1**	**2**	**0**	**0**	**0**	**0**	**2**	**2**	**0**	**0**	**0**	**0**	**2**
	Total Value	4	2	0	0	0	0	2	4	2	0	0	0	2	4	0	0	0	0	4	4	0	0	0	0	4
	# of variables	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
	Mid Value	2,0	1,0	0,0	0,0	0,0	0,0	1,0	2,0	1,0	0,0	0,0	0,0	1,0	2,0	0,0	0,0	0,0	0,0	2,0	2,0	0,0	0,0	0,0	0,0	2,0
	Centre of gravity			1,33					3,00					3,67					4,50					5,00		
	Graph																									
Process Technology																										
	Process technology and technical evolution (importance of process technology)	**2**	**1**	**0**	**0**	**0**	**0**	**0**	**2**	**0**	**0**	**0**	**0**	**0**	**2**	**0**	**0**	**0**	**0**	**2**	**2**	**0**	**0**	**0**	**2**	**2**
	Characteristics of manufacturing (how do companies control processes))	**2**	**1**	**0**	**0**	**0**	**0**	**1**	**2**	**0**	**0**	**0**	**0**	**1**	**2**	**0**	**0**	**0**	**0**	**1**	**1**	**0**	**0**	**0**	**1**	**1**
	Total Value	4	2	0	0	0	0	1	4	0	0	0	0	1	4	0	0	0	0	3	3	0	0	0	3	3
	# of variables	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
	Mid Value	2,0	1,0	0,0	0,0	0,0	0,0	0,5	2,0	0,0	0,0	0,0	0,0	0,5	2,0	0,0	0,0	0,0	0,0	1,5	1,5	0,0	0,0	0,0	1,5	1,5
	Centre of gravity			1,33					2,80					3,80					4,50					4,50		
	Graph																									
Product tecnology																										
	Product technology evolution	**2**	**1**	**0**	**0**	**0**						**0**	**0**	**2**	**0**	**0**	**0**	**0**	**0**	**2**	**0**	**0**	**0**	**0**	**2**	**0**
	Product characteristics and design Design	**2**	**0**	**0**	**0**	**0**						**0**	**1**	**2**	**0**	**0**	**0**	**0**	**0**	**2**	**0**	**0**	**0**	**0**	**2**	**0**
	Total Value	4	1	0	0	0	0	0	0	0	0	0	1	4	0	0	0	0	0	4	0	0	0	0	4	0
	# of variables	2	2	2	2	2	0	0	0	0	0	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
	Mid Value	2,0	0,5	0,0	0,0	0,0	###	###	###	###	###	0,0	0,5	2,0	0,0	0,0	0,0	0,0	0,0	2,0	0,0	0,0	0,0	0,0	2,0	0,0
	Centre of gravity			1,20					#DIV/0!					2,80					4,00					4,00		
	Graph																									
	Grand Total Value	24	13	0	0	0	2	15	11	2	0	0	5	17	10	1	0	0	1	22	9	0	0	0	17	9
	Grand # of variables	12	12	12	12	12	10	10	10	10	10	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12
	Grand - Mid Value	2,0	1,1	0,0	0,0	0,0	0,2	1,5	1,1	0,2	0,0	0,0	0,4	1,4	0,8	0,1	0,0	0,0	0,1	1,8	0,8	0,0	0,0	0,0	1,4	0,8
	Grand - Centre of gravity			**1,35**					**2,43**					**3,21**					**4,25**					**4,35**		

Appendix VI – Pattern Matching FSC Case – TLC and Types of factories

OM- EVALUATION																					
Possible values of variables:																					
2 =	Situation of the case largely matches the theory																				
1 =	Situation of the case matches the theory to some extent																				
0 =	Situation of the case does not match the theory																				
- =	non-existent																				
		Timeframe <90s					**Timeframe 90s**					**Timeframe 2000s**					**Timefr. Mid 2000s**				
	Type of Factory	**H**	**C**	**V**	**S**	**N**	**H**	**C**	**V**	**S**	**N**	**H**	**C**	**V**	**S**	**N**	**H**	**C**	**V**	**S**	**N**
	Sub Variables																				
	Customer requirement and products - Requirements - Product portfolio characteristics	2	0	0	0	0	1	2	1	0	0	0	2	2	1	0	0	1	1	2	2
	Competitive Strategy of the factory - Leadership through - Goal - Strategy	2	0	0	0	0	1	2	1	0	0	1	2	2	2	1	1	2	2	2	1
	Process Strategy - Focus	2	0	0	0	0	0	1	1	0	0	0	2	2	1	-	0	1	2	2	1
	Total Value	6	0	0	0	0	2	5	3	0	0	1	6	6	4	1	1	4	5	6	4
	# of variables	3	3	3	3	3	3	3	3	3	3	3	3	3	3	2	3	3	3	3	3
	Mid Value	2,0	0,0	0,0	0,0	0,0	0,7	1,7	1,0	0,0	0,0	0,3	2,0	2,0	1,3	0,5	0,3	1,3	1,7	2,0	1,3
	Graph																				
High Tech: Additional parameters for special indication		-					-					-					-				
Low Cost: Additional parameters for special indication																					
	Supply Chain Management		1					2					1					1			
	Outsourcing and Off-Shoring		2					2					2					1			
Speed and Flexibility: Additional parameters for special indication																					
	Flexibility			0					1					2					-		
	Collaboration with Suppliers			0					1					2					-		
Solutions: Additional parameters for special indication																					
	Customer Service				0					0					1					-	
	Flexibility				0					0					1					-	
Networking: Additional parameters for special indication																					
	Collaboration with suppliers, CMs and partners					-					-					-					2

TLC- EVALUATION

Possible values of variables:

2 = Situation of the case largely matches the theory
1 = Situation of the case matches the theory to some extent
0 = Situation of the case does not match the theory
- = non-existent

	Timeframe <90s					Timeframe 90s					Timeframe 2000s					Timefr. Mid 2000s				
TLC Phases	**1**	**2**	**3**	**4**	**5**	**1**	**2**	**3**	**4**	**5**	**1**	**2**	**3**	**4**	**5**	**1**	**2**	**3**	**4**	**5**
Market: CUSTOMER																				
Characteristics of customers	**2**	**1**	**0**	**0**	**0**	**0**	**2**	**1**	**0**	**0**	**0**	**0**	**1**	**2**	**0**	**0**	**0**	**1**	**2**	**0**
Relevant to customers	**2**	**1**	**0**	**0**	**0**	**0**	**2**	**0**	**0**	**0**	**0**	**0**	**1**	**1**	**0**	**0**	**0**	**0**	**1**	**0**
Total Value	4	2	0	0	0	0	4	1	0	0	0	0	2	3	0	0	0	1	3	0
# of variables	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
Mid Value	2,0	1,0	0,0	0,0	0,0	0,0	2,0	0,5	0,0	0,0	0,0	0,0	1,0	1,5	0,0	0,0	0,0	0,5	1,5	0,0
Centre of gravity			1,33					2,20					3,60					3,75		
TLC Phases	**1**	**2**	**3**	**4**	**5**	**1**	**2**	**3**	**4**	**5**	**1**	**2**	**3**	**4**	**5**	**1**	**2**	**3**	**4**	**5**
Market Evoluti **Marketing evolution and characteristics**	**2**	**0**	**0**	**0**	**0**	**0**	**2**	**1**	**0**	**0**	**0**	**0**	**1**	**2**	**0**					
Marketing strategies	**2**	**0**	**0**	**0**	**0**	**0**	**2**	**1**	**0**	**0**	**0**	**0**	**1**	**2**	**0**					
Total Value	2	0	0	0	0	0	2	1	0	0	0	0	1	2	0	0	0	0	0	0
# of variables	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0
Mid Value	2,0	0,0	0,0	0,0	0,0	0,0	2,0	1,0	0,0	0,0	0,0	0,0	1,0	2,0	0,0	##	##	##	##	##
Centre of gravity			1,00					2,33					3,67					#DIV/0!		
TLC Phases	**1**	**2**	**3**	**4**	**5**	**1**	**2**	**3**	**4**	**5**	**1**	**2**	**3**	**4**	**5**	**1**	**2**	**3**	**4**	**5**
Competitors																				
Strength of compeition	**2**	**1**	**0**	**0**	**0**	**0**	**0**	**2**	**1**	**0**	**0**	**0**	**1**	**2**	**1**					
Competitive strategies	**2**	**2**	**0**	**0**	**0**	**0**	**0**	**2**	**0**	**0**	**0**	**0**	**2**	**2**						
Total Value	4	3	0	0	0	0	0	4	1	0	0	0	3	4	1	0	0	0	0	0
# of variables	2	2	2	2	2	2	2	2	2	2	2	2	2	2	1	0	0	0	0	0
Mid Value	2,0	1,5	0,0	0,0	0,0	0,0	0,0	2,0	0,5	0,0	0,0	0,0	1,5	2,0	1,0	##	##	##	##	##
Centre of gravity			1,43					3,00					3,57					#DIV/0!		
TLC Phases	**1**	**2**	**3**	**4**	**5**	**1**	**2**	**3**	**4**	**5**	**1**	**2**	**3**	**4**	**5**	**1**	**2**	**3**	**4**	**5**
Profit																				
Evolution of margins	**2**	**2**	**0**	**0**	**0**	**0**	**2**	**1**	**0**	**0**	**0**	**0**	**0**	**2**	**1**					
Total Value	2	2	0	0	0	0	2	1	0	0	0	0	0	2	1	0	0	0	0	0
# of variables	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0
Mid Value	2,0	2,0	0,0	0,0	0,0	0,0	2,0	1,0	0,0	0,0	0,0	0,0	0,0	2,0	1,0	##	##	##	##	##
Centre of gravity			1,50					2,33					4,00					#DIV/0!		
TLC Phases	**1**	**2**	**3**	**4**	**5**	**1**	**2**	**3**	**4**	**5**	**1**	**2**	**3**	**4**	**5**	**1**	**2**	**3**	**4**	**5**
Partners																				
Strenght of suppliers/ CMs/ partners	**2**	**2**	**0**	**0**	**0**	**0**	**2**	**1**	**0**	**0**	**0**	**0**	**1**	**2**	**1**	**0**	**0**	**0**	**0**	**0**
role of suppliers/ CMs / partners	**1**	**2**	**0**	**0**	**0**	**0**	**2**	**1**	**0**	**0**	**0**	**0**	**2**	**2**	**1**	**0**	**0**	**0**	**0**	**0**
Total Value	3	4	0	0	0	0	4	2	0	0	0	0	3	4	2	0	0	0	0	0
# of variables	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
Mid Value	1,5	2,0	0,0	0,0	0,0	0,0	2,0	1,0	0,0	0,0	0,0	0,0	1,5	2,0	1,0	0,0	0,0	0,0	0,0	0,0
Centre of gravity			1,57					2,33					3,57					#DIV/0!		
TLC Phases	**1**	**2**	**3**	**4**	**5**	**1**	**2**	**3**	**4**	**5**	**1**	**2**	**3**	**4**	**5**	**1**	**2**	**3**	**4**	**5**
Process Technology																				
Process technology and technical evolution (importance of process technology)	**2**	**1**	**0**	**0**	**0**	**0**	**0**	**2**	**1**	**0**	**0**	**1**	**2**	**1**	**0**	**0**	**0**	**1**	**2**	**0**
Characteristics of manufacturing (how do companies control processes))	**2**	**2**	**0**	**0**	**0**	**0**	**0**	**2**	**0**	**0**	**0**	**0**	**2**	**2**	**0**	**0**	**0**	**0**	**1**	**0**
Total Value	4	3	0	0	0	0	0	4	1	0	0	1	4	3	0	0	0	1	3	0
# of variables	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
Mid Value	2,0	1,5	0,0	0,0	0,0	0,0	0,0	2,0	0,5	0,0	0,0	0,5	2,0	1,5	0,0	0,0	0,0	0,5	1,5	0,0
Centre of gravity			1,43					3,00					3,25					3,75		
TLC Phases	**1**	**2**	**3**	**4**	**5**	**1**	**2**	**3**	**4**	**5**	**1**	**2**	**3**	**4**	**5**	**1**	**2**	**3**	**4**	**5**
Product tecnology																				
Product technology evolution	**2**	**2**	**0**	**0**	**0**	**0**	**2**	**1**	**0**	**0**	**0**	**1**	**2**	**0**	**0**	**0**	**0**	**1**	**2**	**0**
Product characteristics and design Design	**2**	**2**	**0**	**0**	**0**	**0**	**1**	**0**	**0**	**0**	**0**	**2**	**2**	**-**		**0**	**0**	**0**	**2**	**2**
Total Value	4	4	0	0	0	0	3	1	0	0	0	3	4	0	0	0	0	1	4	2
# of variables	2	2	2	2	2	2	2	2	2	2	2	2	2	1	1	2	2	2	2	2
Mid Value	2,0	2,0	0,0	0,0	0,0	0,0	1,5	0,5	0,0	0,0	0,0	1,5	2,0	0,0	0,0	0,0	0,0	0,5	2,0	1,0
Centre of gravity			1,50					2,25					2,57					3,80		
Grand Total Value	23	18	0	0	0	0	15	14	2	0	0	4	17	18	4	0	0	3	10	2
Grand # of variables	12	12	12	12	12	12	12	12	12	12	12	12	12	11	10	8	8	8	8	8
Grand - Mid Value	1,9	1,5	0,0	0,0	0,0	0,0	1,3	1,2	0,2	0,0	0,0	0,3	1,4	1,6	0,4	0,0	0,0	0,4	1,3	0,3
Grand - Centre of gravity			**1,44**					**2,58**					**3,56**					**3,93**		

Appendix VII – Pattern Matching Agilent Case – TLC and Types of factories

OM- EVALUATION																					
Possible values of variables:																					
2 =	Situation of the case largely matches the theory																				
1 =	Situation of the case matches the theory to some extent																				
0 =	Situation of the case does not match the theory																				
- =	non-existent		80s to Early 90s					Before the bubble					After the bubble					Mid 2000s			
		Time-Phase I					**Time-Phase II**					**Time-Phase III**					**Time-Phase IV**				
	Type of Factory	**H**	**C**	**V**	**S**	**N**	**H**	**C**	**V**	**S**	**N**	**H**	**C**	**V**	**S**	**N**	**H**	**C**	**V**	**S**	**N**
Structure Variable																					
Basic Variable																					
	Customer requirement and products - Requirements - Product portfolio characteristics	2	0	0	0	0	2	0	0	0	0	2	2	1	0	0	2	2	1	0	0
	Competitive Strategy of the factory - Leadership through - Goal - Strategy	2	0	0	0	0	1	0	1	0	0	1	2	1	1	0	1	2	1	1	1
	Process Strategy - Focus	2	0	0	0	0	2	0	2	0	0	2	2	2	0	1	2	1	1	0	1
	Total Value	6	0	0	0	0	5	0	3	0	0	5	6	4	1	1	5	5	3	1	2
	# of variables	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
	Mid Value	2,0	0,0	0,0	0,0	0,0	1,7	0,0	1,0	0,0	0,0	1,7	2,0	1,3	0,3	0,3	1,7	1,7	1,0	0,3	0,7
High Tech: Additional parameters for special indication																					
Low Cost: Additional parameters for special indication																					
	Supply Chain Management (Loch)		0					0					2					0			
	Outsourcing and Off-Shoring (Loch)		0					0					2					0			
Speed and Flexibility: Additional parameters for special indication																					
	Flexibility			0					1					2					1		
	Collaboration with Suppliers (Kleinschmidt)			0					1					2					2		
Solutions: Additional parameters for special indication																					
	Customer Service (Shawnee et al. ,2003)				0					0					-					1	
	Flexibility (Zang)				0					0					1					1	
Networking: Additional parameters for special indication																					
	Collaboration with suppliers, CMs and partners (Körber/ Frohlich and W // Körber // BRUMME					0					1					1					1

TLC- EVALUATION

Possible values of variables:

2 = Situation of the case largely matches the theory
1 = Situation of the case matches the theory to some extent
0 = Situation of the case does not match the theory
\- = non-existent

	Timeframe 80s					Bevore Bubble					During the bubble					After the bubble				
Phases	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Market: CUSTOMER																				
Characteristics of customers	2	1	0	0	0	0	1	2	0	0	0	1	2	1	0	1	1	1	1	0
Relevant to customers	2	1	0	0	0	0	1	2	0	0	0	1	2	1	0	1	2	2	2	0
Total Value	4	2	0	0	0	0	2	4	0	0	0	2	4	2	0	2	3	3	3	0
# of variables	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
Mid Value	2,0	1,0	0,0	0,0	0,0	0,0	1,0	2,0	0,0	0,0	0,0	1,0	2,0	1,0	0,0	1,0	1,5	1,5	1,5	0,0
Centre of gravity	1,33					2,67					2,67					2,64				

	Timeframe 80s					Bevore Bubble					During the bubble					After the bubble				
Phases	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Market — **Marketing evolution and characteristics**	2	2	0	0	0	0	0	2	0	0	0	0	0	1	0	0	0	2	1	0
Marketing strategies	2	2	0	0	0	0	0	-	0	0	0	0	0	0	0	0	0	1	1	0
Total Value	4	4	0	0	0	0	0	2	0	0	0	0	0	1	0	0	0	3	2	0
# of variables	2	2	2	2	2	2	2	1	2	2	2	2	2	2	2	2	2	2	2	2
Mid Value	2,0	2,0	0,0	0,0	0,0	0,0	0,0	2,0	0,0	0,0	0,0	0,0	0,0	0,5	0,0	0,0	0,0	1,5	1,0	0,0
Centre of gravity	1,50					3,00					4,00					3,40				

	Timeframe 70th					Timeframe 80th					Timeframe 90th					Timeframe 2000				
Phases	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Competitors																				
Strength of compeition	2	0	0	0	0	2	-	0	0	0	2	0	0	0	0	-	-	-	-	-
Competitive strategies	2	1	0	0	0	2	2	0	0	0	-	-	-	-	-	-	-	-	-	-
Total Value	4	1	0	0	0	4	2	0	0	0	2	0	0	0	0	0	0	0	0	0
# of variables	2	2	2	2	2	2	1	2	2	2	1	1	1	1	1	0	0	0	0	0
Mid Value	2,0	0,5	0,0	0,0	0,0	2,0	2,0	0,0	0,0	0,0	2,0	0,0	0,0	0,0	0,0	####	###	###	###	###
Centre of gravity	1,20					1,50					1,00					#DIV/0!				

	Timeframe 70th					Timeframe 80th					Timeframe 90th					Timeframe 2000				
Phases	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Profit																				
Evolution of margins	2	2	0	0	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Total Value	2	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
# of variables	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Mid Value	2,0	2,0	0,0	0,0	0,0	###	###	###	###	###	###	###	###	###	###	####	###	###	###	###
Centre of gravity	1,50					#DIV/0!					#DIV/0!					#DIV/0!				

	Timeframe 70th					Timeframe 80th					Timeframe 90th					Timeframe 2000				
Phases	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Partners																				
Strenght of suppliers/ CMs/ partners	2	0	0	0	0	0	0	2	0	0	0	0	1	1	0	0	0	1	2	0
role of suppliers/ CMs / partners	2	0	0	0	0	0	0	2	0	0	0	0	1	1	0	0	0	1	0	0
Total Value	4	0	0	0	0	0	0	4	0	0	0	0	2	2	0	0	0	2	2	0
# of variables	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
Mid Value	2,0	0,0	0,0	0,0	0,0	0,0	0,0	2,0	0,0	0,0	0,0	0,0	1,0	1,0	0,0	0,0	0,0	1,0	1,0	0,0
Centre of gravity	1,00					3,00					3,50					3,50				

	Timeframe 70th					Timeframe 80th					Timeframe 90th					Timeframe 2000				
Phases	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Process Technology																				
Process technology and technical evolution (importance of process technology)	2	1	0	0	0	0	0	2	1	0	0	0	0	1	0	0	0	0	2	0
Characteristics of manufacturing (how do companies control processes))	2	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	1	2	0
Total Value	4	1	0	0	0	0	0	3	1	0	0	0	0	2	0	0	0	1	4	0
# of variables	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
Mid Value	2,0	0,5	0,0	0,0	0,0	0,0	0,0	1,5	0,5	0,0	0,0	0,0	0,0	1,0	0,0	0,0	0,0	0,5	2,0	0,0
Centre of gravity	1,20					3,25					4,00					3,80				

	Timeframe 70th					Timeframe 80th					Timeframe 90th					Timeframe 2000				
Phases	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Product tecnology																				
Product technology evolution	2	1	0	0	0	0	2	0	0	0	0	2	0	0	0	0	0	1	1	0
Product characteristics and design Design	0	-	0	0	0	0	1	0	0	0	0	1	0	0	0	0	0	1	1	0
Total Value	2	1	0	0	0	0	3	0	0	0	0	3	0	0	0	0	0	2	2	0
# of variables	2	1	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
Mid Value	1,0	1,0	0,0	0,0	0,0	0,0	1,5	0,0	0,0	0,0	0,0	1,5	0,0	0,0	0,0	0,0	0,0	1,0	1,0	0,0
Centre of gravity	1,50					2,00					2,00					3,50				
Grand Total Value	24	11	0	0	0	4	7	13	1	0	2	5	6	7	0	2	3	11	13	0
Grand # of variables	13	12	13	13	13	12	11	11	12	12	11	11	11	11	11	10	10	10	10	10
Grand - Mid Value	1,8	0,9	0,0	0,0	0,0	0,3	0,6	1,2	0,1	0,0	0,2	0,5	0,5	0,6	0,0	0,2	0,3	1,1	1,3	0,0
Grand - Centre of gravity	**1,33**					**2,45**					**2,90**					**3,21**				

Appendix VIII – Overview of the types of factories

The High-tech factory
Degree of innovation > 25%
High share of R&D in total costs
Growth industry
Strong market position due to leading-edge technology
Complex products, expensive to manufacture
Costly production conditions
Costly quality assurance

The Low-cost factory
Minimization of manufacturing costs
Management of target costs
High share of material costs and manufacturing costs
Production factors are optimized along the process chain (supply chain) regarding costs
Functional buildings and simple architecture

The Solution factory
High variety of product spectrum with few components
Market demand for customized products
Active variant management
Postponement and modular structures
Short-term response
Simple and error-free procedures and structures
JIT/JIS concepts
Push/Pull concept in the supply chain
Illustration of product structures in the production structure
Internal customer-supplier relationship
The Breathing factory
Fluctuating market demand
High flexibility of resources
Self-organized employee groups (Fractal factory)
Training of employees for various operations
Flexible work and remuneration models
Variable capacity and capacity utilization
Dimensioning to maximum requirements

The Velocity factory
Flexible, fast production
Short throughput through pull principle and one-piece-flow
Optimized information, procurement and distribution logistics
Low stocks and high inventory turns
Fewest possible product stages
As many work processes as possible in one place
Shortest possible tooling times
Lowest possible stock levels

The Cooperative factory
Geographical proximity to the partner
Coordinated production planning
Added know-how
Volatile markets
High product variance and customer-individual products
High productivity
Kanban, JIT, JIS with high delivery reliability
Resource-oriented order calculation
Low share of fixed costs and manufacturing costs
Company-internal or company-spanning cooperation
Standards in product and process development

Appendix IX – The TLC phases

Foster Model
Phase I Technology improvement rate is low Technology does not meet customer demand High cost Low convenience
Phase II Technology improvement rate is high Technology better meets customer demand High cost Accelerated Efforts
Phase III Technology improvement rate matures and slows down Better performance At lower price Higher reliability and convenience Satisfaction of basic needs achieved
Phase IV Technology matures and only marginal improvements possible (physical limit) Improvement in technology makes no sense anymore Customer are satisfied Convenient technology

Moore – the diffusion theory – technology adoption life cycle – crossing the chasm
Phase: Innovators Customers are technologists Buying decision: Product technology counts Marketing: Low marketing efforts
Phase: Early Adopters Customers are no technologists but they believe in technology Buying decision: they rely on their own intuition Marketing: Low efforts
Phase: Early Majority Customers want practicality and still have some sense of technology. Buying decision: They want to see well established references Marketing: 1/3 of all customers → their business is key to any business and profit growth
Phase: Late Adopters Customers wait for technology to mature These people are not able to handle complex technology Buying decision: Standards and well working technology Marketing: This is still important for the company since it is 1/3 of all customers, but profit margins decline
Phase: Laggards Remain with old technology as long as it is available

Norman (1998) – Moving from Technology-Centered to Human-Centered Products
Early Phase The early phase of a technology requires a contradictory strategy to the mature phases. At first, the selling point is the technology. It is important to increase performance and the number of features and functions (see mobile phone)
Maturity Phase At maturity, new customers emerge (the mass market) and the selling points require that the attributes of the technology be minimized. The buyers now focus on solutions and convenience, and on their experience with the product. Many competitors can produce the technology Prices drop Companies need a development philosophy that targets the human user, the customer, not the technology.

Utterback 1996 – Mastering the dynamics of innovation
Phase 1: The fluid phase **Customers** do not yet understand what they really need long term in terms of product design and functionality **Products** are not perfect at any vendors; Few industry standards only; Product innovation is less important than process innovation. Frequency of change is high (product design is not yet perfect **Competitors:** number of new competitors is small but increases over the TLC **Technology** is crude, expensive and unreliable, but is highly desirable for some niche markets. **Manufacturing**: Control over the processes is not perfect; Product design changes so quickly that that linked processes can not be developed; Materials: Off-the-shelf; Equipment: General purpose equipment; Labor: Skilled; Plant size: Small; Location: Close to R&D or close to customer base if customer is needed to define solution; Not efficient manufacturing but cost of flexibility is low; No industry standards
Phase 2: The transitional phase **Market**: Product is accepted and there is market growth **Customers**: Their needs become better understood **Product**: Dominant design evolves **Competitors**: They try to produce products for specific users **Manufacturing**: Factory floor becomes more important; Large-scale production; Product and process innovation links; Material becomes more specific, specialized equipment is bought; Managerial control is important
Phase 3: The specific (mature) phase **Product**: Dominant design has been accepted by the market **Product innovation:** The early years of a new technology; Ends with the emergence of a dominant design; It becomes increasingly difficult to improve on past performance, users develop loyalties and preferences **Manufacturing** Must be capable of manufacturing very specific products at a high level of efficiency; Quality-to-cost ratio becomes important; Few differences among competitors' products; Linkage between product and process are now extremely close; Mass customization is needed

SUMMARY

Since the evolution of global business and supply chain opportunities, many organizations have found themselves confronted with increasing levels of turbulence in this environment. A key competence that is required in this volatile environment is the capability to reconfigure manufacturing systems in such a way that management can ensure continuous best-in-class fulfillment. Our research seeks to enhance decision making with regard to the development of manufacturing capabilities and to show how and in what sequence these have to be switched along the environmental dynamics described by the technology life cycle (TLC). A byproduct of our research is a brief discussion of the value of local manufacturing.

The motivation for our research is based on the author's managerial experience of running a server and workstation Solution factory for the European market, located in Germany, a high-cost country. A competitive advantage over all HP internal and external manufacturing alternatives around the world could only be achieved by continuous maximization of the value-add provided by an ongoing adaptation of the factory capabilities.

For the development of the conceptual model, the exploratory case served as the basis, which was extended and well grounded in the literature in the area of TLC theories and operations management theories. Based on the TLC literature, we deduced five different phases as to how market characteristics change, triggered by the technological evolution of the products produced. The fifth phase is a "wind-down" phase and is not discussed in this study. Regarding the second dimension, five types of factories were defined based on the literature in operations management. These were the High-tech factory, the Low-cost factory, the Velocity factory, the Solution factory, the Cooperative factory, equipped with a specific set of capabilities.

Research methodology

The goal of our research is to develop and test a theory explaining a relationship between variables of a real-life phenomenon within the complex world of manufacturing. Our intent is to explain how and why things happen in this world. However, we could not explain this complex relationship based on a quantitative method. A qualitative model was required. Further on, it was not possible just to look at key words – we had to look at whole associations of relations, as this was an attempt to assign a real-life situation to the TLC phases in operations management theories. Consequently, an explanatory and qualitative case study approach seemed to be the best research methodology. Two more cases within the high-tech electronics industry were carefully selected. The FSC case was picked because it showed similar characteristics to the HP case, and it was therefore intended to be a likely case. The Agilent case was picked because it differed in many criteria, yet still belonged to the same domain. Therefore, it was considered a less likely case.

Research quality

A chain of evidence was constructed so that through-labeling linkages could be established: From the definition of the variables, sourced from the literature, and the exploratory case, toward the interview question, toward the criteria database of the

measurement model. Construct quality was achieved by this well-defined measurement system combined with multiple sources which allowed a stringent pattern matching approach. Theory in the TLC and operations management and the experience of the exploratory case were applied to build the framework, on the basis of which we defined the criteria of the measurement model. Both worlds were described in detail to make pattern matching possible. For the dimension of the TLC, the phases defined in the conceptual model were characterized by constructs and variables. Constructs are clusters of variables, and we defined seven based on the environmental dynamism theory. These are: Customers, Market Evolution, Profit Situation, Competitors, Supply Chain In-/and Outbound partners, Process Technology and Product Technology. The variables within each construct, which were used to describe in detail each phase of the TLC, were deduced from the TLC literature. For the five types of factories we defined three constructs: Customer requirements and products, competitive strategy of the factory, and process strategy. Again, each construct was split into variables to facilitate a more detailed description. For all types of factories, the same variables were used. However, a few additional variables were installed. These covered specific aspects of a specific type of factory and were called "additional variables for special indication". Their value was simply to underline the findings. Regarding the evaluation, each variable could be ranked between "0" and "2" indicating that the theoretical description of the variable within a certain phase of the TLC does not match (0), does match to some extent (1) or does match the case (2) in a certain timeframe measured. For each variable, the median (mid-value) was calculated. Within the dimension of the TLC, we calculated a "center-of-gravity value". This is a decimal number indicating how close a company was at a particular time to one of the five phases defined by the TLC theory. Pattern matching was carried out by an independent person who was knowledgeable enough in the area of manufacturing and TLC theories to handle the complexity of the measurement model. The results were intensively discussed with the management teams involved and conclusions were drawn jointly with the research team.

Results

The results of the research indicate that there are at least five different types of factories and five different phases within the TLC as defined in the conceptual model. The theoretical descriptions of the TLC in the literature were extended based on the HP case. There, we discuss customers' expectations regarding product performance vs. available performance supplied by the industry. The delta between available and needed performance triggers customers' requirements and their willingness to pay high prices. The different types of factories are vested with specific capabilities which must be developed in a certain sequence if the technology evolves in accordance with the theoretical descriptions of the TLC. This conclusion was found in the HP case and supported by the FSC case and partly by the Agilent case. The sequence is: High-tech factory toward Low-cost factory toward Velocity factory toward Solution factory toward the Cooperative factory.

The Agilent case showed some of the limitations of the model: First, the sequence of capability development might be different if the market does not evolve step by step from a supplier to a customer market. Second, Agilent did not really develop a Solution factory or a Cooperative factory for fiber optical data transmission testing since the development of test solutions had so far been the core competence of their OEM customers. Third,

Agilent provided different types of factories simultaneously since they had to manage different technologies in different phases of the TLC simultaneously.
Other findings were that new capabilities need not come from internal sources at the local factory: Agilent demonstrated that these new capabilities could be acquired by outsourcing to contract manufacturers. To cut costs or reduce fixed costs, a great deal of outsourcing was done in the computer cases as well. This supports this statement. It is also important to state that capability switching is not binary 0 or 1. It is an evolution, and the former important capabilities remain important for a certain time. Thus, there is no transfer but rather an extension from one type of factory to another.

We also found that these firms needed to keep local operational capabilities since they were of value along all phases of the TLC. All types of factories need to be local to R&D or the customer base to work efficiently. Only the Low-cost factory could be achieved off-shore. However, off-shoring would not allow developing efficient Velocity-, Solutions- or Cooperative factories, which come in later phases.
Within the managerial area, we found that managers should carefully evaluate: First, the changing customer preferences; second, the partner collaboration opportunity regarding their capabilities (up- and downstream of the supply chain) and their willingness to support; third, the competitor strategy and whether they installed different business and supply chain models with different manufacturing capabilities; and finally the technological changes of process and product innovation.

Limitations
The number of cases is small, and more tests of similar and less likely cases would improve external validity. Tests within other domains would give an interesting picture of the limitations regarding the domain. The construct validity could be improved by shaping the measurement system in order to sharpen the criteria and the evaluation method. This would then also impact the interview questions. A discussion about the speed and excellence of capability switching, which was not covered in this research, would also be of importance.

SAMENVATTING

Vanaf het moment dat global business en supply chain concepten ontwikkeld werden nam voor veel organisaties de dynamiek op de markt sterk toe. Voor organisaties die mee voorop willen blijven lopen is snel met hun productiesystemen in kunnen spelen op de fluctuaties in de markt dan ook een vereiste kerncompetentie geworden. Dat betekent dat productiebedrijven snel moeten kunnen omschakelen van de ene productiewijze naar de andere als de markt dat eist, we noemen dit met een Engels woord “capability switching”
Ons onderzoek heeft tot doel instrumentarium aan te dragen dat organisaties kan helpen bij het ontwikkelen van bovenstaande kerncompetentie. Waarbij de benodigde aanpassing wordt gekoppeld aan de technologische levenscyclus (TLC) van de beschouwde producten. Een nevenprodukt van ons onderzoek is een beschouwing over de waarde van productie in de lokale markten.
De motivatie van ons onderzoek is gebaseerd op de ervaring van de auteur als verantwoordelijk manager van een in het hoog loonland Duitsland gevestigd productiebedrijf van Hewlett Packard (HP) van servers en werkstations voor de Europese markt. Alleen door continue voorop te lopen met de inrichting van het fabricageprocess, om daardoor adequaat te kunnen reageren op de dynamiek in de markt, is overleven in een hoog lonenland mogelijk en kan maximale waardetoevoeging voor een op de wereldmarkt opererend bedrijf gerealiseerd worden.
Het conceptuele onderzoeksmodel is ontwikkeld op basis van de HP casus volgens de zogenaamde Yin methodiek. Waarbij de theorie over Technologische levenscycli (TLC) en Operations management de inbedding leverden. Op basis van de TLC literatuur zijn vijf verschillende fasen afgeleid om te analyseren hoe de markt kenmerken gedurende de technologische evolutie van de geproduceerde producten, verandert. De vijf typen van fabrieken die bij de verschillende fasen horen zijn respectievelijk de “High-Tech-fabriek”, de “Lage-Kosten-fabriek”, de “Snelheids-fabriek”, de “Oplossing-fabriek” en de “Coöperatieve-fabriek” elk uitgerust met de door de naam aangegeven specifieke set van deskundig- en vaardigheden die bij de betreffende fase horen..

Onderzoeksmethodologie
Het doel van ons onderzoek is een theorie te ontwikkelen en te testen, waarme de relaties, tussen de verschillende variabelen die de dynamische en complexe wereld van productiebedrijven karakteriseren, verklaart kunnen worden. Onze intentie is om inzicht te veschaffen in het hoe en waarom van bepaalde phenomenen. Voor het bestuderen van deze complexe relaties gedurende de TLC bleek de kwalitatieve case onderzoeksmethode voor de hand liggend. Om de ontwikkelde hypothesen te toetsen zijn er aansluitend nog twee andere casussen in de high-tech industrie geselecteerd. De Fujitsu Siemens Case (FSC) is gekozen wegens het gelijke karakter met de HP casus. De Agilent casus is geselecteerd omdat deze juist op vele punten afweek maar zich wel in het zelfde domein afspeelde.

De TLC en Operations Management theorie en de ervaring met de HP case zijn gebruikt om een framework te bouwen op basis waarvan de criteria voor het meetsysteem gedefinieerd konden worden.
Het meetmodel moest immers een goede patroon vergelijking van de verschillende fasen in de TLC mogelijk maken door middel van zowel constructen als variabelen.. De

constructen zijn clusters van variabelen waarvan we er op basis van de 'environmental dynamism' theorie zeven hebben afgeleid. Deze zijn: klanten, marktevolutie, winstsituatie, concurrenten, supply chain- interne en -externe partners, process technology en product technology. De verschillende variabelen in elke cluster zijn afgeleid uit de TLC literatuur en worden gebruikt om elke fase in de TLC in detail te beschrijven.

Voor de vijf verschillende typen van fabrieken, hebben we drie constructen gedefinieerd, namelijk: klant- en producteisen, de concurrentie strategie van de fabriek en de proces strategie. Opnieuw zijn deze clusters opgesplitst in variabelen om een nog gedetailleerde beschrijving te kunnen geven. Voor alle typen van fabrieken zijn dezelfde variabelen gebruikt. Soms is een enkele extra variabele toegevoegd om specifieke aspekten van een fabriekstype te beschrijven, deze worden 'toegevoegde variabele voor speciale indicatie' genoemd. Elke variabele kon de waarden tussen '0' en '2' aan nemen, waarmee de match aangegeven werd met een bepaalde fase van TLC geen match (0), gedeeltelijk (1) of wel sterke match (2) met een bepaalde fase.

Voor elke variabele wordt de mediaan berekend Het zwaartepunt van de totale meeting geeft dan aan in hoeverre een bedrijf op een bepaald moment bij een van de vijf fases van de TLC theorie past.

Het matchen van de meetresultaten is uitbesteed aan een onafhankelijk partij die bekend was met de High Tech productiebranche en met de TLC theorien. Hierdoor is de objectiviteit van de toetsing met het complexe meetingsmodel gewaarborgd

De Resultaten

De resultaten uit de analyses zijn intensief bediscussieerd met de betrokken managementteams op basis waarvan we tot de volgende conclusies kwamen.

Het onderzoek geeft aan dat zoals gedefinieerd in het conceptuele model er tenminste vijf verschillende typen fabrieken en vijf verschillende fasen in de TLC zijn.

De in de literatuur beschreven theorie over de technologische life cycles kan op basis van de HP casus uitgebreid worden. Doordat wij klantverwachtingen met betrekking tot product prestatie afzetten tegen de door de bedrijven aangeboden prestatie. De gap tussen beschikbare en de door de klant gewenste prestatie beïnvloedt hun bereidheid om hoge prijzen te betalen die aan een vorige fase in de lifecycle verbonden zijn.

De verschillende typen fabrieken moeten met specifieke capaciteiten worden toegerust die in lijn zijn met de technologie behorend bij de fase waarin de TLC zich bevindt. Deze conclusie werd in de HP casus getrokken en werd ondersteund door de FSC casus en gedeeltelijk door de Agilent casus. De opeenvolging is zoals eerder vermeld de "High-Tech-fabriek", de "Lage-Kosten-fabriek", de "Snelheids-fabriek", de "Oplossing-fabriek" en de "Coöperatieve-fabriek".

De Agilent case toonde ons evenwel ook een aantal van de beperkingen van ons model: Als eerste zou de opeenvolging van de capaciteitsontwikkeling verschillend kunnen zijn als de markt zich niet stap voor stap ontwikkeld van een aanbiedermarkt naar een klantenmarkt. Ten tweede heeft Agilent niet echt een oplossing-fabriek en een coöperatieve-fabriek voor vezel optische data transmissie testen ontwikkeld omdat de ontwikkeling van testoplossingen tot de kernbekwaamheden van hun OEM-klanten behoorde. Ten derde had Agilent verschillende typen fabrieken tegelijkertijd aangezien de markt van hen verschillende technologieën in verschillende fasen van de TLC gelijktijdig vroeg.

De vereiste nieuwe capabilities hoeven niet noodzakelijkerwijs vanuit de eigen lokale fabriek komen: Agilent heeft bijvoorbeeld deze nieuwe capabilities uitbesteed aan derden. Ook in de Computerfabricage is om kosten te besparen of vaste kosten te verminderen een groot gedeelte outgesourced. Uiteraard is capabilityswitching niet 0 of 1 maar is het vaak een evolutionair proces waarin oude capabilities nog een tijd relevantie hebben waardoor het meer op aanpassing van de fabriek lijkt.

Ook moeten de lokale vestigingen vaak hun operationele capabilities in elke fase van de TLC instant houden om adequaat in te kunnen spelen op de eisen van de klanten en de daarvoor benodigde R&D. De low cost fabriek vormt hierop een uitzondering. Maar off-shoring zou de ontwikkeling van efficiënte Snelheids-fabrieken, Oplossing-fabrieken of Coöperatieve-fabrieken, die in een later stadium komen, niet toestaan.
Managers moeten dus zorgvuldig de veranderende voorkeuren van de klanten evalueren, de mogelijkheden om samen te werken met partners met specifieke capabilities om gezamenlijk aan de klanteisen tegemoet te komen onderzoeken. Daarnaast moet ook de snelheid waarmee de concurrentie inspeelt op de veranderende markt in de gaten gehouden worden. Dit alles in het licht van de technologische veranderingen van zowel producten als processen.

Tot Slot
Hoewel de resultaten overtuigend zijn is het aantal cases gering en kan verder onderzoek nog extra inzichten verschaffen. Ook zouden soortgelijke onderzoeken in andere sectoren tot een verrijking van de resultaten van ons onderzoek kunnen leiden. Verfijning van het model, de metingen en de bijbehorende criteria kan leiden tot additionele resultaten. Ook hebben we in dit onderzoek geen aandacht besteed aan een analyse van de invloed van snelheid en kwaliteit van capabilityswitching. Voor wetenschappelijk onderzoekers blijft het dus een interessant onderzoeksgebied!

ZUSAMMENFASSUNG

Als Werkleiter für das europäische Server und Workstation -Werk von HP im Hochlohnland Deutschland galt es für den Autor immer neue Fertigungsstrategien zu entwickeln, um die Führungsposition im Wettbewerb gegenüber sämtlichen internen und externen Fertigungsalternativen zu verteidigen. Kein Wettbewerbsvorteil ist von langer Dauer. Es ist überlebenswichtig zu erkennen, wann eine Strategie obsolet wird, um so frühzeitig die gegenwärtigen Fähigkeiten einer Fabrik zu adaptieren.

Den Impuls für diese Forschungsarbeit gab die Entwicklung bei HP. In dieser Studie wird ein theoretisches Modell entwickelt welches aufzeigt, warum und wie das Potential einer erfolgreichen Fabrik entlang des Technologie – Lebenszykluses immer wieder neu ausgerichtet werden muss. Anhand zweier weiterer Case Studien wurde dieses Modell getestet und angepasst. In dieser Thesis werden Leitlinien entwickelt, wie Fabriken über ihre Lebenszeit ihre Fähigkeiten verändern müssen. Des weitern wird ein Verfahren aufgezeigt, welches zur Messung der Phasen des Technologie – Lebenszykluses und der „Typen von Fabriken“ herangezogen werden kann.

BIOGRAPHICAL NOTE

Hendrik Brumme graduated in 1988 in Industrial Engineering and Economics (Diplom Wirtschafts Ingenieur) from Universität Karlsruhe in Germany. He began his career at HP in 1988, working in different supply chain functions in the Enterprise and Imaging & Printer business. In 1998, he was appointed Director of Operations for the HP Solution factory in Germany, producing and refurbishing UNIX and NT servers, Workstations and Mass Storage Devices for the European market. This manufacturing facility won several industrial awards for excellence while evolving from a manufacturing operation toward a service-oriented solution delivery center. In 2003, Hendrik developed the enterprise value collaboration network called HP 'Partner Park'. After 16 years of industrial experience, Hendrik decided to start a new academic career in March, 2004. In 2005, he started a Ph.D. at RSM Erasmus University in the Netherlands. Currently, he is Vice President of the Reutlingen International University.

ERASMUS RESEARCH INSTITUTE OF MANAGEMENT (ERIM)

ERIM PH.D. SERIES
RESEARCH IN MANAGEMENT

ERIM Electronic Series Portal: http://hdl.handle.net/1765/1

Althuizen, N.A.P., *Analogical Reasoning as a Decision Support Principle for Weakly Structured Marketing Problems*, Promotor: Prof. dr. ir. B. Wierenga, EPS-2006-095-MKT, ISBN: 90-5892-129-8, http://hdl.handle.net/1765/8190

Alvarez, H.L., *Distributed Collaborative Learning Communities Enabled by Information Communication Technology*, Promotor: Prof. dr. K. Kumar, EPS-2006-080-LIS, ISBN: 90-5892-112-3, http://hdl.handle.net/1765/7830

Appelman, J.H., *Governance of Global Interorganizational Tourism Networks: Changing Forms of Co-ordination between the Travel Agency and Aviation Sector*, Promotors: Prof. dr. F.M. Go & Prof. dr. B. Nooteboom, EPS-2004-036-MKT, ISBN: 90-5892-060-7, http://hdl.handle.net/1765/1199

Baquero, G, *On Hedge Fund Performance, Capital Flows and Investor Psychology*, Promotor: Prof. dr. M.J.C.M. Verbeek, EPS-2006-094-F&A, ISBN: 90-5892-131-X, http://hdl.handle.net/1765/8192

Berens, G., *Corporate Branding: The Development of Corporate Associations and their Influence on Stakeholder Reactions*, Promotor: Prof. dr. C.B.M. van Riel, EPS-2004-039-ORG, ISBN: 90-5892-065-8, http://hdl.handle.net/1765/1273

Berghe, D.A.F. van den, *Working Across Borders: Multinational Enterprises and the Internationalization of Employment*, Promotors: Prof. dr. R.J.M. van Tulder & Prof. dr. E.J.J. Schenk, EPS-2003-029-ORG, ISBN: 90-5892-05-34, http://hdl.handle.net/1765/1041

Berghman, L.A., *Strategic Innovation Capacity: A Mixed Method Study on Deliberate Strategic Learning Mechanisms*, Promotor: Prof. dr. P. Mattyssens, EPS-2006-087-MKT, ISBN: 90-5892-120-4, http://hdl.handle.net/1765/7991

Bijman, W.J.J., *Essays on Agricultural Co-operatives: Governance Structure in Fruit and Vegetable Chains*, Promotor: Prof. dr. G.W.J. Hendrikse, EPS-2002-015-ORG, ISBN: 90-5892-024-0, http://hdl.handle.net/1765/867

Bispo, A., *Labour Market Segmentation: An investigation into the Dutch hospitality industry*, Promotors: Prof. dr. G.H.M. Evers & Prof. dr. A.R. Thurik, EPS-2007-108-ORG, ISBN: 90-5892-136-9, http://hdl.handle.net/1765/10283

Blindenbach-Driessen, F., *Innovation Management in Project-Based Firms*, Promotor: Prof. dr. S.L. van de Velde, EPS-2006-082-LIS, ISBN: 90-5892-110-7, http://hdl.handle.net/1765/7828

Boer, C.A., *Distributed Simulation in Industry,* Promotors: Prof. dr. A. de Bruin & Prof. dr. ir. A. Verbraeck, EPS-2005-065-LIS, ISBN: 90-5892-093-3, http://hdl.handle.net/1765/6925

Boer, N.I., *Knowledge Sharing within Organizations: A situated and Relational Perspective,* Promotor: Prof. dr. K. Kumar, EPS-2005-060-LIS, ISBN: 90-5892-086-0, http://hdl.handle.net/1765/6770

Boer-Sorbán, K., *Agent-Based Simulation of Financial Markets: A modular, Continuous-Time Approach,* Promotor: Prof. dr. A. de Bruin, EPS-2008-119-LIS, ISBN: 90-5892-155-0, http://hdl.handle.net/1765/10870

Brito, M.P. de, *Managing Reverse Logistics or Reversing Logistics Management?* Promotors: Prof. dr. ir. R. Dekker & Prof. dr. M. B. M. de Koster, EPS-2004-035-LIS, ISBN: 90-5892-058-5, http://hdl.handle.net/1765/1132

Brohm, R., *Polycentric Order in Organizations: A Dialogue between Michael Polanyi and IT-Consultants on Knowledge, Morality, and Organization,* Promotors: Prof. dr. G. W. J. Hendrikse & Prof. dr. H. K. Letiche, EPS-2005-063-ORG, ISBN: 90-5892-095-X, http://hdl.handle.net/1765/6911

Campbell, R.A.J., *Rethinking Risk in International Financial Markets*, Promotor: Prof. dr. C.G. Koedijk, EPS-2001-005-F&A, ISBN: 90-5892-008-9, http://hdl.handle.net/1765/306

Chen, H., *Individual Mobile Communication Services and Tariffs*, Promotor: Prof. dr. L.F.J.M. Pau, EPS-2008-123-LIS, ISBN: 90-5892-158-1, http://hdl.handle.net/1765/1

Chen, Y., *Labour Flexibility in China's Companies: An Empirical Study*, Promotors: Prof. dr. A. Buitendam & Prof. dr. B. Krug, EPS-2001-006-ORG, ISBN: 90-5892-012-7, http://hdl.handle.net/1765/307

Damen, F.J.A., *Taking the Lead: The Role of Affect in Leadership Effectiveness*, Promotor: Prof. dr. D.L. van Knippenberg, EPS-2007-107-ORG, http://hdl.handle.net/1765/10282

Daniševská, P., *Empirical Studies on Financial Intermediation and Corporate Policies*, Promotor: Prof. dr. C.G. Koedijk, EPS-2004-044-F&A, ISBN: 90-5892-070-4, http://hdl.handle.net/1765/1518

Delporte-Vermeiren, D.J.E., *Improving the Flexibility and Profitability of ICT-enabled Business Networks: An Assessment Method and Tool*, Promotors: Prof. mr. dr. P.H.M. Vervest & Prof. dr. ir. H.W.G.M. van Heck, EPS-2003-020-LIS, ISBN: 90-5892-040-2, http://hdl.handle.net/1765/359

Derwall, J.M.M., *The Economic Virtues of SRI and CSR*, Promotor: Prof. dr. C.G. Koedijk, EPS-2007-101-F&A, ISBN: 90-5892-132-8, http://hdl.handle.net/1765/8986

Dijksterhuis, M., *Organizational Dynamics of Cognition and Action in the Changing Dutch and US Banking Industries*, Promotors: Prof. dr. ir. F.A.J. van den Bosch & Prof. dr. H.W. Volberda, EPS-2003-026-STR, ISBN: 90-5892-048-8, http://hdl.handle.net/1765/1037

Elstak, M.N., *Flipping the Identity Coin: The Comparative Effect of Perceived, Projected and Desired Organizational Identity on Organizational Identification and Desired Behavior*, Promotor: Prof. dr. C.B.M. van Riel, EPS-2008-117-ORG, ISBN: 90-5892-148-2, http://hdl.handle.net/1765/10723

Fenema, P.C. van, *Coordination and Control of Globally Distributed Software Projects*, Promotor: Prof. dr. K. Kumar, EPS-2002-019-LIS, ISBN: 90-5892-030-5, http://hdl.handle.net/1765/360

Fleischmann, M., *Quantitative Models for Reverse Logistics*, Promotors: Prof. dr. ir. J.A.E.E. van Nunen & Prof. dr. ir. R. Dekker, EPS-2000-002-LIS, ISBN: 35-4041-711-7, http://hdl.handle.net/1765/1044

Flier, B., *Strategic Renewal of European Financial Incumbents: Coevolution of Environmental Selection, Institutional Effects, and Managerial Intentionality*, Promotors: Prof. dr. ir. F.A.J. van den Bosch & Prof. dr. H.W. Volberda, EPS-2003-033-STR, ISBN: 90-5892-055-0, http://hdl.handle.net/1765/1071

Fok, D., *Advanced Econometric Marketing Models*, Promotor: Prof. dr. Ph.H.B.F. Franses, EPS-2003-027-MKT, ISBN: 90-5892-049-6, http://hdl.handle.net/1765/1035

Ganzaroli, A., *Creating Trust between Local and Global Systems*, Promotors: Prof. dr. K. Kumar & Prof. dr. R.M. Lee, EPS-2002-018-LIS, ISBN: 90-5892-031-3, http://hdl.handle.net/1765/361

Gilsing, V.A., *Exploration, Exploitation and Co-evolution in Innovation Networks*, Promotors: Prof. dr. B. Nooteboom & Prof. dr. J.P.M. Groenewegen, EPS-2003-032-ORG, ISBN: 90-5892-054-2, http://hdl.handle.net/1765/1040

Ginkel, W.P. van, *The Use of Distributed Information in Decision Making Groups: The Role of Shared Task Representations*, Promotor: Prof. dr. D. van Knippenberg, EPS-2007-097-ORG, http://hdl.handle.net/1765/8424

Govers, R., *Virtual Tourism Destination Image: Glocal Identities Constructed, Perceived and Experienced*, Promotors: Prof. dr. F.M. Go & Prof. dr. K. Kumar, EPS-2005-069-MKT, ISBN: 90-5892-107-7, http://hdl.handle.net/1765/6981

Graaf, G. de, *Tractable Morality: Customer Discourses of Bankers, Veterinarians and Charity Workers*, Promotors: Prof. dr. F. Leijnse & Prof. dr. T. van Willigenburg, EPS-2003-031-ORG, ISBN: 90-5892-051-8, http://hdl.handle.net/1765/1038

Groot, E.A. de, *Essays on Economic Cycles*, Promotors: Prof. dr. Ph.H.B.F. Franses & Prof. dr. H.R. Commandeur, EPS-2006-091-MKT, ISBN: 90-5892-123-9, http://hdl.handle.net/1765/8216

Gutkowska, A.B., *Essays on the Dynamic Portfolio Choice*, Promotor: Prof. dr. A.C.F. Vorst, EPS-2006-085-F&A, ISBN: 90-5892-118-2, http://hdl.handle.net/1765/7994

Hagemeijer, R.E., *The Unmasking of the Other*, Promotors: Prof. dr. S.J. Magala & Prof. dr. H.K. Letiche, EPS-2005-068-ORG, ISBN: 90-5892-097-6, http://hdl.handle.net/1765/6963

Halderen, M.D. van, *Organizational Identity Expressiveness and Perception Management: Principles for Expressing the Organizational Identity in Order to Manage the Perceptions and Behavioral Reactions of External Stakeholders*, Promotor: Prof. dr. S.B.M. van Riel, EPS-2008-122-ORG, ISBN: 90-5892-153-6, http://hdl.handle.net/1765/10872

Hartigh, E. den, *Increasing Returns and Firm Performance: An Empirical Study*, Promotor: Prof. dr. H.R. Commandeur, EPS-2005-067-STR, ISBN: 90-5892-098-4, http://hdl.handle.net/1765/6939

Hermans. J.M., *ICT in Information Services; Use and Deployment of the Dutch Securities Trade, 1860-1970,* Promotor: Prof. dr. drs. F.H.A. Janszen, EPS-2004-046-ORG, ISBN 90-5892-072-0, http://hdl.handle.net/1765/1793

Heugens, P.P.M.A.R., *Strategic Issues Management: Implications for Corporate Performance*, Promotors: Prof. dr. ir. F.A.J. van den Bosch & Prof. dr. C.B.M. van Riel, EPS-2001-007-STR, ISBN: 90-5892-009-7, http://hdl.handle.net/1765/358

Heuvel, W. van den, *The Economic Lot-Sizing Problem: New Results and Extensions*, Promotor: Prof. dr. A.P.L. Wagelmans, EPS-2006-093-LIS, ISBN: 90-5892-124-7, http://hdl.handle.net/1765/1805

Hoedemaekers, C.M.W., *Performance, Pinned down: A Lacanian Analysis of Subjectivity at Work*, Promotors: Prof. dr. S. Magala & Prof. dr. D.H. den Hartog, EPS-2008-121-ORG, ISBN: 90-5892-156-7, http://hdl.handle.net/1765/10871

Hooghiemstra, R., *The Construction of Reality: Cultural Differences in Self-serving Behaviour in Accounting Narratives*, Promotors: Prof. dr. L.G. van der Tas RA & Prof. dr. A.Th.H. Pruyn, EPS-2003-025-F&A, ISBN: 90-5892-047-X, http://hdl.handle.net/1765/871

Hu, Y., *Essays on the Governance of Agricultural Products: Cooperatives and Contract Farming*, Promotors: Prof. dr. G.W.J. Hendrkse & Prof. Dr. B. Krug, EPS-2007-113-ORG, ISBN: 90-5892-145-1, http://hdl.handle.net/1765/10535

Huij, J.J., *New Insights into Mutual Funds: Performance and Family Strategies*, Promotor: Prof. dr. M.C.J.M. Verbeek, EPS-2007-099-F&A, ISBN: 90-5892-134-4, http://hdl.handle.net/1765/9398

Huurman, C.I., *Dealing with Electricity Prices*, Promotor: Prof. dr. C.D. Koedijk, EPS-2007-098-F&A, ISBN: 90-5892-130-1, http://hdl.handle.net/1765/9399

Iastrebova, K, *Manager's Information Overload: The Impact of Coping Strategies on Decision-Making Performance*, Promotor: Prof. dr. H.G. van Dissel, EPS-2006-077-LIS, ISBN: 90-5892-111-5, http://hdl.handle.net/1765/7329

Iwaarden, J.D. van, *Changing Quality Controls: The Effects of Increasing Product Variety and Shortening Product Life Cycles,* Promotors: Prof. dr. B.G. Dale & Prof. dr. A.R.T. Williams, EPS-2006-084-ORG, ISBN: 90-5892-117-4, http://hdl.handle.net/1765/7992

Jansen, J.J.P., *Ambidextrous Organizations*, Promotors: Prof. dr. ir. F.A.J. Van den Bosch & Prof. dr. H.W. Volberda, EPS-2005-055-STR, ISBN: 90-5892-081-X, http://hdl.handle.net/1765/6774

Jong, C. de, *Dealing with Derivatives: Studies on the Role, Informational Content and Pricing of Financial Derivatives*, Promotor: Prof. dr. C.G. Koedijk, EPS-2003-023-F&A, ISBN: 90-5892-043-7, http://hdl.handle.net/1765/1043

Keizer, A.B., *The Changing Logic of Japanese Employment Practices: A Firm-Level Analysis of Four Industries,* Promotors: Prof. dr. J.A. Stam & Prof. dr. J.P.M. Groenewegen, EPS-2005-057-ORG, ISBN: 90-5892-087-9, http://hdl.handle.net/1765/6667

Kijkuit, R.C., *Social Networks in the Front End: The Organizational Life of an Idea,* Promotor: Prof. dr. B. Nooteboom, EPS-2007-104-ORG, ISBN: 90-5892-137-6, http://hdl.handle.net/1765/10074

Kippers, J., *Empirical Studies on Cash Payments,* Promotor: Prof. dr. Ph.H.B.F. Franses, EPS-2004-043-F&A, ISBN: 90-5892-069-0, http://hdl.handle.net/1765/1520

Kole, E., *On Crises, Crashes and Comovements*, Promotors: Prof. dr. C.G. Koedijk & Prof. dr. M.J.C.M. Verbeek, EPS-2006-083-F&A, ISBN: 90-5892-114-X, http://hdl.handle.net/1765/7829

Kooij-de Bode, J.M., *Distributed Information and Group Decision-Making: Effects of Diversity and Affect*, Promotor: Prof. dr. D.L. van Knippenberg, EPS-2007-115-ORG, http://hdl.handle.net/1765/10722

Knapp, S., *The Econometrics of Maritime Safety: Recommendations to Enhance Safety at Sea*, Promotor: Prof. dr. Ph.H.B.F. Franses, EPS-2007-096-ORG, ISBN: 90-5892-127-1, http://hdl.handle.net/1765/7913

Koppius, O.R., *Information Architecture and Electronic Market Performance*, Promotors: Prof. dr. P.H.M. Vervest & Prof. dr. ir. H.W.G.M. van Heck, EPS-2002-013-LIS, ISBN: 90-5892-023-2, http://hdl.handle.net/1765/921

Kotlarsky, J., *Management of Globally Distributed Component-Based Software Development Projects,* Promotor: Prof. dr. K. Kumar, EPS-2005-059-LIS, ISBN: 90-5892-088-7, http://hdl.handle.net/1765/6772

Kuilman, J., *The Re-Emergence of Foreign Banks in Shanghai: An Ecological Analysis,* Promotor: Prof. dr. B. Krug, EPS-2005-066-ORG, ISBN: 90-5892-096-8, http://hdl.handle.net/1765/6926

Langen, P.W. de, *The Performance of Seaport Clusters: A Framework to Analyze Cluster Performance and an Application to the Seaport Clusters of Durban, Rotterdam and the Lower Mississippi*, Promotors: Prof. dr. B. Nooteboom & Prof. drs. H.W.H. Welters, EPS-2004-034-LIS, ISBN: 90-5892-056-9, http://hdl.handle.net/1765/1133

Le Anh, T., *Intelligent Control of Vehicle-Based Internal Transport Systems*, Promotors: Prof. dr. M.B.M. de Koster & Prof. dr. ir. R. Dekker, EPS-2005-051-LIS, ISBN: 90-5892-079-8, http://hdl.handle.net/1765/6554

Le-Duc, T., *Design and Control of Efficient Order Picking Processes*, Promotor: Prof. dr. M.B.M. de Koster, EPS-2005-064-LIS, ISBN: 90-5892-094-1, http://hdl.handle.net/1765/6910

Leeuwen, E.P. van, *Recovered-Resource Dependent Industries and the Strategic Renewal of Incumbent Firm: A Multi-Level Study of Recovered Resource Dependence Management and Strategic Renewal in the European Paper and Board Industry*, Promotors: Prof. dr. ir. F.A.J. Van den Bosch & Prof. dr. H.W. Volberda, EPS-2007-109-STR, ISBN: 90-5892-140-6, http://hdl.handle.net/1765/10183

Lentink, R.M., *Algorithmic Decision Support for Shunt Planning*, Promotors: Prof. dr. L.G. Kroon & Prof. dr. ir. J.A.E.E. van Nunen, EPS-2006-073-LIS, ISBN: 90-5892-104-2, http://hdl.handle.net/1765/7328

Liang, G., *New Competition: Foreign Direct Investment and Industrial Development in China,* Promotor: Prof. dr. R.J.M. van Tulder, EPS-2004-047-ORG, ISBN: 90-5892-073-9, http://hdl.handle.net/1765/1795

Liere, D.W. van, *Network Horizon and the Dynamics of Network Positions: A Multi-Method Multi-Level Longitudinal Study of Interfirm Networks,* Promotor: Prof. dr. P.H.M. Vervest, EPS-2007-105-LIS, ISBN: 90-5892-139-0, http://hdl.handle.net/1765/10181

Loef, J., *Incongruity between Ads and Consumer Expectations of Advertising*, Promotors: Prof. dr. W.F. van Raaij & Prof. dr. G. Antonides, EPS-2002-017-MKT, ISBN: 90-5892-028-3, http://hdl.handle.net/1765/869

Londoño, M. del Pilar, *Institutional Arrangements that Affect Free Trade Agreements: Economic Rationality Versus Interest Groups*, Promotors: Prof. dr. H.E. Haralambides & Prof. dr. J.F. Francois, EPS-2006-078-LIS, ISBN: 90-5892-108-5, http://hdl.handle.net/1765/7578

Maeseneire, W., de, *Essays on Firm Valuation and Value Appropriation,* Promotor: Prof. dr. J.T.J. Smit, EPS-2005-053-F&A, ISBN: 90-5892-082-8, http://hdl.handle.net/1765/6768

Mandele, L.M., van der, *Leadership and the Inflection Point: A Longitudinal Perspective*, Promotors: Prof. dr. H.W. Volberda & Prof. dr. H.R. Commandeur, EPS-2004-042-STR, ISBN: 90-5892-067-4, http://hdl.handle.net/1765/1302

Meer, J.R. van der, *Operational Control of Internal Transport*, Promotors: Prof. dr. M.B.M. de Koster & Prof. dr. ir. R. Dekker, EPS-2000-001-LIS, ISBN: 90-5892-004-6, http://hdl.handle.net/1765/859

Mentink, A., *Essays on Corporate Bonds*, Promotor: Prof. dr. A.C.F. Vorst, EPS-2005-070-F&A, ISBN: 90-5892-100-X, http://hdl.handle.net/1765/7121

Meyer, R.J.H., *Mapping the Mind of the Strategist: A Quantitative Methodology for Measuring the Strategic Beliefs of Executives*, Promotor: Prof. dr. R.J.M. van Tulder, EPS-2007-106-ORG, ISBN: 978-90-5892-141-3, http://hdl.handle.net/1765/10182

Miltenburg, P.R., *Effects of Modular Sourcing on Manufacturing Flexibility in the Automotive Industry: A Study among German OEMs*, Promotors: Prof. dr. J. Paauwe & Prof. dr. H.R. Commandeur, EPS-2003-030-ORG, ISBN: 90-5892-052-6, http://hdl.handle.net/1765/1039

Moerman, G.A., *Empirical Studies on Asset Pricing and Banking in the Euro Area,* Promotor: Prof. dr. C.G. Koedijk, EPS-2005-058-F&A, ISBN: 90-5892-090-9, http://hdl.handle.net/1765/6666

Mol, M.M., *Outsourcing, Supplier-relations and Internationalisation: Global Source Strategy as a Chinese Puzzle*, Promotor: Prof. dr. R.J.M. van Tulder, EPS-2001-010-ORG, ISBN: 90-5892-014-3, http://hdl.handle.net/1765/355

Mom, T.J.M., *Managers' Exploration and Exploitation Activities: The Influence of Organizational Factors and Knowledge Inflows*, Promotors: Prof. dr. ir. F.A.J. Van den Bosch & Prof. dr. H.W. Volberda, EPS-2006-079-STR, ISBN: 90-5892-116-6, http://hdl.handle.net/1765

Mulder, A., *Government Dilemmas in the Private Provision of Public Goods*, Promotor: Prof. dr. R.J.M. van Tulder, EPS-2004-045-ORG, ISBN: 90-5892-071-2, http://hdl.handle.net/1765/1790

Muller, A.R., *The Rise of Regionalism: Core Company Strategies Under The Second Wave of Integration*, Promotor: Prof. dr. R.J.M. van Tulder, EPS-2004-038-ORG, ISBN: 90-5892-062-3, http://hdl.handle.net/1765/1272

Ning, H., *Hierarchical Portfolio Management: Theory and Applications*, Promotor: Prof. dr. J. Spronk, EPS-2007-118-F&A, ISBN: 90-5892-152-9, http://hdl.handle.net/1765/10868

Noeverman, J., *Management Control Systems, Evaluative Style, and Behaviour: Exploring the Concept and Behavioural Consequences of Evaluative Style*, Promotors: Prof. dr. E.G.J. Vosselman & Prof. dr. A.R.T. Williams, EPS-2007-120-F&A, ISBN: 90-5892-151-2, http://hdl.handle.net/1765/10869

Oosterhout, J., van, *The Quest for Legitimacy: On Authority and Responsibility in Governance*, Promotors: Prof. dr. T. van Willigenburg & Prof.mr. H.R. van Gunsteren, EPS-2002-012-ORG, ISBN: 90-5892-022-4, http://hdl.handle.net/1765/362

Paape, L., *Corporate Governance: The Impact on the Role, Position, and Scope of Services of the Internal Audit Function*, Promotors: Prof. dr. G.J. van der Pijl & Prof. dr. H. Commandeur, EPS-2007-111-MKT, ISBN: 90-5892-143-7, http://hdl.handle.net/1765/10417

Pak, K., *Revenue Management: New Features and Models*, Promotor: Prof. dr. ir. R. Dekker, EPS-2005-061-LIS, ISBN: 90-5892-092-5, http://hdl.handle.net/1765/362/6771

Pattikawa, L.H, *Innovation in the Pharmaceutical Industry: Evidence from Drug Introduction in the U.S.*, Promotors: Prof. dr. H.R.Commandeur, EPS-2007-102-MKT, ISBN: 90-5892-135-2, http://hdl.handle.net/1765/9626

Peeters, L.W.P., *Cyclic Railway Timetable Optimization*, Promotors: Prof. dr. L.G. Kroon & Prof. dr. ir. J.A.E.E. van Nunen, EPS-2003-022-LIS, ISBN: 90-5892-042-9, http://hdl.handle.net/1765/429

Pietersz, R., *Pricing Models for Bermudan-style Interest Rate Derivatives*, Promotors: Prof. dr. A.A.J. Pelsser & Prof. dr. A.C.F. Vorst, EPS-2005-071-F&A, ISBN: 90-5892-099-2, http://hdl.handle.net/1765/7122

Popova, V., *Knowledge Discovery and Monotonicity*, Promotor: Prof. dr. A. de Bruin, EPS-2004-037-LIS, ISBN: 90-5892-061-5, http://hdl.handle.net/1765/1201

Pouchkarev, I., *Performance Evaluation of Constrained Portfolios*, Promotors: Prof. dr. J. Spronk & Dr. W.G.P.M. Hallerbach, EPS-2005-052-F&A, ISBN: 90-5892-083-6, http://hdl.handle.net/1765/6731

Puvanasvari Ratnasingam, P., *Interorganizational Trust in Business to Business E-Commerce*, Promotors: Prof. dr. K. Kumar & Prof. dr. H.G. van Dissel, EPS-2001-009-LIS, ISBN: 90-5892-017-8, http://hdl.handle.net/1765/356

Rinsum, M. van, *Performance Measurement and Managerial Time Orientation*, Promotor: Prof. dr. F.G.H. Hartmann, EPS-2006-088-F&A, ISBN: 90-5892-121-2, http://hdl.handle.net/1765/7993

Romero Morales, D., *Optimization Problems in Supply Chain Management*, Promotors: Prof. dr. ir. J.A.E.E. van Nunen & Dr. H.E. Romeijn, EPS-2000-003-LIS, ISBN: 90-9014078-6, http://hdl.handle.net/1765/865

Roodbergen, K.J., *Layout and Routing Methods for Warehouses*, Promotors: Prof. dr. M.B.M. de Koster & Prof. dr. ir. J.A.E.E. van Nunen, EPS-2001-004-LIS, ISBN: 90-5892-005-4, http://hdl.handle.net/1765/861

Schramade, W.L.J., *Corporate Bonds Issuers,* Promotor: Prof. dr. A. De Jong, EPS-2006-092-F&A, ISBN: 90-5892-125-5, http://hdl.handle.net/1765/8191

Schweizer, T.S., *An Individual Psychology of Novelty-Seeking, Creativity and Innovation,* Promotor: Prof. dr. R.J.M. van Tulder, EPS-2004-048-ORG, ISBN: 90-5892-07-71, http://hdl.handle.net/1765/1818

Six, F.E., *Trust and Trouble: Building Interpersonal Trust Within Organizations*, Promotors: Prof. dr. B. Nooteboom & Prof. dr. A.M. Sorge, EPS-2004-040-ORG, ISBN: 90-5892-064-X, http://hdl.handle.net/1765/1271

Slager, A.M.H., *Banking across Borders*, Promotors: Prof. dr. R.J.M. van Tulder & Prof. dr. D.M.N. van Wensveen, EPS-2004-041-ORG, ISBN: 90-5892-066–6, http://hdl.handle.net/1765/1301

Sloot, L., *Understanding Consumer Reactions to Assortment Unavailability*, Promotors: Prof. dr. H.R. Commandeur, Prof. dr. E. Peelen & Prof. dr. P.C. Verhoef, EPS-2006-074-MKT, ISBN: 90-5892-102-6, http://hdl.handle.net/1765/7438

Smit, W., *Market Information Sharing in Channel Relationships: Its Nature, Antecedents and Consequences*, Promotors: Prof. dr. ir. G.H. van Bruggen & Prof. dr. ir. B. Wierenga, EPS-2006-076-MKT, ISBN: 90-5892-106-9, http://hdl.handle.net/1765/7327

Sonnenberg, M., *The Signalling Effect of HRM on Psychological Contracts of Employees: A Multi-level Perspective*, Promotor: Prof. dr. J. Paauwe, EPS-2006-086-ORG, ISBN: 90-5892-119-0, http://hdl.handle.net/1765/7995

Speklé, R.F., *Beyond Generics: A closer Look at Hybrid and Hierarchical Governance*, Promotor: Prof. dr. M.A. van Hoepen RA, EPS-2001-008-F&A, ISBN: 90-5892-011-9, http://hdl.handle.net/1765/357

Teunter, L.H., *Analysis of Sales Promotion Effects on Household Purchase Behavior*, Promotors: Prof. dr. ir. B. Wierenga & Prof. dr. T. Kloek, EPS-2002-016-MKT, ISBN: 90-5892-029-1, http://hdl.handle.net/1765/868

Tims, B., *Empirical Studies on Exchange Rate Puzzles and Volatility*, Promotor: Prof. dr. C.G. Koedijk, EPS-2006-089-F&A, ISBN: 90-5892-113-1, http://hdl.handle.net/1765/8066

Valck, K. de, *Virtual Communities of Consumption: Networks of Consumer Knowledge and Companionship*, Promotors: Prof. dr. ir. G.H. van Bruggen & Prof. dr. ir. B. Wierenga, EPS-2005-050-MKT, ISBN: 90-5892-078-X, http://hdl.handle.net/1765/6663

Valk, W. van der, *Buyer-Seller Interaction Patterns During Ongoing Service Exchange*, Promotors: Prof. dr. J.Y.F. Wynstra & Prof. dr. ir. B. Axelsson, EPS-2007-116-MKT, ISBN: 90-5892-146-8, http://hdl.handle.net/1765/10856

Verheul, I., *Is There a (Fe)male Approach? Understanding Gender Differences in Entrepreneurship*, Prof. dr. A.R. Thurik, EPS-2005-054-ORG, ISBN: 90-5892-080-1, http://hdl.handle.net/1765/2005

Vis, I.F.A., *Planning and Control Concepts for Material Handling Systems*, Promotors: Prof. dr. M.B.M. de Koster & Prof. dr. ir. R. Dekker, EPS-2002-014-LIS, ISBN: 90-5892-021-6, http://hdl.handle.net/1765/866

Vlaar, P.W.L., *Making Sense of Formalization in Interorganizational Relationships: Beyond Coordination and Control,* Promotors: Prof. dr. ir. F.A.J. Van den Bosch & Prof. dr. H.W. Volberda, EPS-2006-075-STR, ISBN 90-5892-103-4, http://hdl.handle.net/1765/7326

Vliet, P. van, *Downside Risk and Empirical Asset Pricing*, Promotor: Prof. dr. G.T. Post, EPS-2004-049-F&A, ISBN: 90-5892-07-55, http://hdl.handle.net/1765/1819

Vlist, P. van der, *Synchronizing the Retail Supply Chain*, Promotors: Prof. dr. ir. J.A.E.E. van Nunen & Prof. dr. A.G. de Kok, EPS-2007-110-LIS, ISBN: 90-5892-142-0, http://hdl.handle.net/1765/10418

Vries-van Ketel E. de, *How Assortment Variety Affects Assortment Attractiveness: A Consumer Perspective*, Promotors: Prof. dr. G.H. van Bruggen & Prof. dr. ir. A. Smidts, EPS-2006-072-MKT, ISBN: 90-5892-101-8, http://hdl.handle.net/1765/7193

Vromans, M.J.C.M., *Reliability of Railway Systems*, Promotors: Prof. dr. L.G. Kroon, Prof. dr. ir. R. Dekker & Prof. dr. ir. J.A.E.E. van Nunen, EPS-2005-062-LIS, ISBN: 90-5892-089-5, http://hdl.handle.net/1765/6773

Vroomen, B.L.K., *The Effects of the Internet, Recommendation Quality and Decision Strategies on Consumer Choice*, Promotor: Prof. dr. Ph.H.B.F. Franses, EPS-2006-090-MKT, ISBN: 90-5892-122-0, http://hdl.handle.net/1765/8067

Waal, T. de, *Processing of Erroneous and Unsafe Data*, Promotor: Prof. dr. ir. R. Dekker, EPS-2003-024-LIS, ISBN: 90-5892-045-3, http://hdl.handle.net/1765/870

Watkins Fassler, K., *Macroeconomic Crisis and Firm Performance,* Promotors: Prof. dr. J. Spronk & Prof. dr. D.J. van Dijk, EPS-2007-103-F&A, ISBN: 90-5892-138-3, http://hdl.handle.net/1765/10065

Wennekers, A.R.M., *Entrepreneurship at Country Level: Economic and Non-Economic Determinants,* Promotor: Prof. dr. A.R. Thurik, EPS-2006-81-ORG, ISBN: 90-5892-115-8, http://hdl.handle.net/1765/7982

Wielemaker, M.W., *Managing Initiatives: A Synthesis of the Conditioning and Knowledge-Creating View*, Promotors: Prof. dr. H.W. Volberda & Prof. dr. C.W.F. Baden-Fuller, EPS-2003-28-STR, ISBN: 90-5892-050-X, http://hdl.handle.net/1765/1042

Wijk, R.A.J.L. van, *Organizing Knowledge in Internal Networks: A Multilevel Study*, Promotor: Prof. dr. ir. F.A.J. van den Bosch, EPS-2003-021-STR, ISBN: 90-5892-039-9, http://hdl.handle.net/1765/347

Zhang, X., *Strategizing of Foreign Firms in China: An Institution-based Perspective*, Promotor: Prof. dr. B. Krug, EPS-2007-114-ORG, ISBN: 90-5892-147-5, http://hdl.handle.net/1765/10721

Zhu, Z., *Essays on China's Tax System*, Promotors: Prof. dr. B. Krug & Prof. dr. G.W.J. Hendrikse, EPS-2007-112-ORG, ISBN: 90-5892-144-4, http://hdl.handle.net/1765/10502

Erasmus Research Institute of Management - ERIM

MANUFACTURING CAPABILITY SWITCHING IN THE HIGH-TECH ELECTRONICS TECHNOLOGY LIFE CYCLE

Responsible for running a $2.5 billion HP computer factory in a high-cost country like Germany, the author perceived constant pressure defining new manufacturing strategies to keep a competitive advantage for the factory over all internal and external manufacturing alternatives around the world. However, it was clear that a competitive advantage does not last for ever but is rather limited by time, and that it is vital to recognize when an old competitive advantage has lost its strength. This uncertainty could be reduced by a better understanding of long-term market and technological trends and how local factories need to adapt their capabilities over time. Inspired by the HP experience we developed in our research a conceptual model to explain why switching of capabilities during the TLC is needed for success and how it should be done. Two more qualitative cases are presented and used to test and refine the conceptual model. As a result we propose in this thesis detailed guidelines for capability switching in local manufacturing over the lifetime of a factory. These guidelines also provide valid and reliable measures of the phases of a technology's status within the Technology Life Cycle and the corresponding type of local factory which are necessary for developing successful manufacturing capabilities.

ERIM

The Erasmus Research Institute of Management (ERIM) is the Research School (Onderzoekschool) in the field of management of the Erasmus University Rotterdam. The founding participants of ERIM are RSM Erasmus University and the Erasmus School of Economics. ERIM was founded in 1999 and is officially accredited by the Royal Netherlands Academy of Arts and Sciences (KNAW). The research undertaken by ERIM is focussed on the management of the firm in its environment, its intra- and interfirm relations, and its business processes in their interdependent connections.

The objective of ERIM is to carry out first rate research in management, and to offer an advanced doctoral programme in Research in Management. Within ERIM, over three hundred senior researchers and PhD candidates are active in the different research programmes. From a variety of academic backgrounds and expertises, the ERIM community is united in striving for excellence and working at the forefront of creating new business knowledge.

ERIM PhD Series
Research in Management

Erasmus University Rotterdam
RSM Erasmus University
Erasmus School of Economics
P.O. Box 1738, 3000 DR Rotterdam
The Netherlands

Tel. +31 10 408 11 82
Fax +31 10 408 96 40
E-mail info@erim.eur.nl
Internet www.erim.eur.nl

Design & layout: B&T Ontwerp en advies (www.b-en-t.nl) Print: Haveka (www.haveka.nl)